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Research Article

Multivariate analysis of yield contributory traits for selection criteria in Urdbean (*V. mungo* L. Hepper)

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Abstract

The present study was consisted of 100 urdbean genotypes grown at two locations i.e. at Punjab Agricultural University, Ludhiana and its Regional Research Station, Gurdaspur during *Summer*, 2019. In principal component analysis, first four PCs possessed Eigen value more than 1 and revealed 73.29% and 66.43 % variability at Ludhiana and Gurdaspur respectively. PCA analysis suggested the importance of biological yield per plant, plant height, days to 50% flowering, harvest index, yield per plant and pods per plant to speed up the urdbean improvement. The correlation studies suggested significantly positive association of clusters per plant, pods per plant, biological yield per plant and harvest index with grain yield per plant at both locations. Path analysis indicated that harvest index, biological yield per plant, nodes per plant, branches per plant showed the higher and positive direct effect on seed yield at both locations. Direct selection of genotypes with positively correlated characters can be considered useful for increasing seed yield.

Keywords

Urdbean, Correlation, Path Analysis, Principal Component Analysis

INTRODUCTION

Urdbean (*V. mungo* L. Hepper, $2n=22$), also known as blackgram or mash, is an important legume crop grown in India. It belongs to *leguminosae* family and is being cultivated since ancient times in India. In India, urdbean is being cultivated on 56.02 lakh hectares with a production of 30.60 lakh tonnes and productivity of 5.46q per hectare, whereas in Punjab, it occupies 2 thousand hectares with the production of 1.11 thousand tonnes and productivity of 5.55q per hectare in 2018-19 (Indiastat.com). Urdbean is protein rich food and contains almost 25% protein, which is nearly three times that of cereals. It also possesses rich amount of carbohydrate with important vitamins and minerals important for human health (Ghafoor *et al* 2001). The ability to restore soil fertility through symbiotic nitrogen fixation and short duration of urdbean makes it suitable for inter and multiple cropping systems. The major constraints in obtaining more productivity in urdbean are lack of genetic variability, absence of suitable ideotypes for different conditions, lower harvest index and susceptibility to biotic and abiotic stresses.

Seed yield is a complex trait, which is an outcome of expression and association of several genes. Correlations studies provides the mutual relationship and directional association of different characters with seed yield and among themselves. Path analysis reveals the direct and indirect effect of different characters on seed yield. Knowledge of inter-relationships present among yield related characters is important to make the selection effective for yield improvement (Sohel *et al* 2016). Principal component analysis is a technique used to reduce the dimensionality of characters, increasing interpretability with minimum loss of information (Jolliffe and Cadima, 2016). It helps in categorizing the distinctiveness of plant characters among promising genotypes. Keeping the above points in view, the present study was conducted to study the correlation, path analysis and principal component analysis to identify the suitable characters, that can be exploited in future urdbean improvement programs.

MATERIAL AND METHODS

The material consisted of 100 urdbean genotypes collected from different sources, which were grown in 10x10 simple lattice design at two locations at *i.e.* at experimental farm of Department of Plant Breeding and Genetics, PAU, Ludhiana and PAU, Regional Research Station, Gurdaspur during *Summer*, 2019. Being located at 30.9°N and 75.85°E, Ludhiana is categorized as sub-tropical zone with relatively high temperature and less rainfall, whereas Gurdaspur, which is located at 32.02°N and 75.24°E, categorized by high humidity coupled with high rainfall making it suitable for urdbean plant growth. The plants were grown in 2m long rows with row to row plant spacing of 30cm. Data were recorded on 13 characters, in which days to 50% flowering and days to 90% pod maturity were recorded on plot basis, whereas plant height at 90% pod maturity (cm), branches per plant, nodes per plant, clusters per plant, pods per plant, pod length (cm), seeds per pod, biological yield per plant (g), yield per plant (g), harvest index (%) and hundred seed weight (g) were recorded on five randomly selected plants. Correlation coefficients, and direct and indirect effects from path analysis were calculated according to the methods given by Dewey and Lu (1959). The correlation network diagram was drawn from phenotypic correlations using “qgraph” package in R software. For path analysis, seed yield was kept as resultant variable, while others as dependent variable. The path analysis was performed through “stats” package in R software.

RESULTS AND DISCUSSION

Large number of characters are measured by plant breeders, but not all of them have discriminatory power for germplasm evaluation and characterization (Maji and Shaibu, 2012). In such scenario, principal component analysis can be helpful to reveal patterns and eliminate redundancy in data sets (Iezzoni and Pritts, 1991). It is used to simplify and analyse the inter-relationship among large set of variables in terms of relatively small set of variables without much loss of essential information of original data set. In present study, PCA was performed for 100 urdbean germplasm lines under study for both locations (Ludhiana and Gurdaspur) (**Fig. 1(a)** and **Fig. 1(b)**). PCA analysis revealed that first four components had Eigen values more than 1 both at Ludhiana (**Table 1(a)**) and Gurdaspur (**Table 1(b)**). These first four components revealed 73.29% variability at Ludhiana and 66.43% variability at Gurdaspur among 100 genotypes of urdbean studied for yield and yield contributing characters (**Fig. 2(a)** and **Fig. 2(b)**). Ghafoor *et al* (2001) observed contribution of 79.5% variability in 484 urdbean accessions by first four principal components. Singh *et al* (2010) reported 98.79% of variance explained by first eight principal components in urdbean. Katiyar and Kumar (2015) had also done principal component analysis and observed 93.57% variability in 45 urdbean lines comprising of first seven principal components. Jeberson (2019) also reported 84.52% of the variability explained by first three principal components.

Table 1(a). Partial contribution of characters, eigen value, variation and cumulative proportions of principal components at PAU, Ludhiana

Characters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
DtF	0.33	-0.17	-0.12	0.03	-0.40	0.10	-0.34	0.51	-0.29	0.27	0.37	-0.12	-0.02
DtM	0.32	-0.17	-0.36	0.04	-0.15	-0.14	-0.42	-0.29	-0.11	-0.61	-0.22	0.00	0.06
PH	0.36	-0.13	-0.31	0.04	0.17	0.10	-0.05	-0.23	0.07	0.59	-0.29	0.44	0.15
BpP	0.09	0.29	-0.17	-0.55	-0.61	0.14	0.27	-0.12	0.27	-0.04	0.04	0.15	0.02
NpP	0.28	0.16	-0.14	-0.34	0.28	-0.61	0.21	-0.17	-0.31	0.12	0.29	-0.22	0.02
CpP	0.27	0.18	-0.25	-0.03	0.38	0.71	0.17	-0.08	-0.12	-0.17	0.21	-0.26	-0.09
PpP	0.28	0.38	0.16	0.03	0.08	-0.04	0.21	0.49	-0.34	-0.24	-0.39	0.37	0.01
PL	0.32	-0.25	0.36	0.03	-0.24	0.07	0.28	-0.16	-0.11	0.14	-0.47	-0.55	0.03
SpP	0.28	-0.27	0.44	0.20	-0.11	0.05	0.24	-0.32	-0.11	-0.17	0.46	0.43	-0.01
BYpP	0.40	-0.06	0.01	0.09	0.14	-0.19	0.04	0.22	0.62	-0.07	0.02	-0.05	-0.57
YpP	0.26	0.44	0.14	0.34	-0.02	-0.07	-0.13	-0.01	0.38	0.00	0.15	-0.18	0.62
HSW	-0.13	0.00	-0.51	0.59	-0.26	-0.15	0.52	0.02	-0.08	0.00	0.04	-0.05	-0.06
HI	0.00	0.55	0.15	0.25	-0.19	0.01	-0.31	-0.38	-0.21	0.21	-0.03	-0.02	-0.50
Eigen Value	4.85	2.40	1.23	1.05	0.84	0.68	0.58	0.40	0.36	0.27	0.19	0.13	0.01
Variation (%)	37.33	18.45	9.42	8.10	6.44	5.22	4.48	3.08	2.79	2.11	1.48	1.02	0.09
Cumulative Proportion (%)	37.33	55.77	65.19	73.29	79.74	84.95	89.43	92.51	95.30	97.41	98.88	99.91	100

First principal component was found to be influenced mostly by vegetative characters like biological yield per plant at Ludhiana and Gurdaspur (0.4 & 0.432) followed by plant height (0.364 and 0.346) and days to 50% flowering (0.329 and 0.316). Ghafoor *et al* (2008) also observed

the presence of biological yield per plant in first principal component studied for 37 urdbean lines. In contrast, second principal component was mostly influenced by characters like harvest index (0.553 and 0.498) followed by yield per plant (0.437 and 0.467) and pods per plant

Table 1(b). Partial contribution of characters, eigen value, variation and cumulative proportions of principal components at RRS, Gurdaspur

Characters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
DtF	0.32	-0.08	-0.05	-0.01	0.42	-0.29	0.10	-0.75	-0.23	0.02	-0.06	0.04	0.05
DtM	0.24	-0.25	-0.16	-0.10	0.35	-0.01	-0.77	0.27	-0.12	-0.15	-0.12	-0.09	-0.01
PH	0.35	-0.24	-0.17	-0.33	-0.09	0.18	0.22	0.10	0.09	0.60	-0.42	-0.20	0.05
BpP	0.23	0.12	-0.36	0.16	-0.26	0.61	-0.20	-0.40	0.29	-0.16	0.15	-0.10	-0.01
NpP	0.31	-0.08	-0.37	-0.25	-0.25	0.03	0.29	0.21	-0.56	-0.35	0.21	0.17	-0.01
CpP	0.19	0.41	-0.16	0.46	0.07	-0.03	-0.11	0.17	-0.32	0.56	0.31	0.00	0.01
PpP	0.28	0.40	-0.01	0.36	-0.05	-0.12	0.13	0.14	-0.01	-0.34	-0.66	-0.16	-0.03
PL	0.33	-0.04	0.58	-0.05	-0.11	0.07	0.02	0.01	-0.13	-0.10	0.30	-0.65	0.04
SpP	0.30	0.07	0.56	-0.05	-0.08	0.33	-0.14	-0.02	-0.12	0.07	-0.14	0.64	0.01
BYpP	0.43	0.00	-0.01	-0.02	0.17	-0.22	0.16	0.18	0.51	-0.05	0.28	0.15	-0.56
YpP	0.17	0.50	-0.05	-0.43	0.05	-0.21	-0.07	0.06	0.30	-0.04	0.15	0.06	0.60
HSW	-0.15	0.23	0.00	-0.15	0.69	0.53	0.30	0.15	-0.09	-0.09	0.01	-0.09	-0.07
HI	-0.17	0.47	0.00	-0.48	-0.18	-0.07	-0.25	-0.19	-0.20	0.10	-0.11	-0.12	-0.56
Eigen Value	3.86	2.38	1.36	1.03	0.91	0.86	0.69	0.59	0.55	0.32	0.24	0.19	0.02
Variation (%)	29.72	18.30	10.46	7.95	6.99	6.60	5.31	4.50	4.21	2.47	1.88	1.47	0.14
Cumulative Proportion (%)	29.72	48.02	58.49	66.43	73.43	80.02	85.34	89.83	94.05	96.52	98.39	99.86	100

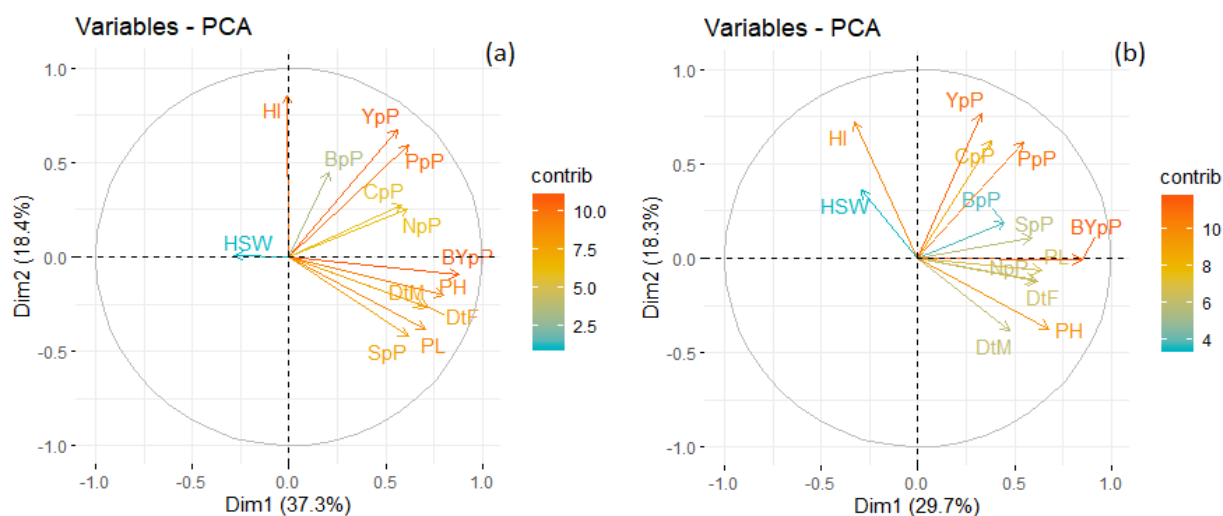


Fig. 1. Biplot of characters for 100 accessions of urdbean based on PC1 and PC2: (a) PAU, Ludhiana (b) RRS, Gurdaspur

(0.382 and 0.400). Jeberson *et al* (2019) also reported the high contribution of vegetative characters in PC1 and yielding characters in PC2 in urdbean. Third principal component was largely influenced by seeds per pod (0.441 and 0.578) and pod length (0.355 and 0.561). Fourth principal component was largely contributed by hundred seed weight (0.59) at Ludhiana and clusters per plant (0.46) at Gurdaspur. Fifth principal component was mostly influenced by clusters per plant (0.38) at Ludhiana

and hundred seed weight (0.69). So, characters dominant in first three principal components (**Fig. 3(a) and 3(b)**) like biological yield per plant, plant height at 90% pod maturity, days to 50% flowering, harvest index, yield per plant, pods per plant, pod length and seeds per pod are most important in reflecting the variation and can be utilized to speed up the urdbean improvement programs rather than going for all characters.

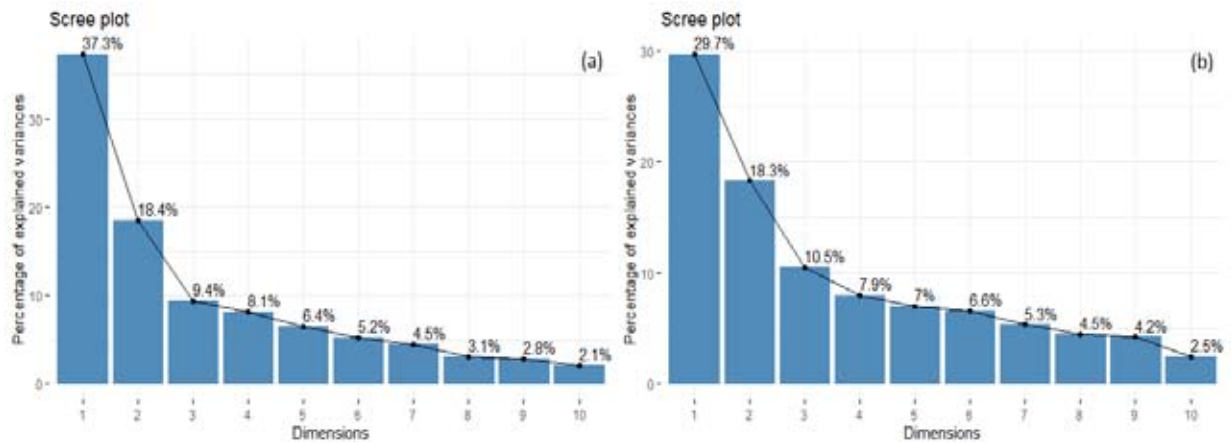


Fig. 2. Scree plot showing variation contribution of principal components at: (a) PAU, Ludhiana (b) RRS, Gurdaspur

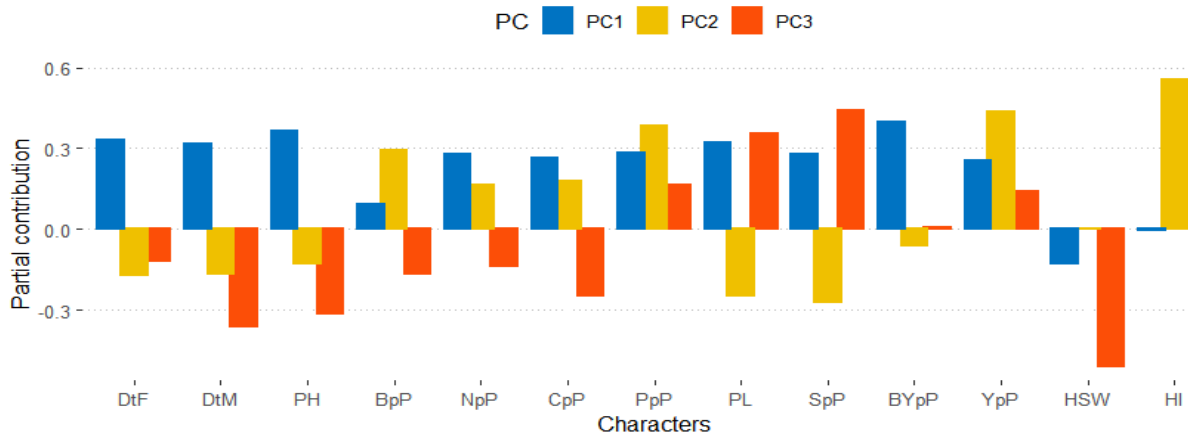


Fig 3(a): Partial contribution of all characters towards first three principal components (PC1, PC2 and PC3) at PAU, Ludhiana

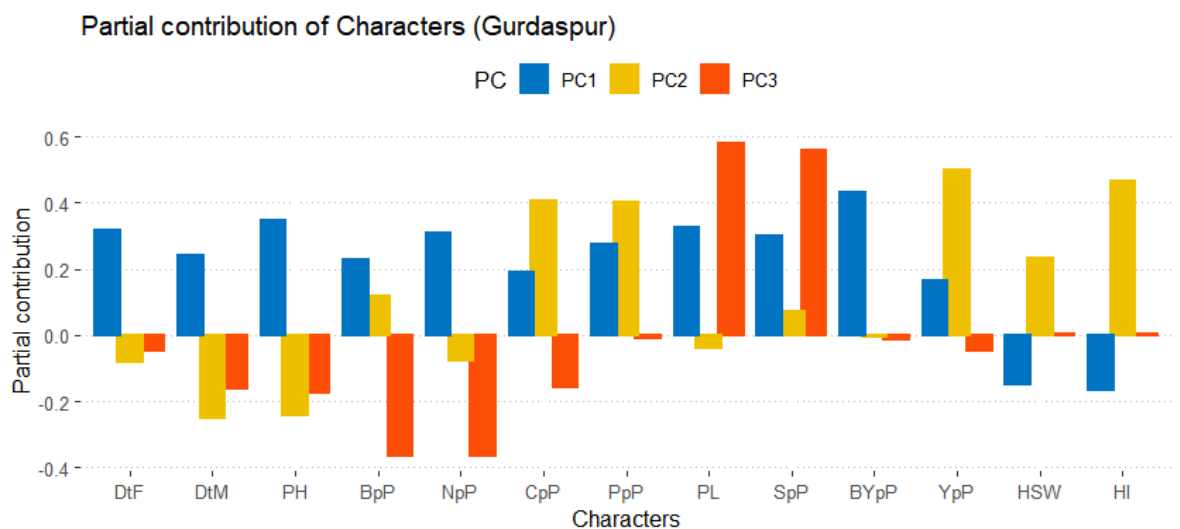


Fig 3(b): Partial contribution of all characters towards first three principal components (PC1, PC2 and PC3) at RRS, Gurdaspur

Correlation network (Ludhiana)

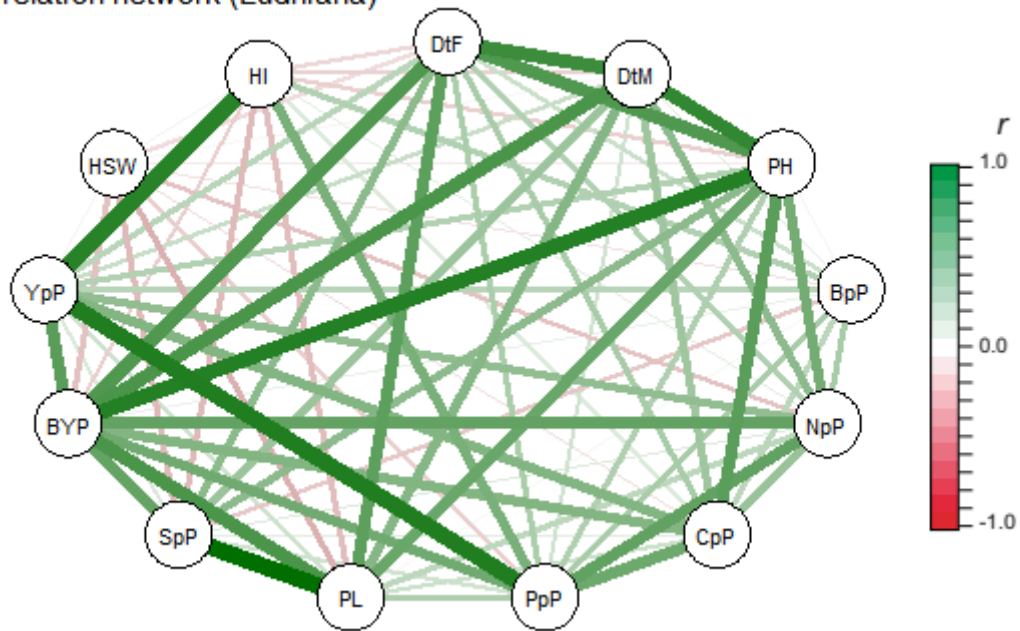


Fig. 4(a) Correlation network of different character pairs at PAU, Ludhiana

Correlation network (Gurdaspur)

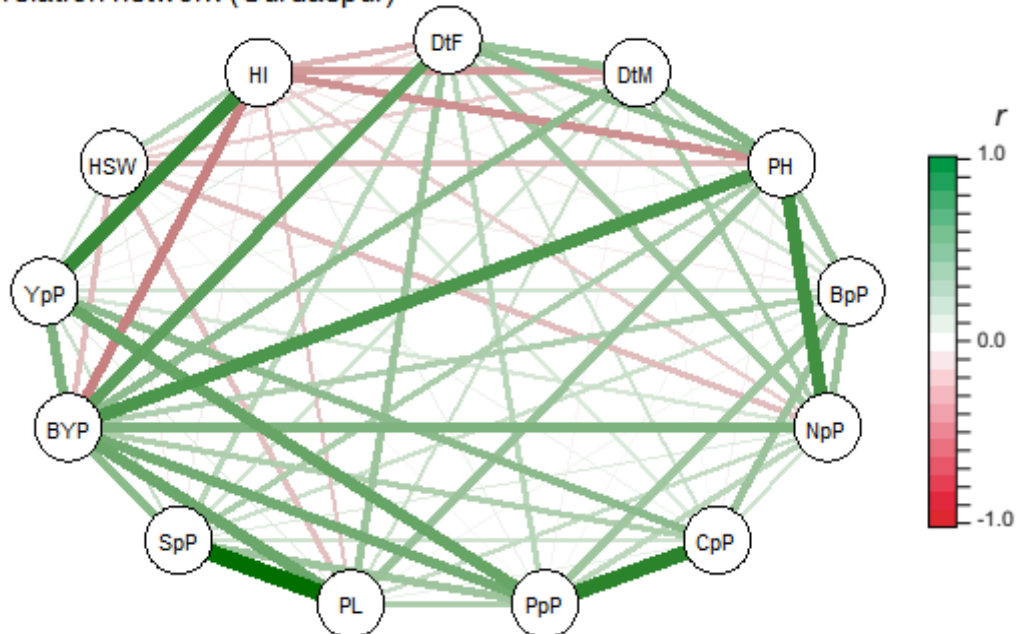


Fig.4(b) Correlation network of different character pairs at RRS, Gurdaspur

(DtF – Days to 50% flowering, DtM- Days to 90% pod maturity, PH- Plant height at 90% pod maturity (cm), BpP-Branches per plant, NpP- Nodes per plant, CpP-Clusters per plant, PpP- Pods per plant, PL- Pod length (cm), SpP- Seeds per pod, BYpP-Biological yield per plant (g), YpP- Yield per plant (g), HSW- Hundred seed weight (g) and HI- Harvest Index)

Table 2(a). Phenotypic (lower diagonal) and genotypic (upper diagonal) correlation among different characters at PAU, Ludhiana

	DtF	DtM	PH	BpP	NpP	CpP	PpP	PL	SpP	BYpP	YpP	HSW	HI
DtF		0.733**	0.545**	0.421**	0.124	0.339**	0.358**	0.715**	0.358**	0.589**	0.258**	-0.109	-0.085
DtM	0.492**		0.543**	0.034	0.134	0.492**	0.372**	0.707**	0.5**	0.596**	0.241*	-0.036	-0.087
PH	0.242*	0.299**		0.065	0.218*	0.785**	0.365**	0.285**	0.134	0.537**	0.317**	-0.12	0.06
BpP	0.061	0.109	0.089		0.412**	0.441**	0.486**	0.068	-0.251**	0.209*	0.341**	-0.18	0.314**
NpP	-0.017	0.071	0.184	0.336**		0.446**	0.82**	0.144	-0.054	0.478**	0.482**	-0.341**	0.302**
CpP	0.094	0.1	0.493**	0.199*	0.237*		0.44**	0.214*	0.036	0.333**	0.397**	-0.215*	0.256**
PpP	0.156	0.037	0.293**	0.239*	0.476**	0.554**		0.341**	0.128	0.53**	0.73**	-0.281**	0.598**
PL	0.334**	0.373**	0.232*	0.078	0.104	0.034	0.199*		0.716**	0.713**	0.259**	-0.459**	-0.1
SpP	0.211*	0.287**	0.119	-0.179	-0.041	-0.008	0.088	0.608**		0.516**	0.174	-0.314**	-0.119
BYpP	0.269**	0.241*	0.374**	0.042	0.259**	0.404**	0.558**	0.399**	0.371**		0.63**	-0.327**	0.096
YpP	0.151	0.096	0.279**	0.207*	0.326**	0.468**	0.718**	0.143	0.115	0.639**		-0.075	0.817**
HSW	-0.082	-0.039	-0.04	-0.076	-0.152	-0.088	-0.142	-0.294**	-0.234*	-0.218*	-0.036		0.023
HI	-0.006	-0.038	0.065	0.266**	0.237*	0.202*	0.447	-0.083	-0.133	-0.065	0.696**	0.045	

Table 2(b). Phenotypic (lower diagonal) and genotypic (upper diagonal) correlation among different characters at RRS, Gurdaspur

	DtF	DtM	PH	BpP	NpP	CpP	PpP	PL	SpP	BYpP	YpP	HSW	HI
DtF		0.2*	-0.028	0.174	0.121	0.273**	0.274**	0.253	-0.106	0.259**	0.008	-0.076	-0.175
DtM	0.136		0.267**	0.214*	0.195*	0.051	-0.111	-0.01	0.003	0.209*	-0.103	-0.12	-0.269**
PH	-0.004	0.248*		0.4**	0.641**	-0.058	-0.012	0.216*	0.098	0.36**	-0.073	-0.282**	-0.316**
BpP	0.002	0.095	0.219*		0.384**	0.634**	0.585**	-0.008	0.436**	0.32**	0.275**	0.098	-0.026
NpP	0.101	0.116	0.523**	0.212*		0.337**	0.317**	0.347**	0.201*	0.337**	0.063	-0.312	-0.191*
CpP	0.116	0.049	-0.051	0.153	0.115		0.706**	0.137	0.356**	0.345**	0.363**	-0.081	0.097
PpP	0.16	-0.084	0.013	0.187	0.118	0.704**		0.343**	0.383**	0.529**	0.455**	-0.207*	0.075
PL	0.121	-0.013	0.189	0.132	0.198*	0.078	0.203*		0.602**	0.511**	0.252	-0.411**	-0.029
SpP	-0.061	-0.016	0.094	0.234*	0.107	0.235*	0.313**	0.448**		0.311**	0.271**	-0.303**	0.105
BYpP	0.153	0.187	0.323**	0.17	0.17	0.319**	0.445**	0.352**	0.216*		0.373**	-0.248*	-0.350**
YpP	-0.03	-0.091	-0.055	0.075	-0.03	0.395**	0.477**	0.179	0.241*	0.453**		0.159	0.712**
HSW	-0.085	-0.103	-0.212*	0.027	-0.204*	0.002	-0.044	-0.231*	-0.187	-0.185	0.149		0.215*
HI	-0.162	-0.259**	-0.281**	-0.059	-0.136	0.147	0.13	-0.012	0.125	-0.325**	0.662**	0.213*	

** - Significant at 1% level and * - Significant at 5% level.

Correlation between different characters depicts the presence of linkage and pleiotropic effect of different genes. Environment plays an important role in developing phenotypic correlation. Correlation studies were done to study the relationship between yield and yield contributing characters. In the present study, genotypic correlations were observed higher than their corresponding phenotypic correlation that shows the strong inherent association between various characters at genetic level. Along with correlation analysis, network analysis is performed for better visualization of the phenotypic associations among different characters under study for both locations Ludhiana (**Fig 4(a)**) and Gurdaspur (**Fig. 4(b)**). At Ludhiana, 40 out of total 78 associations were significantly correlated (**Table 2(a)**). Among these associations, 37

were positively significant whereas, three were negatively significant. At Gurdaspur, 28 out of total 78 associations were significantly correlated (**Table 2(b)**). Among these associations, 22 were positively significant whereas, six were negatively significant. Significantly positive associations among the characters suggested an additive genetic model thereby less affected by the environment. At Ludhiana, 21 out of 38 and at Gurdaspur, 31 out of 50 non-significant associations were positive and non-significant respectively, referring information of inherent relations among the pairs, while rest 17 and 19 associations were negative and non-significant at Ludhiana and Gurdaspur respectively, referring complex linked relations among different combinations. The clusters per plant, pods per plant, biological yield per plant and harvest index showed

positively significant correlation with yield per plant at both locations. Clusters per plant also showed positive association with branches per plant, nodes per plant and pods per plant. It implies that the selection of clusters per plant could result in increased seed yield through increased branches, nodes and the number of pods.

Umadevi and Meenakshi (2005), Parveen *et al* (2011), Senthamizhselvi *et al* (2019) and Shanthi *et al* (2019) also observed positive association of clusters and pods per plant with seed yield per plant. Plant height at 90% maturity, branches per plant, nodes per plant and seeds

per pod also showed positively significant correlation with seed yield. Branches per plant and seeds per pod at Gurdaspur showed a significant positive genotypic correlation with seed yield. Similar results for biological yield per plant, branches per plant and seeds per pod has been reported by Chauhan *et al* (2007), Lal and Singh (2014) and Patidar and Sharma (2017). Plant height also showed a positive association with biological yield that indicate higher vegetative growth. Similar kind of positive association of plant height with biological yield per plant has been reported earlier by Hassan *et al* (2003) and Patidar and Sharma (2017).

Table 3(a). Direct (diagonal) and indirect effects of different characters on yield at PAU, Ludhiana

	DtF	DtM	PH	BpP	NpP	CpP	PpP	PL	SpP	BYpP	HSW	HI	YpP (r_g)
DtF	-0.023	0.074	0.081	0.054	0.036	-0.054	-0.129	-0.022	0.043	0.285	-0.010	-0.077	0.258**
DtM	-0.017	0.100	0.081	0.004	0.039	-0.079	-0.134	-0.021	0.060	0.289	-0.003	-0.079	0.241*
PH	-0.013	0.055	0.149	0.008	0.063	-0.125	-0.131	-0.009	0.016	0.260	-0.011	0.054	0.317**
BpP	-0.010	0.004	0.010	0.127	0.119	-0.070	-0.175	-0.002	-0.030	0.101	-0.017	0.284	0.341**
NpP	-0.003	0.014	0.032	0.052	0.290	-0.071	-0.295	-0.004	-0.007	0.232	-0.032	0.273	0.482**
CpP	-0.008	0.049	0.117	0.056	0.129	-0.160	-0.158	-0.007	0.004	0.162	-0.020	0.232	0.397**
PpP	-0.008	0.037	0.054	0.062	0.238	-0.070	-0.360	-0.010	0.015	0.257	-0.026	0.541	0.730**
PL	-0.016	0.071	0.042	0.009	0.042	-0.034	-0.123	-0.030	0.086	0.346	-0.042	-0.090	0.259**
SpP	-0.008	0.050	0.020	-0.032	-0.016	-0.006	-0.046	-0.022	0.119	0.250	-0.029	-0.107	0.174
BYpP	-0.014	0.060	0.080	0.027	0.139	-0.053	-0.191	-0.022	0.062	0.485	-0.030	0.087	0.630**
HSW	0.003	-0.004	-0.018	-0.023	-0.099	0.034	0.101	0.014	-0.038	-0.159	0.092	0.021	-0.074
HI	0.002	-0.009	0.009	0.040	0.088	-0.041	-0.215	0.003	-0.014	0.047	0.002	0.905	0.817**

YpP (r_g) = Genotypic correlation with yield per plant, ** - Significant at 1% level and* - Significant at 5% level. Residual effect = 0.16

Table 3(b). Direct (diagonal) and indirect effects of different characters on yield at RRS, Gurdaspur

	DtF	DtM	PH	BpP	NpP	CpP	PpP	PL	SpP	BYpP	HSW	HI	YpP (r_g)
DtF	-0.627	-0.062	0.050	0.449	0.049	-0.145	-0.389	0.322	0.168	0.320	0.059	-0.185	0.008
DtM	-0.125	-0.308	-0.481	0.554	0.080	-0.027	0.158	-0.013	-0.005	0.258	0.093	-0.285	-0.103
PH	0.017	-0.082	-1.800	1.034	0.262	0.031	0.017	0.274	-0.155	0.445	0.219	-0.334	-0.073
BpP	-0.109	-0.066	-0.719	2.589	0.157	-0.337	-0.829	-0.010	-0.693	0.396	-0.076	-0.028	0.275**
NpP	-0.076	-0.060	-1.154	0.993	0.409	-0.179	-0.449	0.441	-0.319	0.417	0.242	-0.202	0.063
CpP	-0.171	-0.016	0.104	1.641	0.138	-0.532	-1.001	0.174	-0.566	0.426	0.063	0.103	0.363**
PpP	-0.172	0.034	0.022	1.514	0.130	-0.376	-1.418	0.436	-0.610	0.653	0.161	0.079	0.455**
PL	-0.159	0.003	-0.388	-0.020	0.142	-0.073	-0.486	1.272	-0.958	0.632	0.319	-0.031	0.252
SpP	0.066	-0.001	-0.176	1.128	0.082	-0.189	-0.543	0.766	-1.591	0.384	0.235	0.111	0.271**
BYpP	-0.162	-0.064	-0.648	0.829	0.138	-0.184	-0.750	0.650	-0.494	1.236	0.192	-0.370	0.373**
HSW	0.047	0.037	0.508	0.253	-0.128	0.043	0.294	-0.523	0.482	-0.306	-0.775	0.227	0.159
HI	0.110	0.083	0.569	-0.068	-0.078	-0.052	-0.106	-0.037	-0.166	-0.433	-0.167	1.058	0.712**

YpP (r_g) = Genotypic correlation with yield per plant, ** - Significant at 1% level and* - Significant at 5% level. Residual effect = 0.19

Increased biological yield resulted into high yield through increasing the number of clusters per plant, pods per plant and seeds per pod, but decreases harvest index. So these characters, must be given due importance at the time of selection for grain yield improvement.

Positive association of biological yield per plant with pods per plant was supported by reports of Hassan *et al* (2003) and Sohel *et al* (2016); with clusters per plant by Tabasum *et al* (2010) and Rajasekhar *et al* (2017). The characters like days to 50% flowering and days to

90% maturity, has almost negligible association with seed yield at Gurdaspur, but significantly positive at genotypic level at Ludhiana indicating the role of environment. Soundarapandian *et al* (1976) and Parveen *et al* (2011) also observed similar kind of association for days to 50% flowering and days to 90% maturity with seed yield. The characters like days to 90% pod maturity, plant height at 90% pod maturity and biological yield per plant showed a significantly negative association with harvest index at Gurdaspur. It means that the late maturity and higher vegetative growth at Gurdaspur is associated with lower harvest index, whereas comparatively early maturity and lesser vegetative growth at Ludhiana is associated with higher harvest index. Negative association of harvest index with biological yield was corroborated by findings of Rajasekhar *et al* (2017) and Ch and Lal (2019); with plant height by Sohel *et al* (2016) and Partap *et al* (2019). Number of nodes per plant, clusters per plant, pods per plant, pod length, seeds per pod and biological yield per plant was observed to be significantly and negatively associated with hundred seed weight genotypically at both locations. Similar findings were reported by Tabasum *et al* (2010) for pod length; Partap *et al* (2019) for pods per plant and Rajasekhar *et al* (2017) for seeds per pod.

The correlation analysis only provides nature and degree of relationship of yield contributing characters on yield per plant. In case of inclusion of more variables for correlation studies, path analysis provides an effective method to determine the relative importance of each factor to produce a given correlation. Path coefficient analysis is an important tool for partitioning of correlation coefficients into direct and indirect effects of independent variable on direct variable. It splits the total correlation coefficient in such a manner that the sum of direct and indirect effects is equal to the genotypic correlation coefficient. In present study, yield per plant was considered as dependent variable, whereas other 12 characters were considered as independent variables. The path analysis revealed that harvest index (0.905) has showed a maximum direct effect on plant yield followed by biological yield per plant (0.4847), nodes per plant (0.29), plant height at 90% maturity (0.1489), branches per plant (0.1271), seeds per pod (0.1194), days to 90% pod maturity (0.1004) and hundred seed weight (0.0924) at Ludhiana (**Table 3(a)**) whereas branches per plant (2.589) has showed a maximum direct effect on yield per plant followed by pod length (1.2715), biological yield per plant (1.236), harvest index (1.0575) and nodes per plant (0.4086) at Gurdaspur (Table 3(b)). Hence, the selection based on these characters can be utilized for improving seed yield per plant. Govindaraj and Subramanian (2001), Umadevi and Meenakshi (2005) and Chauhan *et al* (2007) had also observed positive direct effect of biological yield per plant, seeds per pod and harvest index on seed yield. Though, hundred seed weight influenced seed yield negligibly at Ludhiana and negatively at Gurdaspur but influenced positively via higher indirect effects on clusters per plant,

pods per plant, pod length and seeds per pod. These results were in accordance with reports of Veeranjaneyulu *et al* (2007), Parveen *et al* (2011) and Sohel *et al* (2016) for hundred seed weight. Clusters per plant and pods per plant affected seed yield through high direct negative effect. Similar findings were earlier reported by Hadimani *et al* (2019) for both characters, Parveen *et al* (2011) for clusters per plant and Patidar and Sharma (2017) for pods per plant. Clusters and pods per plant also affected seed yield through positive indirect effects on pod length, hundred seed weight and harvest index at Gurdaspur and through positive indirect effects on seeds per pod and harvest index at Ludhiana. All characters except hundred seed weight at Ludhiana and hundred seed weight and harvest index at Gurdaspur affected seed yield positively through indirect effect on biological yield per plant. Hassan *et al* (2003) also reported similar results for biological yield per plant. All characters possessed positive or negligible negative indirect effect through branches per plant and nodes per plant. Seed yield, being a very complex character, needs to be improved through indirect selection based on component traits. All the above results indicated that the important consideration should be given to biological yield per plant, seeds per pod, harvest index, nodes per plant and branches per plant for improvement of urdbean.

Correlation, path analysis and principal component analysis was performed for 100 urdbean genotypes grown at two locations Ludhiana and Gurdaspur. The characters like clusters per plant, pods per plant, biological yield per plant and harvest index showed positive and significant correlation with yield per plant at both locations. Harvest index, biological yield per plant, nodes per plant, branches per plant showed higher and positive direct effect on seed yield at both locations. Biological yield per plant, plant height at 90% pod maturity, days to 50% flowering, harvest index, yield per plant and pods per plant depicted their importance through PCA at both locations. Direct selection based on these characters can be much rewarding for yield improvement in urdbean.

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