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Identifying Rhizobium efficient lines for higher biomass production in diverse horsegram (*Macrotyloma uniflorum*) lines under two environments

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Abstract

Horsegram (*Macrotyloma uniflorum*) is a potential legume crop consumed as pulse and used as fodder in different parts of the world. The present investigation was carried out to study the correlation and path analysis among the various genotypes of horsegram with and without treatment of *Rhizobium* culture. Ninety six diverse lines were sown in two different conditions (E_1 and E_2) in randomized block design. The data revealed that there was significant differences for these traits among the genotypes after treatment of *Rhizobium* culture as compared to without treated experiment. The PCV was found to be slightly higher than GCV in all traits indicating the importance of greater genetic variability with less influence of environment. Estimates of heritability and genetic advance were higher for all the traits in E_2; indicating the role of *Rhizobium* in the transmission of genotypes. Estimates of correlation coefficients at genotypic, phenotypic and environmental level indicates significant positive relationship of nodule, root fresh weight and root volume with shoot fresh weight in both conditions. So, these finding can help in further breeding programmes to select the characters related to high biomass production using *Rhizobium* treatment.

Key words: Horsegram, correlation, *Rhizobium*, heritability.

Pulses have been known to have great influence in Indian agriculture. They contribute to the 25 per cent of the total global production. Pulses are undoubtly an important component of rainfed agriculture. Legumes are important sources of high quality, plant-based protein, especially in developing countries, associated with nitrogen (N) rich biomass and seeds. Horsegram (*Macrotyloma uniflorum*) is a potential legume crop consumed as pulse and used as fodder in different parts of the world. It has been grown in India on a significant area as pulse crop (Blumenthal and Staples 1993; Jansen 1989). It is commonly named as kulthi and it is one of the many underexploited legumes. Horsegram belongs to the Phaseoleae tribe of family Fabaceae having diploid chromosome numbers of 2n= 20, 22 and 24 (Cook *et al*. 2005). India is considered to be the centre of origin for cultivated horsegram (Vavilov 1951; Verdcourt 1971; Blumenthal and Staples 1993). Horsegram is known to be a drought tolerant crop and is grown in dry seasons in a wide range of soil types which are water deficient (Oram 1990). In addition to its drought tolerance capability horsegram has also been found to forbearing other stresses such as salinity and heavy metal stress (Smartt 1990; Reddy *et al*. 2008).

Nitrogen is a crucial element for all organisms. It is derived from dinitrogen (N_2), which makes up to 78% of our planet's atmosphere by the process of nitrogen fixation. This process converts N_2 into ammonia as N_2 cannot be metabolized by organisms. Thus, nitrogen fixation is vital for growth and development of all life forms. Nitrogen fixation is executed in soil by nitrogen-fixing bacteria and archaea (Mus and Crook *et al*. 2016). Among all nitrogen-fixing bacteria, rhizobia can live in soil as saprophytes or present in root nodules of their host legumes as symbionts. Nitrogen is required for high yields in pulses, but application of nitrogen fertilizers is not always mandatory in pulse crops. Proper treatment of *Rhizobium* inoculant helps plants to derive a significant portion of their nitrogen requirement through fixation. Hence, the present study was carried out with the objective of testing efficiency of *Rhizobium* treatment and its effects on growth and development in horsegram.

Materials and Methods

The present investigation consisted of a core set of total 96 diverse horsegram lines. Trial was conducted in two different conditions (without and with *Rhizobium* culture) in Randomized block design (RBD) with two replications in each condition during *kharif* season between July and November 2020. Seeds were sown without and with *Rhizobium* culture in E_1 and E_2, respectively. Phenotypic data was recorded after emergence of flowering on different phenotypic traits *viz*., root length (cm), root fresh weight (gm), root volume (ml), nodule number and shoot fresh weight (gm). Computation of genotypic variance, phenotypic variance and genetic advance was performed by using formula of Johnson *et al*. (1955). Genotypic and phenotypic coefficient of variation (Burton, 1952), heritability in broad sense (Lush, 1940), correlation coefficient (Singh and Chaudhary, 1995) and path analysis (Dewey and Lu, 1959) were estimated as per the guidelines of the authors given in the parentheses. Statistical analysis of data was done using OPSTAT statistical analysis software of CCS HAU, Hisar.

Results and Discussion

The analysis of variance revealed significant differences among genotypes for root length and shoot fresh weight as mean sum of squares for these traits found significant in controlled conditions (E_1) (Table 1). Whereas, the sum of squares for all the characters studied were significant in *Rhizobium* treatment (E_2); indicated the existence of variability for these characters and offers some scope for bringing improvement in horsegram.

The mean performance for root and shoot traits among 96 genotypes of horsegram varied in two environments (Table 2) (Figure 1). In E_1 nodule number ranged from 6.50 to 159.50 with mean value 57.31. While, it ranged from 3.00 - 205.00 in E_2. Root length ranged 47-150 cm in E_1, and 43 to 139 cm in E_2. Root fresh weight ranged 2.99 – 21.99gm in E_1, and 3.20-25.29gm in E_2. Root volume ranged 2.50-38.00ml in E_1, and 5.00- 23.50ml in E_2. The mean value for shoot fresh weight was recorded within range 16.40-161.69gm for E_1 and 22.45-155.19gm for E_2. On the basis of mean performance for studied traits, it was observed that some genotypes recorded higher mean values for all the traits in E_2 as compared to E_1, which concluded that different genotypes respond differently to the treatment of *Rhizobium*.

The estimates of genotypic (GCV) and phenotypic coefficient of variation (PCV), heritability (broad sense) and genetic advance (GA) for both the environments were presented in Table 3 and Figure 2. The values of PCV and GCV were categorized as low (below 10%), moderate (11%-20%) and high (above 20%) according to the scale given by Sivasubramanian and Menon, 1973. High value of GCV and PCV was recorded for Nodule (37.66, 60.86), root fresh weight (21.74, 33.31), root volume (22.03, 44.13) and shoot fresh weight (33.91, 41.41). Whereas, moderate GCV and PCV were found for root length (15.50, 18.80) only, similar results were also noticed by Alle *et al*. (2015) and Vijayakumar *et al*. (2016) in horsegram. The PCV was found to be slightly higher than GCV in all traits studied indicating the importance of greater genetic variability with less influence of environment. Hence selection based on phenotype will be more reliable in horsegram improvement.

Table1. Analysis of variance for RBD for different characters in horsegram

Source of Variation	DF	Nodule		Root length		Root Fresh Weight		Root Volume		Shoot Fresh Weight	
		E1	E2	E1	E2	E1	E2	E1	E2	E1	E2
Replication	1	17366.02	20110.54	23809.74	13753.25	1311.68	1382.18	1541.33	1068.79	27910.46	25551.40
Treatment	95	1682.47	3346.86**	531.05*	761.74**	17.27	35.64**	44.48	35.31**	1532.72*	1524.75**
Error	95	750.54	311.18	101.47	92.54	6.95	3.65	26.73	3.34	302.51	61.12

*Significance at 5% level; **Significance at 1% level

Table 2. Mean values of horse gram genotypes for different traits studied under both environments

Geno type	Nodule Number		Root length		Root Fresh Weight		Root Volume		Shoot Fresh Weight	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
1	41.00	19.50	112.50	80.00	8.98	6.94	11.00	12.00	50.38	29.30
2	22.50	29.00	110.50	58.00	8.31	5.42	13.00	7.50	44.37	25.30
3	57.50	80.50	93.00	139.00	13.29	6.49	17.00	8.50	69.86	69.01
4	63.00	84.50	106.00	137.00	13.30	7.95	16.00	10.00	96.16	51.25
5	62.00	46.50	102.00	94.50	7.51	10.79	15.00	12.50	114.61	81.28
6	48.00	51.50	47.00	80.50	13.29	7.48	15.75	8.00	59.06	46.87
7	38.00	36.50	93.50	101.00	15.45	8.51	19.50	11.00	66.08	35.37
8	47.00	104.50	74.50	96.50	11.58	8.81	16.00	10.50	68.68	115.33
9	29.00	26.00	60.50	101.50	9.76	9.92	12.00	12.00	50.90	45.52
10	47.00	40.00	68.50	84.50	14.38	7.74	15.00	11.00	80.06	76.65
11	81.50	66.50	85.00	80.50	17.86	9.48	22.75	12.50	66.50	61.00
12	46.50	36.50	107.00	65.00	10.20	8.99	17.00	10.50	101.75	104.94
13	46.50	50.50	118.50	98.00	11.67	13.69	15.00	18.50	128.76	82.02
14	54.00	60.50	100.50	120.00	7.56	7.18	12.50	8.00	35.82	72.34
15	48.00	63.00	66.00	135.00	6.09	14.75	2.50	18.00	105.65	71.50
16	100.00	174.50	97.50	107.50	13.29	14.42	15.00	18.50	97.43	138.96
17	28.50	37.50	89.50	119.00	7.45	11.74	10.00	13.00	46.51	57.58
18	61.00	15.50	86.00	43.00	8.22	11.10	13.00	13.00	84.15	71.92
19	82.00	23.00	87.50	118.50	12.43	14.48	16.50	15.00	50.73	65.76
20	60.50	26.00	93.00	89.50	11.10	11.60	16.50	10.00	53.57	41.14
21	59.50	65.00	104.50	116.00	9.84	12.04	13.00	14.50	61.24	71.03
22	60.00	65.50	106.50	114.50	12.73	13.17	16.00	14.50	75.79	64.34
23	24.00	47.00	119.00	74.50	7.10	14.24	10.50	19.50	27.09	72.00
24	22.50	14.00	101.00	87.50	10.33	9.53	14.50	6.00	72.97	22.45
25	43.00	89.00	96.50	111.50	12.97	9.96	21.00	18.00	72.34	79.40
26	24.50	53.00	112.50	108.50	9.39	22.94	11.50	18.50	57.16	88.37
27	50.00	24.00	83.70	115.00	14.52	25.96	7.50	18.50	41.00	58.71
28	21.00	22.00	101.00	121.00	21.29	15.24	24.50	17.50	53.27	49.74
29	32.00	53.00	150.00	111.50	9.34	10.18	8.00	10.00	67.39	89.06
30	52.00	72.00	118.50	95.00	9.30	13.46	8.50	11.00	79.45	95.31
31	66.50	87.50	116.50	100.00	7.73	8.09	8.50	11.50	86.71	94.89
32	71.50	47.50	110.50	94.00	9.21	12.18	9.00	11.00	158.00	52.34
33	47.50	58.50	108.50	85.00	13.01	9.71	11.00	14.00	89.31	155.19
34	66.50	69.00	108.50	100.00	13.44	11.83	16.00	17.00	90.97	86.18
35	47.00	54.50	85.00	85.00	8.97	7.63	11.00	10.00	49.45	53.68
36	46.00	23.50	108.00	108.00	10.73	13.50	14.00	15.00	84.98	96.31
37	49.50	31.50	114.00	100.50	9.33	7.70	12.00	12.00	77.98	56.81
38	45.50	20.00	113.00	128.00	13.32	7.14	11.50	9.00	89.20	76.08
39	44.50	14.00	114.00	113.50	9.04	6.20	12.00	8.50	70.25	41.95
40	22.50	46.50	115.50	84.50	10.57	8.44	12.50	11.00	65.86	79.07
41	52.00	34.00	99.00	87.50	7.04	14.16	17.00	17.00	67.40	67.27
42	70.00	47.50	107.50	99.50	10.92	9.65	13.00	10.50	77.57	59.61
43	6.50	9.50	90.00	79.20	2.99	9.28	2.50	10.00	16.40	47.82
44	50.00	27.50	70.50	74.00	9.99	15.24	11.00	19.00	88.31	57.38
45	52.00	27.00	94.00	100.85	9.00	24.42	12.00	23.00	70.27	82.51
46	28.00	15.50	61.50	84.50	8.18	12.29	9.00	8.50	50.55	33.56
47	23.00	23.00	65.00	101.50	6.82	12.19	9.00	13.00	94.16	52.54
48	15.50	3.00	72.50	77.50	4.87	4.86	5.00	6.00	19.46	35.47

49	58.00	63.50	111.00	104.00	8.74	10.35	11.00	13.50	68.25	93.82
50	35.50	108.50	104.50	96.00	10.44	7.04	10.50	9.00	74.28	49.42
51	24.00	37.00	94.50	75.50	6.12	3.51	5.50	7.00	40.56	35.63
52	38.00	102.50	79.00	88.50	8.45	4.98	11.00	6.00	85.47	42.24
53	24.50	72.50	99.50	116.00	9.44	6.99	15.00	9.50	68.01	110.88
54	23.50	125.00	103.50	100.00	11.57	19.39	8.00	7.00	118.62	99.78
55	115.00	15.00	98.00	85.50	15.32	14.32	19.00	13.50	137.08	58.53
56	61.50	65.00	100.65	127.00	19.25	4.95	20.00	6.50	59.83	47.37
57	60.00	74.00	97.00	92.50	7.30	3.20	12.50	5.00	73.25	62.94
58	63.00	19.50	103.00	57.50	9.84	6.95	12.00	11.50	71.41	83.88
59	35.00	99.00	103.50	100.50	13.90	7.46	14.50	11.50	80.07	57.54
60	59.00	48.00	103.50	65.00	11.47	10.73	20.00	16.00	85.11	82.16
61	86.00	94.00	98.50	80.00	8.40	7.41	9.00	12.00	77.20	42.73
62	66.00	80.00	100.50	114.50	12.27	16.15	16.00	20.50	161.69	100.42
63	75.50	15.00	89.00	88.50	10.34	6.63	15.00	7.00	79.58	36.21
64	50.50	60.50	72.50	133.50	12.83	10.49	21.00	14.00	123.02	118.32
65	39.00	108.00	87.00	118.75	7.98	8.25	20.00	10.00	50.57	102.04
66	97.00	56.00	84.50	80.00	11.34	12.97	15.00	15.50	143.61	105.46
67	69.00	93.50	102.00	86.00	10.73	14.41	14.50	16.00	137.71	124.62
68	149.00	83.00	76.50	137.50	14.69	11.78	18.00	16.00	74.71	87.64
69	63.50	95.00	88.50	115.50	9.83	19.48	12.00	23.50	80.38	61.58
70	30.50	92.00	75.00	119.50	8.00	8.54	9.50	14.00	58.81	65.89
71	57.50	100.00	84.50	124.50	9.51	8.58	13.50	13.50	91.11	73.27
72	49.00	110.50	87.50	117.50	12.34	8.29	15.00	11.00	88.61	79.12
73	51.50	67.50	105.00	95.00	5.62	8.53	10.00	11.00	35.51	74.35
74	72.00	87.00	96.50	133.00	12.59	11.10	18.00	14.00	55.71	84.61
75	83.50	98.50	94.50	94.00	9.07	15.34	12.00	18.00	66.61	110.60
76	93.00	50.50	72.00	91.00	8.64	12.29	13.00	14.00	73.99	74.13
77	103.00	41.00	63.50	90.00	10.57	14.89	14.00	19.00	59.53	91.52
78	64.50	42.00	68.50	92.50	11.09	10.25	14.00	15.00	42.58	43.10
79	105.00	99.50	103.50	84.00	10.32	13.28	15.00	15.00	83.19	94.93
80	30.50	106.00	87.50	104.50	9.01	8.33	11.00	12.50	47.58	74.41
81	101.00	93.50	89.50	68.50	9.16	13.28	12.00	15.00	46.52	82.65
82	94.50	117.50	100.00	80.00	8.95	11.67	12.00	15.00	54.70	97.85
83	12.00	36.50	82.00	112.50	7.07	14.43	9.50	11.50	29.78	55.47
84	21.00	63.50	94.00	112.00	9.66	6.04	9.00	9.00	77.89	35.90
85	56.00	117.00	94.00	101.50	7.97	16.64	11.00	19.00	33.91	91.63
86	103.00	123.00	85.00	105.00	9.70	14.49	11.00	15.50	67.99	108.41
87	29.50	124.50	95.00	102.50	10.43	13.05	11.00	12.00	44.86	58.33
88	79.00	205.00	78.50	74.50	14.72	13.97	17.00	20.00	73.94	108.70
89	119.50	192.00	66.50	81.00	12.87	13.62	16.00	18.50	68.94	121.60
90	159.50	57.00	102.00	84.50	11.92	16.90	12.00	19.00	60.12	114.10
91	34.00	113.00	99.00	111.00	6.27	16.10	38.00	18.00	65.44	111.08
92	46.00	119.50	97.50	91.50	12.48	10.85	18.00	14.00	103.13	109.50
93	65.50	93.50	104.00	90.00	9.25	10.31	12.50	20.50	52.50	66.13
94	91.00	35.50	98.00	136.50	10.31	9.23	14.00	12.00	67.05	57.99
95	110.50	147.50	105.00	111.00	10.41	14.25	16.00	19.00	74.07	130.86
96	91.50	132.00	109.50	103.00	11.64	16.20	12.50	19.00	82.35	108.90
Mean	**57.31**	**66.62**	**94.58**	**98.74**	**10.45**	**11.21**	**13.52**	**13.32**	**73.15**	**74.90**
Max	**159.50**	**205.00**	**150.00**	**139.00**	**21.29**	**25.96**	**38.00**	**23.50**	**161.69**	**155.19**
Min	**6.50**	**3.00**	**47.00**	**43.00**	**2.99**	**3.20**	**2.50**	**5.00**	**16.40**	**22.45**

Table 3. Estimates of variability and heritability parameters for both the environments

Characters	GCV		PCV		Heritability		GA (%Mean)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Nodule Number	37.66	58.48	60.86	64.20	38.30	82.99	48.02	109.74
Root length	15.50	18.53	18.80	20.93	67.92	78.33	26.31	33.78
Root Fresh Weight	21.74	35.67	33.31	39.54	42.58	81.40	29.22	66.30
Root Volume	22.03	30.02	44.13	33.01	24.93	82.70	22.66	56.24
Shoot Fresh Weight	33.91	36.12	41.41	37.60	67.03	92.29	57.19	71.48

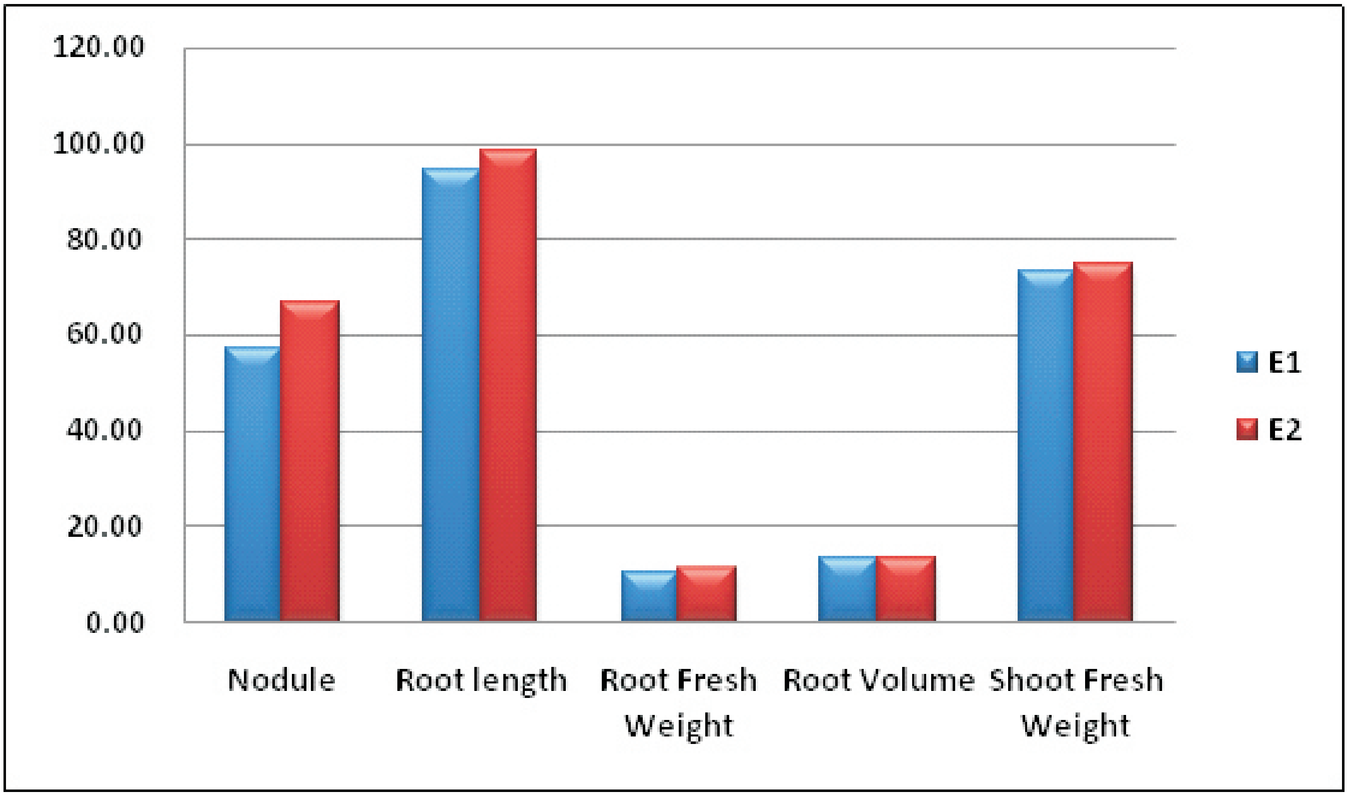

Figure1. Mean Values of different characters for both conditions

Heritability (h^2) provides information on heritable portion of observed effects. Classification of heritability into low (below 30%), medium (30% - 60%) and high (above 60%) was suggested by Johnson *et al*. (1955a). highest heritability was recorded for root length (67.92%), followed by shoot fresh weight (67.03%). Root fresh weight (42.58%) and nodule number (38.30%) exhibited moderate heritability, whereas low heritability was found for root volume (24.93%) only. Heritability estimates along with genetic advance provide a reliable measure for predicting the genetic gain under selection. Classification of genetic advance as percent of mean (GA) into low (below 30%), medium (30% - 50%) and high (above 50%) was suggested by Johnson *et al*. (1955). High genetic advance as percent of mean (GA) coupled with high heritability was observed for shoot fresh weight only; indicating the preponderance of additive gene action in expression of this trait in E_1. Moderate genetic advance coupled with moderate heritability was observed for nodule number; low genetic advance with low heritability exhibited by root volume only.

In E_2, high value of GCV and PCV was recorded for all the traits studied except root length, which showed moderate GCV with high PCV. All the characters exhibited high heritability in *Rhizobium* treated experiment. Highest heritability was recorded

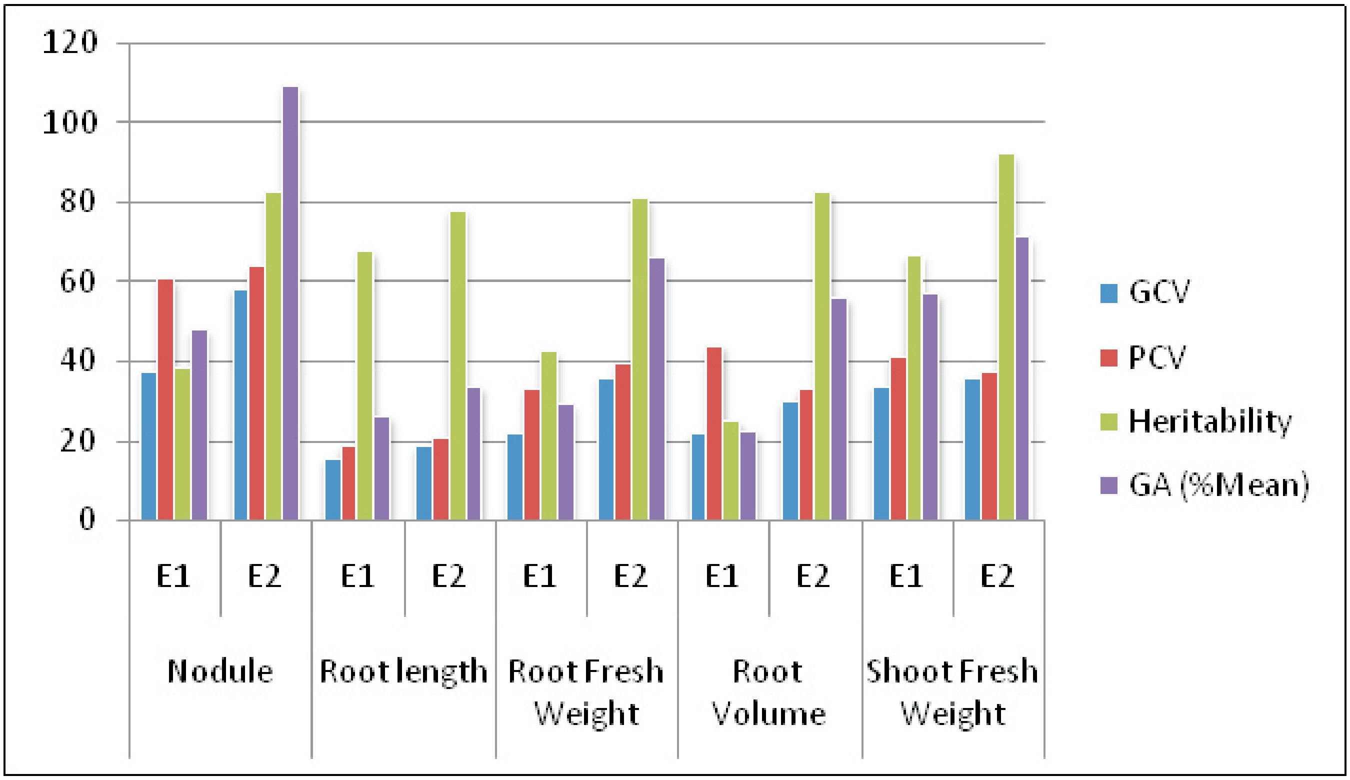

Figure 2. Estimates of variability and heritability parameters

for shoot fresh weight (92.29%) followed by nodule number (82.99%), root volume (82.70%), Root fresh weight (81.40%) and root length (78.33%). High genetic advance as percent of mean (GAM) coupled with high heritability was observed for nodule number, root fresh weight, root volume and shoot fresh weight. Root length exhibited moderate genetic advance with high heritability.

Correlation and path analysis

The estimation of correlation coefficients for E_1 and E_2 at genotypic, phenotypic and environmental level was mentioned in Table 4. In E_1, genotypic correlation was found to be higher in magnitude than phenotypic correlation. This may be due to modifying effects of environment on association of traits at genetic level (Johnson *et al*., 1955). Shoot fresh weight showed significant positive correlation with nodule number, root fresh weight and root volume at genotypic level. Root volume was found significantly & positively correlated with nodule number and root fresh weight. Root fresh weight showed significant positive correlation with nodule number only.

Shoot fresh weight showed significant positive correlation with all the other traits studied under this experiment at phenotypic level. Root volume was found significantly positive correlated with nodule number and root fresh weight. Root fresh weight showed significant positive correlation with nodule number only. Knowledge on inter correlation between quantitative traits may facilitate breeders to decide the direction of selection on related traits for improvement.

At environmental level, shoot fresh weight showed significant positive correlation with root length, root fresh weight and root volume. The root volume exhibited significant positive correlation with root length and root fresh weight. Root fresh weight showed significant positive correlation with root length only.

In E_2, shoot fresh weight showed significant positive correlation with nodule number, root fresh weight and root volume at genotypic level. Root volume was found significantly positive correlated with nodule number and root fresh weight. Root length is significantly positive correlated with nodule number. Root fresh weight showed significant positive correlation with nodule number only.

Shoot fresh weight showed significant positive correlation with all the other traits studied under this experiment except root length at phenotypic level.

Table 4. Estimates of genotypic and phenotypic and environmental correlation coefficients in horsegram accessions for different characters studied in E_1 and E_2

			Root length	Root Fresh Weight	Root Volume	Shoot Fresh Weight
Nodule Number	G	E_1	-0.099	0.530**	0.339**	0.337**
		E_2	0.150*	0.168*	0.337**	0.602**
	P	E_1	-0.059	0.192**	0.164*	0.212**
		E_2	0.136	0.108	0.265**	0.532**
	E	E_1	-0.020	-0.036	0.087	0.090
		E_2	0.079	-0.171*	-0.084	0.044
Root length	G	E_1		-0.104	-0.109	0.107
		E_2		0.078	0.035	0.061
	P	E_1		0.042	0.035	0.154*
		E_2		0.095	0.067	0.058
	E	E_1		0.227**	0.162*	0.253**
		E_2		0.165*	0.201**	0.047
Root Fresh Weight	G	E_1			0.809**	0.304**
		E_2			0.794**	0.394**
	P	E_1			0.438**	0.251**
		E_2			0.730**	0.348**
	E	E_1			0.266**	0.203**
		E_2			0.435**	0.054
Root Volume	G	E_1				0.200**
		E_2				0.508**
	P	E_1				0.177*
		E_2				0.456**
	E	E_1				0.191**
		E_2				0.101

*Significance at 5% level; **Significance at 1% level

Root volume was found significantly and positively correlated with nodule number and root fresh weight. No negative correlation was recorded among these traits.

At environmental level, there was no significant positive correlation of shoot fresh weight with other traits; however root volume exhibited significant positive correlation with root length and root fresh weight. Root fresh weight showed significant positive correlation with root length and negative with nodule number.

Partitioning the genotypic correlation into direct and indirect effects by path analysis would provide idea on relative contribution of each trait and its influence through other traits on yield. The results of path analyses were presented in Table 5. In the present investigation it was found that nodule number recorded highest positive direct effect (0.247) on shoot fresh weight followed by root fresh weight (0.234), root length (0.149). Root volume exhibited negative direct effect (-0.057) on shoot fresh weight in E_1. Nodule number showed positive indirect effect via root fresh weight. While, it showed negligible negative indirect effects through root length (-0.015) and root volume (-0.019). Root length exhibited positive indirect effect via single character i.e. root volume (0.006), and negative via two traits *viz*., nodule number

Table 5. Estimates of direct and indirect effects for root and shoot traits in horsegram in E_1 and E_2

		Nodule Number	Root length	Root Fresh Weight	Root Volume	Shoot Fresh Weight
Nodule Number	E_1	0.247	-0.015	0.124	-0.019	0.337**
	E_2	0.503	-0.005	0.019	0.085	0.602**
Root length	E_1	-0.024	0.149	-0.024	0.006	0.107
	E_2	0.075	-0.032	0.009	0.009	0.061
Root Fresh Weight	E_1	0.131	-0.016	0.234	-0.046	0.304**
	E_2	0.085	-0.002	0.112	0.199	0.394**
Root Volume	E_1	0.084	-0.016	0.190	-0.057	0.200**
	E_2	0.169	-0.001	0.089	0.251	0.508**

(-0.024) and root fresh weight (-0.024). The positive and indirect effects of root fresh weight on shoot fresh weight were found via nodule (0.131) only. Whereas, it showed negative effects through root length (-0.016) and root volume (-0.046). Root volume exhibited positive and indirect effects via nodule number (0.084) and root fresh weight (0.190), and negative indirect effect through root length (-0.016).

Root length exhibited negative direct effect (-0.032) on shoot fresh weight in E_2 (Table 5). Nodule number showed positive indirect effect via root fresh weight and root volume. While, it showed negligible negative indirect effects through root length (-0.005), root length exhibited positive indirect effect via root volume (0.009), nodule number (0.075) and root fresh weight (0.009). The positive indirect effects of root fresh weight on shoot fresh weight were found via nodule number (0.085) and root volume (0.199), whereas, it showed negative effect through root length (-0.002). Root volume exhibited positive and indirect effects via nodule number (0.169) and root fresh weight (0.089), and negative indirect effect through root length (-0.001). Paliwal et al. (2005), recorded positive direct effect on seed yield for branches per plant, pods per plant and 100 seed weight, Bhave et al. (2007) for plant height. Khulbe *et al*. (2013) recorded that pods per plant and 100 seed weight had positive direct effect on seed yield.

In conclusion, ANOVA revealed that there was more variability for these traits among the genotypes after treatment of Rhizobium culture as compared to without treated experiment. The PCV was found to be slightly higher than GCV in all traits studied indicating the importance of greater genetic variability with less influence of environment. Estimates of heritability and genetic advance were higher for all the traits in E_2; indicating the role of Rhizobium in the transmission of genotypes. The analysis of correlation carried out on five root and shoot traits indicates significant positive relationship of nodule number, root fresh weight and root volume with shoot fresh weight. Path analysis recorded that nodule number, root fresh weight and root volume revealed positive direct effects on shoot fresh weight. In the present investigation it was found that nodule number recorded highest positive direct effect (0.503) on shoot fresh weight followed by root volume (0.251) and root fresh weight (0.112). In case of line number 346 (TCR-1478) maximum no. of nodules (270) were recorded in E_2, which was shown to enhance the shoot fresh weight (134.31gm). Similar results were observed in line no. 341 (TCR1349), 378 (TCR-1446) and line no. 40 (IC-94592) in E_2. So it can be concluded from the above findings that plant biomass production is enhanced when number of nodules are more, as these high nodule numbers are directly related to more nitrogen production and availability in rhizosphere.

Conflicts of interest: The authors declare that there is no conflict of interest in this review article.

References

Alle R, V Hemalatha, KB Eswari and Sivasankar A. 2015. Genetic Variability, Heritability and Genetic Advance of Yield and Its Components in Horsegram (*Macrotyloma uniflorum* [Lam.] Verdc.). Environment & Ecology **33** (4C):2019-2021.

Bhave, SG, Joshi SN, Sawant SS, Bendale VW and Desai SS. 2007. Analysis of genetic parameter for yield and certain yield contributing traits in horsegram. Journal of Maharashtra Agriculture University **32**(2): 239-241.

Blumenthal MJ and Staples IB. 1993. Origin, evaluation and use of Macrotyloma as forage – a review. Tropical Grassland **27**:16-29.

Burton GW. 1952. Quantitative inheritance in grass. In: Proceedings of 6th International grassland Congress. pp: 24-83.

Cook BG, Pengelly BC, Brown SD, Donnelly JL, Eagles DA, Franco MA, Hanson J, Mullen BF, Partridge IJ, Peters M and Schultze-Kraft R. 2005. Tropical Forages: an interactive selection tool. [CD-ROM], CSIRO, DPI&F(Qld) Brisbane: CIAT and ILRI.

Dewey DR and Lu KH. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agronomy Journal **51**:515-518.

Jansen PCM. 1989. *Macrotyloma uniflorum* (Lam.) Verdc.: *Plant resources of South-East Asia, pulses*. Wageningen, the Netherlands: Pudoc. p 53-54.

Johnson HW, HF Robinson and Comstock RE. 1955b. Genotypic and phenotypic correlation in soybean and their implications in selection. Agronomy Journal **47**:477-485

Johnson HW, Robinson HF and Comstock RE. 1955a. Estimates of genetic and environment variability in soybean. Agronomy Journal **47**:314-318.

Khulbe RK, Pant DP and Singh DV. 2013. Genetic studied in horsegram from NW Himalayan regions of Uttarakhand, India. Crop Research **43:** 194-196.

Kumar V, Koraddi AS, Boodi IH and Kallesh D. 2016. Genetic variability studies in horse gram [*Macrotyloma uniflorum* (lam.) Verdc.]. The Bioscan **11**(2):1255-1259.

Lush JL. 1940. Intra-sire correlations and regression of offspring on dams as a method of estimating heritability of characters. **In:** Proceedings of American Society of Animal Production **33:**293-301.

Mus F, Crook MB, Garcia K, Garcia CA, Geddes BA and Kouri ED. 2016. Symbiotic nitrogen fixation and the challenges to its extension to nonlegumes. Applied Environmental Microbiology **82:**3698-3710.

Oram RN. 1990. Register of Australian herbage plant cultivars. edition. Melbourne, Australia, The Common wealth Scientific and Industrial Research Organisation p 304.

Paliwal RV, Sodani SN and Jain LK. 2005. Correlation and path analysis in horse gram (*Macrotyloma uniflorum*). J. Arid leg. P 309-310.

Reddy PCO, Sairanganayakulu G, Thippeswamy M, Reddy PS, Reddy MK and Sudhakar C. 2008. Identification of stress induced genes from the drought tolerant semi-arid legume crop horsegram (Macrotyloma uniflorum (lam.) Verdc.) through analysis of subtracted expressed sequence tags. Plant Sciences **175:** 372-384.

Singh RK and Chaudhary BD. 1995. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, 215-218.

Sivasubramanian S and Menon PM. 1973. Genotypic and phenotypic variability in rice. Madras Agricultural Journal **60** (9-13):1093-1096.

Smartt J. 1990. Grain legumes: evolution and genetic resources. Cambridge University Press, Cambridge, UK p379.

Vavilov NI. 1951. Phytogeographic basis of plant breeding. Chronica Botanica **13:**13-54.

Verdcourt B. 1971. Phaseoleae. In J. C. Gillet, R. M. Polhill, & V. Verdcourt (Eds.), *Flora of east tropical Africa. Leguminosae–subfamily Papilionoideae*. p 81-594.