Assessment of genetic correlation, path coefficient analysis and principal component analysis in horse gram under water stress

ABSTRACT

A field experiment was carried out to evaluate the correlation and path analysis in thirty horse gram germplasm lines under moisture-stressed conditions using fifteen selected characters. The association studies revealed a significant positive correlation of seed yield with relative water content, number of pods per plant, number of seeds per pod, total chlorophyll content, harvest index, proline content, root dry weight, root length and leaf area index. While days to 50% flowering, days to maturity, plant height and number of primary branches showed a significant negative correlation with yield. Path coefficient analysis revealed a high positive direct effect of the number of pods per plant on seed yield and the number of seeds per pod recorded exhibited the highest indirect effect on seed yield via the number of pods per plant under moisture stress conditions in horse gram. So, selection based on the number of pods per plant will be more beneficial under water stress conditions. The exploitation of genetic diversity is key to a successful breeding program. The principal component analysis using selected fifteen characters revealed the existence of adequate genetic variability among genotypes under study. First four principal components accounted for a cumulative variance of 82.47%. The PCA biplot revealed genotypes viz. IC22785, IC392329, HG 26L and IC20753 to highly diverse and these genotypes may be employed for enhancement of various traits in horse gram.

Keywords: Correlation Studies, Drought Stress, Horse Gram, Moisture Stress Condition, Path Coefficient Analysis, Principal Component Analysis

1. INTRODUCTION

Horse gram [*Macrotyloma uniflorum* (Lam.) Verdc.], a member of the Fabaceae family is an underutilized minor crop. The crop is diploid with chromosome number 2n=20, 22, 24 [1]. Four subspecies has been reported under *Macrotyloma uniflorum* viz- *M. uniflorum* var. *stenocarpum* (Brenan) Verdc., *M. uniflorum* var. *verrucosum* Verdc., *M. uniflorum* var. *uniflorum* and *M. uniflorum* var. *benadirianum* (Choiv.) Verdc. It is chiefly grown as a Rabi crop but it is also grown in the Kharif season for green manure and fodder purpose. The crop has higher protein content (21.73%) than other major pulses such as chickpea (18.77%), kidney bean (19.91%), pigeon pea (20.27%), and dry peas (20.43%), and yet comparable to black gram (21.97%), lentil (22.49%) and green gram (22.53%) [2]. Apart from the nutritional aspect, the horse gram has ethnomedicinal values too. Horse gram has considerable tolerance against various abiotic stresses like drought, heat, salinity, etc [3] along with insurmountable pest resistance [4]. As a legume, it supplies the soil with atmospheric nitrogen via symbiotic interaction with the microorganisms Rhizobium. Thus, horse gram can be a potential future crop due to its immense nutritional qualities and endurance in harsh climates.

But this crop is cultivated in a limited region and has poor productivity due to a lack of high-yielding variety and a reliance on local cultivars, like with other pulses. There is an urgent need to improve this underutilized crop. Thus, breeding for high-yielding genotypes and hybrids would be more relevant. Yield is a complex trait affected by the environment as well as other contributing traits. The correlation of various traits coupled with the path coefficient can aid in identifying the optimum proportion of each trait towards yield. The path analysis allows the correlation coefficients to be partitioned into the direct and indirect effects of the various traits on yield. The relationship between yield and its components has proved extremely important in choosing the best plant type. Assessment of the extent of genetic diversity among the genetic stocks for various traits is necessary for crop improvement and principal component analysis helps in this. The principal component analysis (PCA) is a widely used multivariate analysis that aids in elucidating the relationship between characters as well as determine those traits that impart maximum contribution towards yield. It assists in the determination of suitable selection criteria. The PCA offers a chance to employ appropriate germplasm to improve crops for given plant attributes [5]. As a result, the present investigation was undertaken to know the direction and extent of association among selected characters in horse gram under moisture stress conditions as well as scrutinize the level of genetic diversity existing among the genotypes.

2. METHODOLOGY

The present investigation was carried out at Farming Systems Research Station, Sadanandapuram, located at latitude 8°58' N, longitude 76°48' E and at an altitude of 76 m above mean sea level. The thirty genotypes of horse gram in a randomized block design replicated thrice, employed in the investigation of Lalithambika et al. [6] formed the material of this study. The crop was raised using the KAU [7] "Package of Practices Recommendations Crops 2016" guideline. The thirty horse gram genotypes were subjected to water stress by limiting irrigation at the reproductive stage.

The genotypes were assessed for fifteen different characters which comprised of biometric, physiological and biochemical parameters. These traits were days to 50% flowering, number of primary branches per plant, plant height (cm), number of pods per plant, number of seeds per pod, harvest index (%), days to maturity, specific leaf area (cm^2 g^{-1}), leaf area index (LAI), root length (cm), root dry weight (g), RWC (relative water content, %), proline content (µmol g^{-1}), total chlorophyll content (mg g^{-1}) and seed yield per plant (g).

2.1 Data analysis

Correlation analysis was performed on the data over replications for the evaluated characters, as advised by Weber and Morthy [8]. The path analysis [9] was also performed to get a clear picture of the relative contribution of these traits on yield as well as their cause-and-effect association. The principal component analysis was used to evaluate and eliminate redundancy among genotypes with comparable features. The data of the traits were statistically analyzed using the GRAPES software [10].

3. RESULTS AND DISCUSSION

3.1 Correlation study

The seed yield is a quantitative character and hence, direct selection of yield is ineffective. So, more emphasis should be placed on its correlated characters. Genotypic and phenotypic correlations among fifteen characters of horse gram are represented in table 1. In the present study, the genotypic correlation coefficient of different characters with yield was higher generally than the phenotypic correlation coefficient. This implies that there was a strong association between the selected characters and they were less influenced by the environmental condition.

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The association studies revealed a significant positive correlation of seed yield with RWC (r_g = 0.969, r_p = 0.578), followed by number of pods per plant (r_g = 0.966, r_p = 0.902), number of seeds per pod (r_g = 0.960, r_p = 0.705), total chlorophyll content (r_g =0.829, r_p = 0.745), harvest index (r_g = 0.738, r_p = 0.731), proline content (r_g = 0.677, r_p = 0.616), root dry weight (r_g = 0.622, r_p = 0.494), root length (r_g = 0.596, r_p = 0.293) and LAI (r_g = 0.585, r_p = 0.473) and a significant negative correlation with days to 50% flowering (r_g = -0.812, r_p = -0.773), days to maturity (r_g = -0.712, r_p = -0.630), plant height (r_g = -0.634, r_p = -0.518) and number of primary branches (r_g = -0.466, r_p = -0.412). SLA showed a negative but non-significant correlation with seed yield at both genotypic and phenotypic levels.

Days to 50% flowering at genotypic and phenotypic level, exhibited a significant positive correlation with days to maturity (r_g = 0.906, r_p = 0.827), number of primary branches (r_g = 0.742, r_p = -0.742) and plant height (r_g = 0.727, r_p = 0.581). It recorded a significant negative correlation with number of seeds per pod (r_g = -0.876, r_p = -0.68), seed yield per plant (r_g = -0.812, r_p = -0.773), number of pods per plant (r_g = -0.799, r_p = -0.742), harvest index (r_g = -0.734, r_p = -0.701), RWC (r_g = -0.712, r_p = -0.426), total chlorophyll content (r_g = -0.559, r_p = -0.535) and proline content (r_g = -0.524, r_p = -0.496).

A positive correlation at genotypic and phenotypic level was shown by the number of primary branches per plant with days to maturity (r_g = 0.865, r_p = 0.620), days to 50% flowering (r_g = 0.742, r_p = 0.600) and plant height (r_g = 0.680, r_p = 0.476). At genotypic level, a significant negative correlation was shown by number of primary branches per plant with harvest index (r_g = -0.762), number of pods per plant (r_g = -0.595), number of seeds per pod (r_g = -0.566), seed yield per plant (r_g = -0.466), proline content (r_g = -0.422), RWC (r_g = -0.36), SLA (r_g = -0.299) and root dry weight (r_g = -0.197).

At genotypic and phenotypic level, plant height exhibited a positive significant correlation with the days to 50% flowering (r_g = 0.727, r_p = 0.581), days to maturity (r_g = 0.711, r_p = 0.484) and number of primary branches per plant (r_g = 0.680, r_p = 0.476). A significant negative correlation of plant height at genotypic level was observed with number of seeds per pod (r_g = -0.790), followed by number of pods per plant (r_g = -0.706), harvest index (r_g = -0.702), proline content (r_g = -0.674), total chlorophyll content (r_g = -0.646), seed yield per plant (r_g = -0.634), RWC (r_g = -0.574), LAI (r_g = -0.374), root dry weight (r_g = -0.366) and root length (r_g = -0.341).

A significant positive correlation was recorded by number of pods per plant at genotypic and phenotypic level with seed yield per plant (r_g = 0.966, r_p = 0.902), number of seeds per plant (r_g = 0.964, r_p = 0.676), RWC (r_g = 0.941, r_p = 0.560), harvest index (r_g = 0.835, r_p = 0.774), total chlorophyll (r_g = 0.761, r_p = 0.683), proline content (r_g = 0.699, r_p = 0.621), root dry weight (r_g = 0.589, r_p = 0.446), root length (r_g = 0.484, r_p = 0.253) and LAI (r_g = 0.483, r_p = 0.406). Days to 50% flowering (r_g = -0.799), days to maturity (r_g = -0.751), plant height (r_g = -0.706) and number of primary branches per plant (r_g = -0.595) had a significant negative correlation with number of pods per plant at genotypic level.

At genotypic and phenotypic level, number of seeds per pod recorded a positive significant correlation with number of pods per plant (r_g = 0.964, r_p = 0.676), seed yield per plant (r_g = 0.960, r_p = 0.705), RWC (r_g = 0.954, r_p = 0.395), total chlorophyll content (r_g = 0.792, r_p = 0.587), proline content (r_g = 0.305), root dry weight (r_g = 0.655, r_p = 0.473) and LAI (r_g = 0.564, r_p = 0.413). However, at genotypic level number of seeds per pod was significantly negatively correlated with days to 50% flowering (r_g = -0.876), plant height (r_g = -0.790), days to maturity (r_g = -0.748) and number of primary branches per plant (r_g = -0.566).

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Harvest index showed a positive significant correlation with the number of pods per plant (r_g = 0.835, r_p = 0.774), number of seeds per plant (r_g = 0.739, r_p = 0.560), seed yield per plant (r_g = 0.738, r_p = 0.731), RWC (r_g = 0.591, r_p = 0.344), total chlorophyll content (r_g = 0.468, r_p = 0.425), proline content (r_g = 0.431, r_p = 0.390), SLA (r_g = 0.420, r_p = 0.236), root dry weight (r_g = 0.289, r_p = 0.209) and LAI (r_g = 0.250, r_p = 0.217) at genotypic and phenotypic level. Number of primary branches per plant (r_g = -0.762), days to maturity (r_g = -0.738), days to 50% flowering (r_g = -0.734) and plant height (r_g = -0.702) were noticed to be significantly negatively correlated with the harvest index at genotypic level.

Correlation of days to maturity with days to 50% flowering (r_g = 0.906, r_p = 0.827) and plant height (r_g = 0.711, r_p = 0.620) was positively significant at genotypic and phenotypic level. The days to maturity number positively significantly correlated with of primary branches correlated (r_g = 0.843) however, at phenotypic level, it was negatively significantly correlated with number of primary branches (r_p = -0.642). The days to maturity was observed to have a significant negative correlation with number of pods per plant (r_g = -0.751), number of seeds per pod (r_g = -0.748), harvest index (r_g = -0.738), seed yield per plant (r_g = -0.712), total chlorophyll content (r_g = -0.445), RWC (r_g = -0.427), proline content (r_g = -0.383), LAI (r_g = -0.268), root length (r_g = -0.217) and root dry weight (r_g = -0.189) at genotypic level.

At genotypic and phenotypic level, the SLA possessed a positive significant correlation with harvest index (r_g = 0.42, r_p = 0.236). The root length (r_g = -0.621), root dry weight (r_g = -0.482), RWC (r_g = -0.400), number of primary branches per plant (r_g = -0.299), proline content (r_g = -0.272), total chlorophyll content (r_g = -0.237) and LAI (r_g = -0.192) were significantly negatively correlated with SLA at genotypic level.

LAI was significantly positively correlated with RWC (r_g = 0.731, r_p = 0.320), proline content (r_g = 0.644, r_p = 0.506), seed yield per plant (r_g = 0.585, r_p = 0.473), number of seed per pod (r_g = 0.564, r_p = 0.413), total chlorophyll content (r_g = 0.520, r_p = 0.431), number of pods per plant (r_g = 0.483, r_p = 0.406), root dry weight (r_g = 0.466, r_p = 0.232) and harvest index (r_g = 0.250, r_p = 0.217) at genotypic and phenotypic level. The LAI at genotypic level was positively with root length (r_g = 0.340) but at phenotypic level, non-significant correlation was recorded between LAI and root length. At genotypic level, the days to 50% flowering (r_g = -0.482), plant height (r_g = -0.374), days to maturity (r_g = -0.268) and SLA (r_g = -0.192) were significantly negatively correlated with LAI.

At the genotypic and phenotypic levels, a significant positive correlation was recorded by root length with root dry weight (r_g = 0.99, r_p = 0.494), total chlorophyll content (r_g = 0.855, r_p = 0.453), RWC (r_g = 0.763, r_p = 0.290), number of seeds per pod (r_g = 0.708, r_p = 0.305), proline content (r_g = 0.654, r_p = 0.336), seed yield per plant (r_g = 0.596, r_p = 0.293) and number of pods per plant (r_g = 0.484, r_p = 0.253) Root length was significantly positively correlated with LAI at genotypic level (r_g = 0.34) however non-significant correlation was registered between at phenotypic level. Root length was significantly negatively correlated with SLA (r_g = -0.621), days to 50% flowering (r_g = -0.422), plant height r_g = -0.341) and days to maturity (r_g = -0.217) at the genotypic level.

Root dry weight was positively correlated at the genotypic and phenotypic level, with root length (r_g = 0.99, r_p = 0.494), RWC (r_g = 0.932, r_p = 0.478), proline content (r_g = 0.744, r_p = 0.635), total chlorophyll content (r_g = 0.695, r_p = 0.560), number of seeds per pod (r_g = 0.665, r_p = 0.305), seed yield per plant (r_g = 0.622, r_p = 0.494), number of pods per plant (r_g = 0.589, r_p = 0.446), LAI (r_g = 0.466, r_p = 0.232) and harvest index (r_g = 0.289, r_p = 0.209). At genotypic level, significant negative correlation was recorded by root dry weight with SLA (r_g = -0.482), plant height (r_g = -0.366), days to 50% flowering (r_g = -0.317), number of primary branches per plant (r_g = -0.197) and days to maturity (r_g = -0.189).

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At genotypic and phenotypic level, correlation of RWC with seed yield per plant (r_g = 0.969, r_p = 0.578), total chlorophyll content (r_g = 0.956, r_p = 0.534), number of seeds per pod (r_g = 0.954, r_p = 0.395), number of pods per plant (r_g = 0.941, r_p = 0.560), root dry weight (r_g = 0.932, r_p = 0.478), proline content (r_g = 0.857, r_p = 0.514), root length (r_g = 0.763, r_p = 0.290), LAI (r_g = 0.731, r_p = 0.320) and harvest index (r_g = 0.591, r_p = 0.344) were positively significant. A significant negative correlation of RWC was observed with days to 50% flowering (r_g = -0.712), plant height (r_g = -0.574), days to maturity (r_g = -0.427), SLA (r_g = -0.400) and number of primary branches per plant (r_g = -0.366) at genotypic level.

Proline content recorded a significant positive correlation at genotypic and phenotypic level, with RWC (r_g = 0.857, r_p = 0.514), number of seeds per pod (r_g = 0.773, r_p = 0.616), root dry weight (r_g = 0.744, r_p = 0.635), number of pods per plant (r_g = 0.699, r_p = 0.635), total chlorophyll content (r_g = 0.695, r_p = 0.641), seed yield per plant (r_g = 0.677, r_p = 0.616), root length (r_g = 0.654, r_p = 0.336), LAI (r_g = 0.644, r_p = 0.506) and harvest index (r_g = 0.431, r_p = 0.390) whereas this trait was significantly negatively correlated with plant height (r_g = -0.674), days to 50% flowering (r_g = -0.524), number of primary branches per plant (r_g = -0.422), days to maturity (r_g = -0.383) and SLA (r_g = -0.272) at genotypic level.

A significant positive correlation was recorded by total chlorophyll content with RWC (r_g = 0.956, r_p = 0.534), root length (r_g = 0.855, r_p = 0.453), seed yield per plant (r_g = 0.829, r_p = 0.745), number of seeds per pod (r_g = 0.792, r_p = 0.587), root dry weight (r_g = 0.695, r_p = 0.560), LAI (r_g = 0.520, r_p = 0.431), harvest index (r_g = 0.468, r_p = 0.425), number of pods per plant (r_g = 0.761, r_p = 0.683) and proline content (r_g = 0.695, r_p = 0.641) at genotypic and phenotypic level. The plant height (r_g = -0.646), days to 50% flowering (r_g = -0.559), days to maturity (r_g = -0.445) and SLA (r_g = -0.237) were significantly negatively correlated at genotypic level with total chlorophyll content.

Similarly, under water stress condition significant positive correlation of yield was reported with number of pods per plant, number of seeds per pod, and proline content by Vanaja et al. [11] in red gram, RWC by Ahirwar [12] in chickpea, Baroowa and Gogoi [13] in black gram, number of pods per plant, number of seeds per pod, leaf area and chlorophyll content by Bordoloi et al. [14] in black gram. A significant negative correlation of seed yield with days to maturity was reported by Kanouni et al. [15] in chickpea, days to 50% flowering by Eswaran and Senthilkumar [16] in green gram and Bordoloi et al. [14] in black gram.

The significant positive association of traits like number of pods per plant, number of seeds per pod, total chlorophyll content, harvest index and LAI with seed yield shows that the higher the values of these characters, the higher will be the yield under water stress condition. Thus, improvement in these characters will result in higher seed yields. While, a significant negative correlation of days to 50% flowering, days to maturity, plant height and number of primary branches with yield indicates that the lower the values of these characters, the higher will be the yield under moisture stress conditions.

The parameters like RWC, proline content, root dry weight and root length were significantly, positively correlated with seed yield. Hence, these traits can be used to select moisture-stress tolerant genotypes in horse gram.

PATH ANALYSIS

Path coefficient analysis was performed to partition the genotypic correlation coefficient into direct and indirect effect. The direct and indirect effects of different characters on yield in horse gram under moisture stress conditions is furnished in table 2. Direct selection for a specific character will be rewarding if the association

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between that character and seed yield is due to the direct effect of the character. At the same time, if the correlation is due to the indirect effect of a character through another independent trait, then indirect selection through that independent trait will aid in yield improvement. According to Singh and Kakar [17], if the final correlation coefficient is positive but the direct effect is negative or negligible, the indirect causative components must be selected concurrently and if the correlation coefficient is negative but the direct effect is positive and high, a limited simultaneous selection model is to be adopted.

In this study, number of pods per plant exhibited the highest direct effect on seed yield (0.594). The moderate direct effect was recorded by plant height (0.218) with seed yield. Harvest index (0.172), number of primary branches (0.171), total chlorophyll content (0.156), LAI (0.144), number of seeds per pod (0.105) and root length (0.100) registered low direct effect. The proline content (0.022) showed a positive but negligible direct effect on seed yield. While days to maturity (-0.185) exhibited a negative direct effect on seed yield. A negative but negligible direct effect on yield was recorded by characters like days to 50% flowering (-0.067), root dry weight (-0.048) and RWC (-0.034).

The highest positive indirect effect on seed yield was registered via number of pods per plant by number of seeds per pod (0.572), followed by RWC (0.558), harvest index (0.495), total chlorophyll content (0.452), proline content (0.415), root dry weight (0.349), while root length (0.287) and LAI (0.287) recorded moderate indirect effect via number of pods per plant. But the days to 50% flowering (-0.475), days to maturity (-0.446), plant height (-0.419) and number of primary branches (-0.353) exhibited high negative indirect effect through number of pods per plant.

Characters like days to 50% flowering (0.158), days to maturity (0.155) and number of primary branches (0.148) recorded a low indirect effect on seed yield via the plant height. A negative but low indirect effect on yield was reflected by the number of seeds per pod (-0.153), number of pods per plant (-0.154), harvest index (-0.153), proline content (-0.147), total chlorophyll content (-0.141) and RWC (-0.125) through plant height. The LAI (-0.081), root dry weight (-0.08) and root length (-0.074) registered a negative but negligible indirect effect on yield via plant height.

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Table 1: Genotypic correlation (below diagonal) and Phenotypic correlation (above diagonal) of yield and various characters of horse gram

	DF	PB	HT	PP	SP	HI	DM	SLA	LAI	RL	RDW	RWC	PRO	TC	SY
DF	1	.600**	.581**	-.742**	-.680**	.426**	-.701**	.827**	-0.026	-.401**	-.198*	-.266*	-.426**	-.496**	-.535**
PB	.742**	1	.476**	-.465**	-.405**	.566**	-.630**	.620**	-0.135	-0.146	-0.038	-0.153	-0.138	-.356**	-0.131
HT	.727**	.680**	1	-.516**	-.523**	.367**	-.544**	.484**	-0.049	-0.131	-.228*	-.341*	-.310*	-.517**	-.449**
PP	-.799**	-.595**	-.706**	1	.676**	-.373**	.774**	-.642**	-0.057	.406**	.253*	.446**	.560**	.621**	.683**
SP	-.876**	-.566**	-.790**	.964*	1	-.292*	.560**	-.495**	-0.061	.413**	.305*	.473**	.395**	.616**	.587**
HI	-.734**	-.762**	-.702**	.835**	.739**	1	-.816**	.427**	-.354**	-0.019	0.124	0.06	-0.065	-0.126	-0.063
DM	.906**	.843**	.711**	-.751**	-.748**	-.738**	1	-.643**	.236*	.217*	0.022	.209*	.344*	.390**	.425**
SLA	-0.062	-.299*	-0.099	-0.005	0.061	.420**	-0.052	1	-0.03	-.232*	-0.077	-0.153	-.272*	-.350*	-.411**
LAI	-.482**	-0.171	-.374**	.483**	.564**	.250*	-.268*	-.192*	1	-.194*	-.230*	-.227*	-0.138	-0.132	-0.157
RL	-.422**	0.041	-.341*	.484**	.708**	0.06	-.217*	-.621**	.340*	1	0.123	.232*	.320*	.506**	.431**
RDW	-.317*	-.197*	-.366**	.589**	.665**	.289*	-.189*	-.482**	.466**	.990**	1	.494**	.290*	.336*	.453**
RWC	-.712**	-.366**	-.574**	.941**	.954**	.591**	-.427**	-.400**	.731**	.763**	.932**	1	.478**	.635**	.56**
PRO	-.524**	-.442**	-.674**	.699**	.773**	.431**	-.383**	-.272*	.644**	.654**	.744**	.857**	1	.514**	.534**
TC	-.559**	-0.18	-.646**	.761**	.792**	.468**	-.445**	-.237*	.520**	.855**	.695**	.956**	.695**	1	.641**
SY	-.812**	-.466**	-.634**	.966**	.960**	.738**	-.712**	-0.051	.585**	.596**	.622**	.969**	.677**	.829**	1

*Significant at p = 0.05 and ** significant at p = 0.01

DF- days to 50% flowering
PB- number of primary branches per plant
HT- plant height (cm)
PP- number of pods per plant
SP- number of seeds per pod
HI- harvest index (%)
DM- days to maturity
SLA- specific leaf area ($cm^2\ g^{-1}$)

LAI- leaf area index
RL- root length (cm)
RDW- root dry weight (g)
RWC- relative water content (%)
PRO-proline content ($\mu mol\ g^{-1}$)
TC- total chlorophyll content ($mg\ g^{-1}$)
SY- seed yield per plant (g)

The days to maturity (0.144), days to 50% flowering (0.127) and plant height (0.116) recorded a low positive indirect effect on yield via number of primary branches per plant, while a low negative indirect effect on seed yield was shown by harvest index (-0.13) and number of pods per plant (-0.102) via number of primary branches per plant. Through number of primary branches per plant, root length (0.007) recorded a negligible but positive indirect effect, while number of seeds per pod (-0.097), proline content (-0.076), RWC (-0.062), root dry weight (-0.034), total chlorophyll content (-0.031) and LAI (-0.029) showed negative but negligible indirect effect on yield.

The number of pods per plant (0.144), number of seeds per pod (0.127) and RWC (0.102) recorded a low positive indirect effect on yield via harvest index. The total chlorophyll content (0.081), proline content (0.074), root dry weight (0.05), LAI (0.043) and root length (0.01) exhibited positive but negligible indirect effect via harvest index. A low negative indirect effect on yield through harvest index was shown by number of primary branches per plant (-0.131), days to maturity (-0.127), days to 50% flowering (-0.126) and plant height (-0.121).

A positive low indirect effect on seed yield via days to maturity was exhibited by number of pods per plant (0.139), number of seeds per pod (0.138) and harvest index (0.137); while positive but negligible indirect effect on seed yield via days to maturity was recorded by total chlorophyll content (0.082), RWC (0.079), proline content (0.071), LAI (0.05), root length (0.04) and root dry weight (0.035). Days to 50% flowering (-0.167), number of primary branches per plant (-0.156) and plant height (-0.131) registered a negative low indirect effect on yield through days to maturity.

The number of pods per plant (0.101) and RWC (0.100) recorded a low positive indirect effect on seed yield through number of seeds per pod. While a positive but negligible indirect effect on yield through number of seeds per pod was shown by total chlorophyll content (0.083), proline content (0.081), harvest index (0.078), root length (0.074), root dry weight (0.07) and LAI (0.059). A negative but negligible indirect effect on seed yield was registered by days to 50% flowering (-0.092), plant height (-0.083), days to maturity (-0.078) and number of primary branches per plant (-0.059) through number of seeds per pod.

The number of seeds per pod (0.058), harvest index (0.049), RWC (0.047), total chlorophyll content (0.037), proline content (0.035), LAI (0.032), root length (0.028) and root dry weight (0.021) had a negligible positive indirect effect on yield through days to 50% flowering; whereas a negligible positive indirect effect on yield was exhibited by days to maturity (-0.06), number of primary branches per plant (-0.049) and plant height (-0.048) via days to 50% flowering.

A low positive indirect effect on yield via total chlorophyll content was recorded by RWC (0.149), root length (0.133), number of seeds per pod (0.123), number of pods per plant (0.119), proline content (0.108) and root dry weight (0.108). The LAI (0.081) and harvest index (0.073) had a negligible positive indirect effect on seed yield via total chlorophyll content. A negative low indirect effect on yield was shown

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by plant height (-0.101) through total chlorophyll content. The days to 50% flowering (-0.087), days to maturity (-0.069) and number of primary branches per plant (-0.028) via total chlorophyll content had a negative but negligible indirect effect on seed yield.

The RWC (0.105) through LAI exhibited a low positive indirect effect on seed yield. The characters like proline content (0.093), number of seeds per pod (0.081), total chlorophyll content (0.075), number of pods per plant (0.069), root dry weight (0.067), root length (0.049) and harvest index (0.036) showed a negligible positive indirect effect on seed yield through LAI; while days to 50% flowering (-0.069), plant height (-0.054), days to maturity (-0.039) and number of primary branches per plant (-0.069) recorded a negative but negligible indirect effect on seed yield via LAI.

The number of pods per plant (0.144), number of seeds per pod (0.127) and RWC (0.102) recorded a low positive indirect effect on yield via harvest index. The total chlorophyll content (0.081), proline content (0.074), root dry weight (0.05), LAI (0.043) and root length (0.01) exhibited positive but negligible indirect effect via harvest index. A low negative indirect effect on yield through harvest index was shown by number of primary branches per plant (-0.131), days to maturity (-0.127), days to 50% flowering (-0.126) and plant height (-0.121).

A positive low indirect effect on seed yield via days to maturity was registered by number of pods per plant (0.139), number of seeds per pod (0.138) and harvest index (0.137); while a positive but negligible indirect effect on seed yield via days to maturity was exhibited by total chlorophyll content (0.082), RWC (0.079), proline content (0.071), LAI (0.05), root length (0.04) and root dry weight (0.035). Days to 50% flowering (-0.167), number of primary branches per plant (-0.156) and plant height (-0.131) registered a negative low indirect effect on yield through days to maturity.

The number of pods per plant (0.101) and RWC (0.100) recorded a low positive indirect effect on seed yield through number of seeds per pod. While a positive but negligible indirect effect on yield through number of seeds per pod was shown by total chlorophyll content (0.083), proline content (0.081), harvest index (0.078), root length (0.074), root dry weight (0.07) and LAI (0.059). A negative but negligible indirect effect on seed yield was registered by days to 50% flowering (-0.092), plant height (-0.083), days to maturity (-0.078) and number of primary branches per plant (-0.059) through number of seeds per pod.

The number of seeds per pod (0.058), harvest index (0.049), RWC (0.047), total chlorophyll content (0.037), proline content (0.035), LAI (0.032), root length (0.028) and root dry weight (0.021) had a negligible positive indirect effect on yield through days to 50% flowering; whereas a negligible positive indirect effect on yield was exhibited by days to maturity (-0.06), number of primary branches per plant (-0.049) and plant height (-0.048) via days to 50% flowering.

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Table 2. Direct (diagonal values) and indirect effects of different characters on yield in horse gram under moisture stress conditions

	DF	PB	Ht	PP	SP	HI	DM	LAI	RL	RDW	RWC	Pro	TC	G.Cor.
DF	**-0.067**	0.127	0.158	-0.475	-0.092	-0.126	-0.167	-0.069	-0.042	0.015	0.024	-0.011	-0.087	-0.812
PB	-0.049	**0.171**	0.148	-0.353	-0.059	-0.131	-0.156	-0.025	0.004	0.01	0.012	-0.01	-0.028	-0.466
Ht	-0.048	0.116	**0.218**	-0.419	-0.083	-0.121	-0.131	-0.054	-0.034	0.018	0.019	-0.015	-0.101	-0.634
PP	0.053	-0.102	-0.154	**0.594**	0.101	0.144	0.139	0.069	0.048	-0.028	-0.032	0.015	0.119	0.966
SP	0.058	-0.097	-0.172	0.572	**0.105**	0.127	0.138	0.081	0.071	-0.032	-0.032	0.017	0.123	0.960
HI	0.049	-0.130	-0.153	0.495	0.078	**0.172**	0.137	0.036	0.006	-0.014	-0.020	0.009	0.073	0.738
DM	-0.060	0.144	0.155	-0.446	-0.078	-0.127	**-0.185**	-0.039	-0.022	0.009	0.014	-0.008	-0.069	-0.712
LAI	0.032	-0.029	-0.081	0.287	0.059	0.043	0.05	**0.144**	0.034	-0.023	-0.025	0.014	0.081	0.585
RL	0.028	0.007	-0.074	0.287	0.074	0.01	0.04	0.049	**0.100**	-0.048	-0.026	0.014	0.133	0.596
RDW	0.021	-0.034	-0.08	0.349	0.070	0.05	0.035	0.067	0.099	**-0.048**	-0.031	0.016	0.108	0.622
RWC	0.047	-0.062	-0.125	0.558	0.100	0.102	0.079	0.105	0.076	-0.045	**-0.034**	0.019	0.149	0.969
Pro	0.035	-0.076	-0.147	0.415	0.081	0.074	0.071	0.093	0.065	-0.036	-0.029	**0.022**	0.108	0.677
TC	0.037	-0.031	-0.141	0.452	0.083	0.081	0.082	0.075	0.086	-0.034	-0.032	0.015	**0.156**	0.829

DF- Days to 50% flowering
PB- Number of primary branches per plant
HT- Plant height (cm)
PP- Number of pods per plant
SP- number of seeds per pod
HI- Harvest Index (%)
DM- Days to maturity
LAI- Leaf area index
RL- Root length (cm)
RDW- Root dry weight (g)
RWC- Relative water content (%)
PRO- Proline content (µmol g^{-1})
TC- Total Chlorophyll content (mg g^{-1})
G. Cor.- Genotypic correlation

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A low positive indirect effect on yield via total chlorophyll content was recorded by RWC (0.149), root length (0.133), number of seeds per pod (0.123), number of pods per plant (0.119), proline content (0.108) and root dry weight (0.108). The LAI (0.081) and harvest index (0.073) had a negligible positive indirect effect on seed yield via total chlorophyll content. A negative low indirect effect on yield was shown by plant height (-0.101) through total chlorophyll content. The days to 50% flowering (-0.087), days to maturity (-0.069) and number of primary branches per plant (-0.028) via total chlorophyll content had a negative but negligible indirect effect on seed yield.

The RWC (0.105) through LAI exhibited a low positive indirect effect on seed yield. The characters like proline content (0.093), number of seeds per pod (0.081), total chlorophyll content (0.075), number of pods per plant (0.069), root dry weight (0.067), root length (0.049) and harvest index (0.036) showed a negligible positive indirect effect on seed yield through LAI; while days to 50% flowering (-0.069), plant height (-0.054), days to maturity (-0.039) and number of primary branches per plant (-0.069) recorded a negative but negligible indirect effect on seed yield via LAI.

A negligible positive indirect effect on yield via root length was registered by root dry weight (0.099), total chlorophyll content (0.086), RWC (0.076), number of seeds per pod (0.071), proline content (0.065), number of pods per plant (0.048), LAI (0.034), harvest index (0.006) and number of primary branches per plant (0.004). The days to 50% flowering (-0.042), plant height (-0.034) and days to maturity (-0.022) had a negligible negative indirect effect on seed yield via root length.

Through root dry weight, plant height (0.018), days to 50% flowering (0.015), number of primary branches per plant (0.01) and days to maturity (0.009) had a positive but negligible indirect effect on seed yield, whereas root length (-0.048), RWC (-0.045), proline content (-0.036), total chlorophyll content (-0.034), number of seeds per pod (-0.032), number of pods per plant (-0.028), LAI (-0.023) and harvest index (-0.014) had a negative but negligible indirect effect on yield.

Days to 50% flowering (0.024), plant height (0.019), days to maturity (0.014) and number of primary branches per plant (0.012) exhibited a positive but negligible indirect effect on yield via RWC, while negative but negligible indirect effect on yield through RWC was recorded by number of pods per plant (-0.032), number of seeds per pod (-0.032), total chlorophyll content (-0.032), root dry weight (-0.031), root length (-0.026), LAI (-0.025) and harvest index (-0.02).

Through proline content a positive but negligible indirect effect on seed yield was recorded by RWC (0.019), number of seeds per pod (0.017), root dry weight (0.016), number of pods per plant (0.015), LAI (0.014), root length (0.014) and harvest index (0.009), whereas plant height (-0.015), days to 50% flowering (-0.011), number of primary branches per plant (-0.01) and days to maturity (-0.008) had a negative but negligible indirect effect on yield. The residual effect obtained was 0.0065, indicating that chosen traits are ideal for screening for moisture stress tolerance.

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In the present investigation, a high direct effect on seed yield was exhibited by number of pods per plant. This was in agreement with the results of Priyanka [18] and Sivan [19] in horse gram. The plant height recorded a moderate direct effect on seed yield. A similar observation was made by Shivaji [20] in horse gram. Harvest index, number of primary branches, total chlorophyll content, LAI, number of seeds per pod and root length registered low positive direct effect. Paliwal et al. [21] and Sivan [19] also reported number of primary branches has a positive direct effect on seed yield.

PRINCIPAL COMPONENT ANALYSIS

The principal component analysis (PCA) helps plant breeders and physiologists in reducing the number of plants to be evaluated and identify the traits that can be utilized to select tolerant genotypes [22]. Several researchers employed PCA as a measure of genetic divergence [23-26]. The entire variation was divided into fifteen principal components, one for each variable evaluated in the analysis. Gerrano et al. [27] reported that the eigen values can be used as a selection criterion for the crucial main components that contributed the most variance.

The eigen value, percentage variability and cumulative variability of different principal component is depicted in table 3. In present study under moisture stress condition, the first four principal components (PCs) influenced genotypic diversity greatly (> 80%) and their Eigen value was greater than 0.7. The scree plot showing the contribution of various principal components toward total variation is depicted in Fig. 1. According to Gixhari et al. [28] cumulative variability % greater than 75 is suitable for genetic differentiation in pulses. Per cent contributions of fifteen characters towards the first four principal components is shown in table 4. The first principal component contributed 53.92% of the variance. While only 0.205% of the total variance was contributed by PC 15. The maximum and minimum contribution in PC I was explained by seed yield per plant (10.854) and specific leaf area (0.168) respectively.

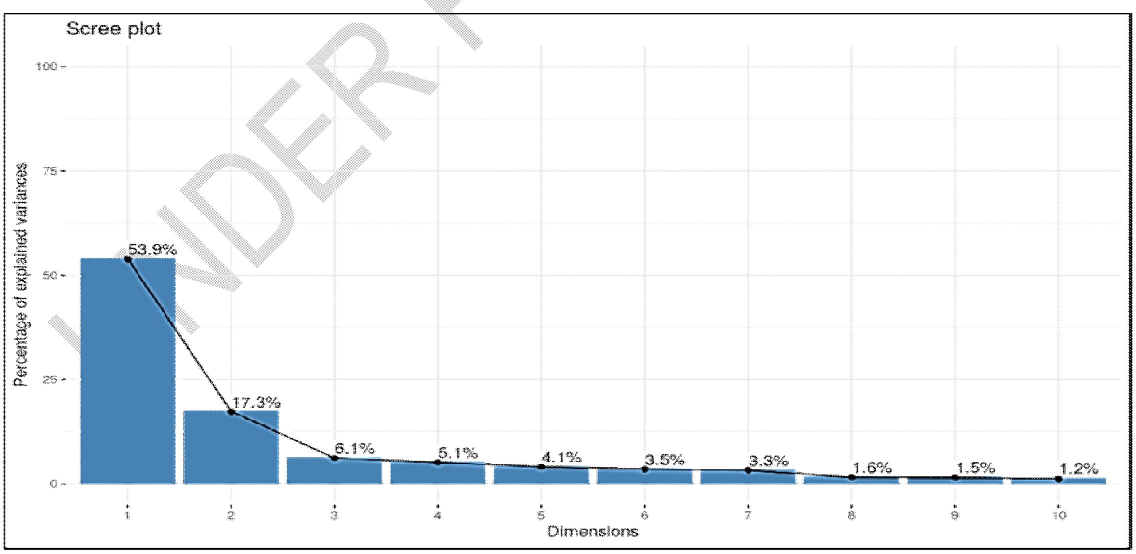

Fig. 1 Scree plot depicting the contribution of various PC toward total variation

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The PC Ⅱ contributed 17.327% variance and traits like specific leaf area (19.156) and seed yield per plant (0) added the highest and lowest contribution in PC Ⅱ respectively. About 6.13 percentage of variance was made by PC Ⅲ. The characters viz. leaf area index (57.239) and number of pods per plant (0.002) made the highest and lowest contribution in PC Ⅲ respectively. The PC Ⅳ contributed 5.09% of the variance and traits viz. specific leaf area (41.157) and root dry weight (0.089) registered largest and smallest per cent contribution to PC Ⅳ respectively. Neelima et al. [26] reported that seed yield per plant, number of pods per plant and days to flowering made largest contribution to variability in horse gram.

Factor loading of various traits in relation to the principal components is reflected in the table 5. Walle et al. [24] revealed considerable sources to the genetic divergence are regarded to be loadings with absolute scores greater than 0.3. The character seed yield per plant had the highest absolute value in the PC Ⅰ, which shows that this trait was primarily responsible for genetic divergence among genotypes.

The biplot created using the first two PC (Fig. 2) exhibited 30 genotypes of horse gram scattered in all four quadrants. The genotypes that are less distant from each other and nearer to the origin are more related. The genotypes IC22785, IC392329, HG 26L and IC20753 are dispersed across all four quadrates of the biplot, indicating the greatest genetic divergence among the genotypes. The water stress-tolerant genotypes were placed in the first quadrant.

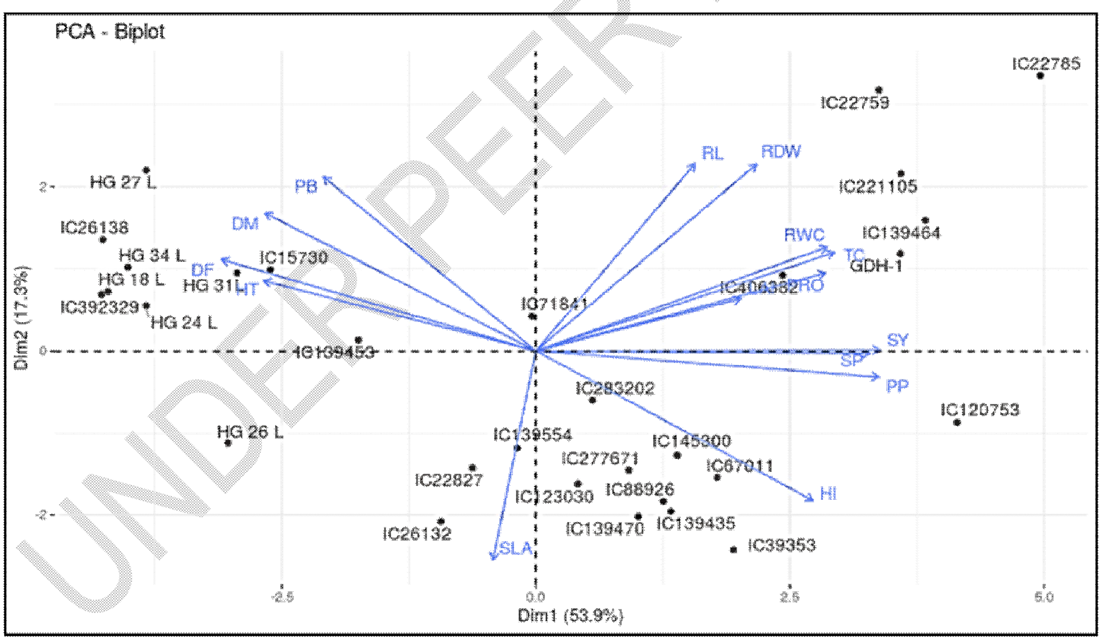

Fig. 2 Biplot depicting variation among 30 horse gram genotypes.

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Table 3. Eigen value, percentage variability and cumulative variability

Principal component	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	8.089	53.924	53.924
PC2	2.599	17.327	71.252
PC3	0.920	6.13	77.382
PC4	0.764	5.09	82.472
PC5	0.608	4.056	86.529
PC6	0.523	3.486	90.014
PC7	0.490	3.269	93.283
PC8	0.235	1.566	94.85
PC9	0.223	1.487	96.337
PC10	0.175	1.17	97.506
PC11	0.145	0.965	98.471
PC12	0.079	0.528	99.00
PC13	0.075	0.5	99.499
PC14	0.044	0.296	99.795
PC15	0.031	0.205	100

Table 4. Per cent contributions of fifteen characters towards first four principal component

Traits	PC1	PC2	PC3	PC4
DF	9.050	3.653	0.101	0.169
PB	4.130	13.22	2.762	13.694
HT	6.781	2.144	1.580	7.324
PP	10.792	0.303	0.002	1.654
SP	10.211	0.003	0.008	1.741
HI	7.035	9.812	0.535	1.880
DM	6.707	8.291	3.975	2.957
RWC	7.783	4.717	2.117	0.990
RL	2.322	15.346	20.027	6.133
RDW	4.468	15.262	6.015	0.089
LAI	3.854	1.198	57.239	0.552
SLA	0.168	19.156	1.077	41.157
TC	8.162	4.239	0.039	6.246
PRO	7.683	2.654	4.061	9.728
SY	10.854	0	0.461	5.684

The Fig. 3 depicts the loadings plot based on the principal components of 15 characters. Character closer to the origin, i.e., leaf area index is presumed to have a lower loading score and contribute less to the genetic divergence among genotypes. Characters under study were distributed among all four quadrants. Molosiwa et al. [29] reported characters positioned in the same quadrant are said to have a positive association, whereas those positioned in the opposite quadrant are said to have an inverse relationship. The seed yield per plant, leaf area index, proline content, total chlorophyll content of leaf, relative water content, root dry weight and root length were placed in the first quadrant ad hence, genotypes belonging to the first quadrant share similarities in these characteristics. The genotypes in the second quadrant had a similar number of primary branches per plant, days to maturity, days to 50% flowering and plant height because they were in the same quadrant. The genotypes placed in the third quadrant are similar for specific leaf area. The fourth quadrant's genotypes shared characters with the other genotypes in terms of harvest index, number of seeds per pod and number of pods per plant.

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Table 5. Factor loadings of each variable in relation to principal components

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15
DF	0.301	-0.191	0.032	0.041	0.352	0.198	-0.057	0.064	0.422	-0.093	-0.076	0.317	0.437	-0.318	0.339
PB	0.203	-0.364	0.166	0.37	-0.218	0.242	0.429	-0.314	-0.081	-0.036	0.069	-0.389	-0.083	-0.315	0.054
HT	0.26	-0.146	0.126	0.271	-0.353	-0.058	-0.646	-0.102	0.26	0.321	0.075	0.108	-0.279	-0.005	-0.011
PP	-0.329	0.055	0.004	0.129	-0.087	0.282	-0.127	-0.146	0.256	0.025	-0.186	-0.073	0.407	-0.115	-0.68
SP	-0.32	0.005	-0.009	0.132	0.046	-0.155	0.094	-0.689	-0.121	-0.006	-0.017	0.58	-0.071	-0.051	0.103
HI	-0.265	0.313	-0.073	0.137	0.118	0.322	-0.207	0.027	0.187	-0.456	-0.166	-0.128	-0.507	-0.263	0.184
DM	0.259	-0.288	0.199	0.172	0.453	0.146	-0.064	-0.078	-0.124	-0.22	-0.308	0.061	-0.204	0.517	-0.269
SLA	0.041	0.438	0.104	0.642	0.407	-0.292	-0.018	0.08	-0.13	0.201	0.145	-0.147	0.131	-0.095	-0.02
LAI	-0.196	-0.109	0.757	-0.074	-0.11	-0.404	-0.061	0.133	0.054	-0.385	0.016	0.001	0.075	-0.132	-0.026
RL	-0.152	-0.392	-0.448	0.248	-0.061	-0.509	-0.001	0.18	0.049	-0.096	-0.482	-0.079	-0.004	-0.126	0.018
RDW	-0.211	-0.391	-0.245	-0.03	0.282	-0.043	-0.345	-0.115	-0.094	-0.243	0.638	-0.211	0.088	-0.011	-0.043
RWC	-0.279	-0.217	0.146	0.1	-0.009	0.357	-0.231	0.32	-0.621	0.229	-0.155	0.176	0.081	-0.203	0.142
PRO	-0.277	-0.163	0.202	-0.312	0.422	-0.065	0.014	-0.159	0.231	0.548	-0.171	-0.322	-0.207	-0.106	0.097
TC	-0.286	-0.206	0.02	0.25	0.016	0.105	0.382	0.425	0.341	0.142	0.33	0.34	-0.285	0.121	-0.137
SY	-0.329	-0.002	0.068	0.238	-0.187	0.137	-0.039	-0.069	0.178	-0.003	-0.062	-0.225	0.307	0.582	0.501

DF- Days to 50% flowering
PB- Number of primary branches per plant
HT- Plant height (cm)
PP- Number of pods per plant
SP- number of seeds per pod
HI- Harvest Index (%)
DM- Days to maturity
SLA- Specific leaf area ($cm^2\ g^{-1}$)
LAI- Leaf area index
RL- Root length (cm)
RDW- Root dry weight (g)
RWC- Relative water content (%)
PRO-Proline content ($\mu mol\ g^{-1}$)
TC- Total Chlorophyll content ($mg\ g^{-1}$)
SY- Seed yield per plant (g)

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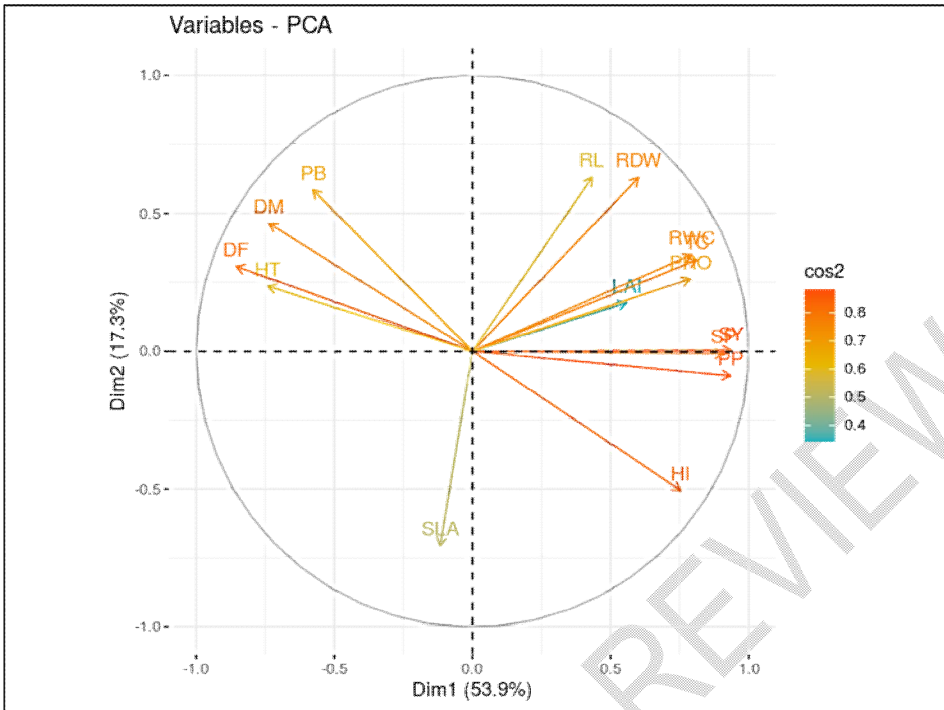

Fig. 3. Factor loadings plot of different characters based on principal components

4. CONCLUSION

The number of pods per plant exhibited a high direct effect on seed yield. The number of pods per plant had a significant positive correlation with yield. Thus, it can be inferred from this study that using the number of pods per plant as a selection criterion can enhance horse gram yield, when water stress is present. The dissection of genetic diversity utilizing the principal component analysis indicated ample variability among the horse gram genotypes, which can be exploited in the hybridisation programmes.

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