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Character Association among Yield, Drought Tolerant and Machine Harvestable Traits in Chickpea (*Cicer arietinum* L.)

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A B S T R A C T

Correlation and path analysis was worked out among thirty chickpea genotypes with three replications under both rainfed and irrigated conditions utilising yield, drought tolerant traits and mechanical harvestable traits during *rabi*, 2018 at Regional Agricultural Research Station, Nandyal, Andhra Pradesh, India. Biological yield per plot and harvest index exhibited significant positive correlation with seed yield and drought tolerance index. 100 seed weight and number of pods per plant also contributed positively to DTI and seed yield under rainfed conditions. Across environments, biological yield and harvest index exhibited consistency in correlations and their direct effects and also indirect effects *via* other correlated traits *viz.*, number of pods per plant, number of primary branches per plant, days to 50% flowering, days to maturity, height of first pod and plant height. Across environments, number of primary branches per plant, mechanical harvestable traits such as height of the first pod, plant height, phenological traits, days to 50 % flowering and days to maturity exhibited negative correlation with seed yield and DTI. Breeding procedures like biparental mating in an appropriate segregating population was suggested for breaking undesirable linkages which provides more chances for recombination to obtain superior lines with desirable combination of yield, drought tolerance and machine harvest ability.

Introduction

India is the largest producer of chickpea in the world with annual production of 9.07 million tons from an area of 9.54 m ha. with productivity of 951.4 kgha^{-1} (FAO STAT, 2019). In India chickpea area is mainly contributed by six states *viz.*, Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Andhra Pradesh and Karnataka. In Andhra Pradesh, the area under chickpea has increased from less than one lakh ha (1993-94) to more than 6.0 lakh ha by 2007-08 registering the highest productivity of 1449 kg ha^{-1}. Introduction and widespread adaptation of short duration, wilt resistant varieties such as 'JG 11', 'JAKI 9218' and 'KAK 2' and mechanization of farming operations has contributed to witness the highest productivity. However, farmers are unable to go for machine harvesting operation, as the existing varieties have semi spreading growth habit and attain a short plant height of 35-40 cm in warm growing environments of Southern India. To enable complete mechanization (machine harvesting

and threshing) of chickpea cultivation, development of chickpea cultivars with 30 to 40 per cent more height than the existing cultivars with semi-erect to erect growth habit and with branching starting from 25- 30 cm from ground level with yield potential equal to or more than existing popular cultivars is pressing need of current chickpea breeding programmes.

In Southern India, drought stress particularly at the end of the growing season is a major constraint to chickpea production and yield stability. This problem is more serious in Andhra Pradesh where chickpea is traditionally planted towards the end of the rainy season and generally grown on progressively declined residual soil moisture. With predicted climate change scenarios and continuous population explosion, there is a great need to develop high-yielding chickpea varieties with improved drought tolerance (Krishnamurthy *et al.,* 2013). Therefore, breeding efforts are needed to develop chickpea varieties suitable for machine harvest and with inbuilt resistance to drought conditions. Therefore, study of genetic variability utilising physiological traits to be utilised in breeding for drought along with seed yield and yield components and traits which make cultivar amenable to machine harvesting will be useful for planning suitable breeding strategies to develop chickpea genotypes with increased drought tolerance.

Materials and Methods

The investigation was carried out during *rabi* 2018-19 at Regional Agricultural Research Station, Nandyal, situated at $15^0$29' North latitude and $78^0$29' East longitude at an altitude of 211.76 m above mean sea level. The research station comes under Scarce Rainfall Agro-Climatic Zone of Andhra Pradesh. The experimental material comprised of 25 *desi* chickpea genotypes and five checks *viz*., NBeG 47, NBeG 49, JG 11, GBM 2 and HC 5 which were sown on 24th October *rabi*, 2018 in a Randomized Block Design (RBD) with three replications under rainfed and irrigated situations. Since very meagre rainfall was received during *rabi* season, a pre sowing irrigation was given to take up the sowing of experiments. In rainfed condition genotypes were grown on receding soil moisture where as in irrigated condition two supplemental irrigations were given at 35 and 55 days after sowing through sprinklers. Each genotype was sown in two rows in a plot of 3m row length at spacing of 30 cm between rows and 10 cm between plants within the row. Observations were recorded on 19 traits *viz*., angle of the primary branch (º), height of the first pod (cm), plant height (cm), days to 50 per cent flowering, days to maturity, duration of reproductive phase, number of primary branches per plant, number of secondary branches per plant, SPAD Chlorophyll Meter Reading (SCMR), number of pods per plant, biological yield (g), harvest index (%), seed yield (g), 100 seed weight (g), Specific leaf area (SLA) (cm^2g^{-1}), Relative water content (RWC) (%) at 30 DAS and 60 DAS, proline (µ mole g^{-1}) and protein content (%) along with drought tolerance index (DTI). Genotypic and phenotypic correlation coefficients were calculated using the method given by Johnson *et al.,* (1955). Path coefficient analysis was carried out as per Sewall Wright (1921) and Dewey and Lu (1959).

Results and Discussion

Correlation coefficients between seed yield and other characters and also *inter se* correlations among attributes under rainfed and irrigated condition were estimated and presented in tables 1 and 2. Genotypic correlations were of high magnitude than their corresponding phenotypic correlations for most of the traits that were correlated with

seed yield indicating a strong genetic association between these traits. However, correlation between seed yield and biological yield revealed that phenotypic correlations were slightly of higher magnitude corresponding to their genotypic correlations indicating that the association of two characters is not only due to genes but also due to favourable influence of environment.

While screening for drought tolerance, the performance of genotypes will be usually measured in terms of yield, either biomass or seed yield, but may also be measured as a yield stability in drought-prone environments (Turner, 1996). Screening for drought tolerance among cultivars must be conducted based on high performance in stressed and non-stressed conditions, so genotypes that have high yield in both stressed and non-stressed conditions are drought tolerant. Drought Tolerance Index (DTI) is the best criteria for screening drought tolerance (Fernandez, 1992).

The correlations of DTI with the other traits under study are presented in Table 3. Traits, number of secondary branches per plant, biological yield per plot, harvest index and seed yield per plot were significantly positively correlated with DTI under both rainfed and irrigated conditions. Earlier, Ganjeali *et al.,* (2011) reported positive correlation of DTI with yield under stress and non stress conditions. Under rainfed condition, number of pods per plant and 100 seed weight also exhibited significant positive correlation with DTI.

Under both rainfed and irrigated conditions height of the first pod, days to 50 % flowering, days to maturity, plant height and number of primary branches per plant were significantly negatively correlated with DTI. Ganjeali *et al.,* (2011) reported negative correlation of DTI with days to 50 % flowering under stress condition. Angle of primary branch and SCMR exhibited significant negative correlation with DTI under irrigated condition.

Under rainfed as well as irrigated conditions, yield attributes, number of pods per plant, biological yield per plot and harvest index exhibited highly significant positive correlation with seed yield. Many researchers reported the importance of number of pods per plant and biological yield in chickpea crop improvement programmes (Singh *et al.,* 2007, Malik *et al.,* 2010, Karasu *et al.,* 2010 and Babbar *et al.,* 2012). Positive correlation of seed yield with harvest index was reported by Kumar *et al.,* (2003), Gohil and Patel (2010), Panda *et al.,* (2015) and Sowjanya *et al.,* (2017). Days to 50 % flowering, days to maturity and number of primary branches per plant showed significant negative correlation with seed yield. SCMR was also negatively correlated with seed yield under irrigated condition.

These results were supported by findings of Arshad *et al.,* (2004), Yucel *et al.,* (2006), Babbar *et al.,* (2012), Mehra *et al.,* (2016), Astereki *et al.,* (2017) and Singh *et al.,* (2017) for days to flowering; Ali *et al.,* (2012), Mehra *et al.,* (2016) and Astereki *et al.,* (2017) for days to maturity. Arshad *et al.,* (2004) reported negative association of number of primary branches with seed yield. Specifically under rainfed condition, number of secondary branches per plant, 100 seed weight and protein and under irrigated conditions, RWC at 60 DAS exhibited positive and significant correlation with seed yield. Panda *et al.,* (2015) reported positive association of seed yield with RWC. Noor *et al.,* (2003), Arshad *et al.,* (2004), Gohil and Patel (2010), Babbar *et al.,* (2012) and Singh *et al.,* (2014) also reported positive correlation of seed yield with 100 seed weight.

Table.1 Phenotypic correlation coefficients among 19 characters in 30 chickpea genotypes under rainfed (below diagonal) and irrigated conditions (above diagonal) during *rabi* 2018-19

	APP	HFP	DFF	DM	DRP	PH	NPB	NSB	SCMR	SLA	NPP	BY/plot	HI	100 SW	RWC at (30DAS)	RWC at (60 DAS)	Proline	Protein	SY/plot
APP	1	0.462**	-0.031	-0.169	-0.191	0.580**	-0.096	-0.265*	0.216*	-0.163	-0.300**	-0.286**	-0.261*	0.165	0.084	-0.216*	0.18	0.101	-0.345**
HFP	0.115	1	0.453**	0.413**	-0.13	0.816**	0.353**	-0.284**	0.404**	-0.122	-0.128	-0.379**	-0.623**	-0.033	0.058	0.017	0.191	0.161	-0.619**
DFF	0.062	0.645**	1	0.788**	0.212*	0.314**	0.530**	-0.368**	0.324**	0.078	0.046	0.014	-0.387**	-0.280**	0.097	0.347**	-0.1	0.215*	-0.239*
DM	0.096	0.466**	0.808**	1	0.155	0.239*	0.521**	-0.239*	0.290**	0.101	0.037	-0.172	-0.321**	-0.211*	0.084	0.260*	-0.199	0.074	-0.303**
DRP	0.032	-0.052	0.249*	0.127	1	-0.124	0.09	-0.005	-0.118	-0.024	0.221*	-0.111	0.087	-0.076	-0.017	-0.158	-0.15	0.186	-0.043
PH	0.203	0.774**	0.508**	0.324**	-0.057	1	0.224*	-0.208*	0.433**	-0.156	-0.243*	-0.361**	-0.529**	0.18	0.099	-0.144	0.053	0.181	-0.540**
NPB	-0.149	0.358**	0.516**	0.561**	-0.033	0.243*	1	0.021	0.367**	-0.149	0.134	0.013	-0.548**	-0.157	-0.173	0.068	-0.059	0.069	-0.328**
NSB	-0.240*	-0.308**	-0.500**	-0.431**	-0.346**	-0.17	-0.026	1	-0.257*	0.034	0.001	0.016	0.091	0.138	-0.047	-0.164	-0.229*	-0.014	0.077
SCMR	0.002	0.081	0.127	0.217*	-0.113	0.005	0.255*	0.093	1	-0.174	-0.315**	-0.153	-0.525**	0.201	-0.255*	-0.063	0.214*	0.063	-0.416**
SLA	-0.001	0.001	0.037	0.058	0.191	-0.173	-0.18	0.044	0.083	1	-0.015	0.037	0.244*	-0.161	0.124	0.297**	0.06	-0.079	0.18
NPP	-0.145	-0.350**	-0.248*	-0.294**	0.071	-0.173	0.203	0.345**	-0.01	-0.245*	1	0.326**	0.285**	-0.412**	0.173	0.061	-0.09	-0.163	0.350**
BY/plot	-0.106	-0.311**	-0.042	0.022	0.116	-0.257*	0.181	0.064	0.359**	0.026	0.436**	1	0.288**	-0.104	0.081	0.287**	0.082	0.008	0.817**
HI	-0.091	-0.547**	-0.777**	-0.808**	-0.023	-0.437**	-0.470**	0.498**	-0.19	-0.064	0.345**	0.041	1	0.092	0.242*	0.12	-0.091	0.004	0.780**
100 SW	0.157	-0.106	-0.355**	-0.312**	-0.341**	0.108	-0.103	0.350**	0.228*	-0.314**	0.087	-0.066	0.383**	1	-0.002	-0.133	0.139	0.228*	0.013
RWC at (30DAS)	0.301**	-0.106	-0.046	-0.012	0.184	-0.08	0.011	-0.108	0.049	-0.086	0.296**	0.184	0.088	0.111	1	0.057	-0.147	-0.001	0.182
RWC at (60 DAS)	-0.005	-0.019	-0.135	-0.159	0.058	-0.05	-0.205	-0.159	-0.067	0.201	-0.112	-0.264*	-0.037	-0.024	0.071	1	0.067	0.101	0.248*
Proline	-0.055	0.076	-0.192	-0.299**	-0.11	0.001	-0.026	-0.071	0.028	0.066	-0.022	-0.013	0.146	0.194	0.079	0.291**	1	-0.09	-0.021
Protein	-0.054	0.018	-0.063	-0.105	-0.126	0.088	0.034	0.059	0.085	-0.19	0.13	0.241*	0.136	0.193	0.141	-0.025	0.068	1	0.003
SY/plot	-0.147	-0.605**	-0.622**	-0.596**	0.05	-0.486**	-0.240*	0.437**	0.078	-0.051	0.539**	0.624**	0.799**	0.263*	0.154	-0.201	0.077	0.231*	1

*, ** significant at P $\leq$ 0.05, P $\leq$ 0.01 respectively.

APP = Angle of primary branch, HFP = Height of the first pod, DFF = Days to 50% flowering, DM = Days to Maturity, DRP = Duration of reproductive phase, PH = Plant height, NPB = No. of primary branches, NSB = No. Of secondary branches, SCMR = SPAD Chlorophyll meter readings, SLA = Specific leaf area, NPP = No. of pods per plant, BY/plot = Biological Yield per plot, HI = Harvest index, 100 SW = 100 Seed Weight, RWC = Relative water content (30 DAS=30 Days after sowing, 60 DAS=60 Days after sowing), Proline = Proline content, Protein = Protein content, SY/plot = Seed yield per plot

Table.2 Genotypic correlation coefficients among 19 characters in 30 chickpea genotypes under rainfed (below diagonal) and irrigated (above diagonal) conditions during *rabi* 2018-19

	APP	HFP	DFF	DM	DRP	PH	NPB	NSB	SCMR	SLA	NPP	BY/plot	HI	100 SW	RWC at (30DAS)	RWC at (60 DAS)	Proline	Protein	SY/plot
APP	1	0.521	-0.026	-0.185	-0.268	0.664	-0.089	-0.437	0.267	-0.203	-0.492	-0.425	-0.285	0.196	0.136	-0.303	0.215	0.11	-0.424
HFP	0.125	1	0.494	0.452	-0.178	0.848	0.5	-0.392	0.45	-0.159	-0.24	-0.532	-0.705	-0.041	0.07	-0.029	0.236	0.182	-0.759
DFF	0.053	0.696	1	0.834	0.307	0.323	0.76	-0.472	0.357	0.058	0.153	-0.053	-0.407	-0.286	0.074	0.625	-0.098	0.241	-0.317
DM	0.123	0.488	0.853	1	0.18	0.244	0.699	-0.321	0.337	0.123	0.068	-0.224	-0.348	-0.221	0.115	0.529	-0.253	0.083	-0.349
DRP	-0.004	-0.103	0.309	0.186	1	-0.162	0.204	-0.061	-0.076	-0.054	0.262	0.001	0.078	-0.109	0.054	-0.233	-0.238	0.255	0.025
PH	0.227	0.82	0.534	0.342	-0.081	1	0.301	-0.298	0.502	-0.151	-0.35	-0.515	-0.594	0.187	0.148	-0.341	0.077	0.234	-0.658
NPB	-0.25	0.403	0.633	0.687	-0.061	0.304	1	-0.098	0.468	-0.176	0.011	-0.087	-0.744	-0.223	-0.248	0.057	-0.103	0.148	-0.536
NSB	-0.323	-0.34	-0.549	-0.469	-0.466	-0.182	-0.047	1	-0.314	0.098	-0.002	0.058	0.142	0.167	-0.149	-0.316	-0.367	-0.077	0.155
SCMR	-0.01	0.072	0.146	0.211	-0.142	-0.06	0.356	0.133	1	-0.233	-0.402	-0.224	-0.607	0.213	-0.379	-0.207	0.297	0.077	-0.527
SLA	0.009	-0.015	0.04	0.063	0.216	-0.221	-0.236	0.063	0.126	1	-0.019	0.058	0.266	-0.164	0.113	0.622	0.126	-0.114	0.215
NPP	-0.187	-0.367	-0.263	-0.305	0.099	-0.18	0.199	0.358	0.01	-0.277	1	0.596	0.37	-0.596	0.337	0.415	-0.184	-0.28	0.522
BY/plot	-0.182	-0.359	-0.029	0.024	0.198	-0.356	0.2	0.094	0.432	0.03	0.514	1	0.424	-0.1	0.207	0.43	0.161	0.08	0.799
HI	-0.129	-0.591	-0.823	-0.868	-0.069	-0.459	-0.623	0.529	-0.211	-0.089	0.371	0.086	1	0.092	0.328	0.282	-0.123	0.013	0.879
100 SW	0.196	-0.109	-0.364	-0.329	-0.421	0.105	-0.136	0.38	0.26	-0.364	0.093	-0.094	0.403	1	0.001	-0.228	0.132	0.25	0.037
RWC at (30DAS)	0.497	-0.18	-0.07	-0.03	0.246	-0.107	-0.047	-0.271	0.002	-0.034	0.388	0.389	0.094	0.147	1	0.203	-0.169	-0.017	0.311
RWC at (60 DAS)	-0.068	-0.086	-0.205	-0.28	0.063	0.012	-0.362	-0.272	-0.061	0.486	-0.233	-0.377	-0.038	-0.012	-0.085	1	0.286	0.204	0.404
Proline	-0.042	0.076	-0.22	-0.316	-0.13	0.001	-0.04	-0.109	0.032	0.071	-0.023	-0.025	0.167	0.205	0.155	0.581	1	-0.061	-0.017
Protein	-0.139	0.115	-0.142	-0.224	-0.364	0.185	0.131	0.074	0.14	-0.475	0.226	0.431	0.224	0.378	0.392	-0.037	0.171	1	0.042
SY/plot	-0.21	-0.656	-0.648	-0.645	0.04	-0.551	-0.359	0.485	0.087	-0.069	0.588	0.619	0.831	0.265	0.25	-0.277	0.081	0.387	1

APP = Angle of primary branch, HFP = Height of the first pod, DFF = Days to 50% flowering, DM = Days to Maturity, DRP = Duration of reproductive phase, PH = Plant height, NPB = No. of primary branches, NSB = No. Of secondary branches, SCMR = SPAD Chlorophyll meter readings, SLA = Specific leaf area, NPP = No. of pods per plant, BY/plot = Biological Yield per plot, HI = Harvest index, 100 SW = 100 Seed Weight, RWC = Relative water content (30 DAS=30 Days after sowing, 60 DAS=60 Days after sowing), Proline = Proline content, Protein = Protein content, SY/plot = Seed yield per plot

Table.3 Correlation of DTI with yield and yield attributing traits under rainfed and irrigated condition

	Rainfed		Irrigated	
	Phenotypic correlation	Genotypic correlation	Phenotypic correlation	Genotypic correlation
Angle of primary branch (º)	-0.188	-0.234	-0.234*	-0.252
Height of the first pod (cm)	-0.705**	-0.777	-0.732**	-0.814
Days to 50 % flowering	-0.630**	-0.668	-0.580**	-0.65
Days to maturity	-0.557**	-0.603	-0.598**	-0.644
Duration of reproductive Phase	0.058	0.026	-0.064	-0.05
Plant height (cm)	-0.653**	-0.741	-0.552**	-0.613
No. of primary branches per plant	-0.312**	-0.419	-0.292**	-0.456
No. of secondary branches per plant	0.386**	0.479	0.313**	0.438
SCMR	-0.007	-0.011	-0.341**	-0.39
SLA (cm^2 g^{-1})	0.061	0.044	0.024	0.026
No. of pods per plant	0.438**	0.5	0.118	0.18
Biological yield/plot (g)	0.480**	0.495	0.525**	0.54
Harvest Index (%)	0.737**	0.806	0.631**	0.668
100 Seed weight (g)	0.213*	0.223	0.191	0.218
RWC (%) at 30 DAS	0.1	0.211	-0.172	-0.162
RWC (%) at 60 DAS	-0.092	-0.216	-0.008	-0.142
Proline (µ mole g^{-1})	0.013	0.045	-0.003	0.019
Protein (%)	0.119	0.175	-0.054	-0.06
Seed yield / plot (g)	0.875**	0.917	0.729**	0.738

Table.4 Phenotypic path coefficients among 19 characters in 30 chickpea genotypes under rainfed and irrigated condition during *rabi* 2018-19

		APP	HFP	DFF	DM	DRP	PH	NPB	NSB	SCMR	SLA
APP	**RF**	**-0.0080**	-0.0009	-0.0005	-0.0008	-0.0003	-0.0016	0.0012	0.0019	0.0000	0.0000
	IR	**-0.0168**	-0.0078	0.0005	0.0028	0.0032	-0.0097	0.0016	0.0045	-0.0036	0.0027
HFP	**RF**	0.0023	**0.0199**	0.0129	0.0093	-0.0010	0.0154	0.0071	-0.0061	0.0016	0.0000
	IR	0.0069	**0.0150**	0.0068	0.0062	-0.0020	0.0123	0.0053	-0.0043	0.0061	-0.0018
DFF	**RF**	-0.0015	-0.0160	**-0.0248**	-0.0200	-0.0062	-0.0126	-0.0128	0.0124	-0.0031	-0.0009
	IR	0.0011	-0.0162	**-0.0357**	-0.0281	-0.0076	-0.0112	-0.0189	0.0131	-0.0116	-0.0028
DM	**RF**	0.0058	0.0283	0.0491	**0.0608**	0.0077	0.0197	0.0341	-0.0262	0.0132	0.0036
	IR	-0.0054	0.0131	0.0249	**0.0317**	0.0049	0.0076	0.0165	-0.0076	0.0092	0.0032
DRP	**RF**	0.0002	-0.0003	0.0013	0.0006	**0.0050**	-0.0003	-0.0002	-0.0017	-0.0006	0.0010
	IR	0.0029	0.0020	-0.0033	-0.0024	**-0.0154**	0.0019	-0.0014	0.0001	0.0018	0.0004
PH	**RF**	0.0005	0.0020	0.0013	0.0009	-0.0002	**0.0026**	0.0006	-0.0004	0.0000	-0.0005
	IR	0.0117	0.0164	0.0063	0.0048	-0.0025	**0.0201**	0.0045	-0.0042	0.0087	-0.0031
NPB	**RF**	0.0006	-0.0014	-0.0020	-0.0022	0.0001	-0.0009	**-0.0039**	0.0001	-0.0010	0.0007
	IR	0.0005	-0.0018	-0.0027	-0.0026	-0.0005	-0.0011	**-0.0051**	-0.0001	-0.0019	0.0008
NSB	**RF**	-0.0001	-0.0001	-0.0002	-0.0002	-0.0001	-0.0001	0.0000	**0.0004**	0.0000	0.0000
	IR	0.0028	0.0030	0.0038	0.0025	0.0001	0.0022	-0.0002	**-0.0104**	0.0027	-0.0004
SCMR	**RF**	0.0000	0.0012	0.0019	0.0032	-0.0017	0.0001	0.0038	0.0014	**0.0149**	0.0012
	IR	-0.0053	-0.0099	-0.0079	-0.0071	0.0029	-0.0106	-0.0090	0.0063	**-0.0245**	0.0043
SLA	**RF**	0.0000	0.0000	-0.0006	-0.0010	-0.0034	0.0031	0.0032	-0.0008	-0.0015	**-0.0176**
	IR	-0.0034	-0.0025	0.0016	0.0021	-0.0005	-0.0033	-0.0031	0.0007	-0.0036	**0.0209**
NPP	**RF**	-0.0038	-0.0091	-0.0064	-0.0076	0.0018	-0.0045	0.0053	0.0090	-0.0003	-0.0064
	IR	0.0084	0.0036	-0.0013	-0.0010	-0.0062	0.0068	-0.0037	0.0000	0.0088	0.0004
BY/plot	**RF**	-0.0624	-0.1837	-0.0250	0.0132	0.0684	-0.1515	0.1069	0.0380	0.2120	0.0152
	IR	-0.1934	-0.2561	0.0097	-0.1161	-0.0750	-0.2443	0.0086	0.0109	-0.1036	0.0249
HI	**RF**	-0.0745	-0.4457	-0.6328	-0.6584	-0.0185	-0.3560	-0.3828	0.4055	-0.1546	-0.0524
	IR	-0.1539	-0.3676	-0.2285	-0.1896	0.0514	-0.3119	-0.3235	0.0536	-0.3094	0.1442
100 SW	**RF**	0.0007	-0.0005	-0.0015	-0.0014	-0.0015	0.0005	-0.0004	0.0015	0.0010	-0.0014
	IR	0.0043	-0.0009	-0.0073	-0.0055	-0.0020	0.0047	-0.0041	0.0036	0.0052	-0.0042
RWC at 30 DAS	**RF**	-0.0088	0.0031	0.0013	0.0003	-0.0054	0.0023	-0.0003	0.0031	-0.0014	0.0025
	IR	-0.0022	-0.0015	-0.0025	-0.0022	0.0004	-0.0025	0.0044	0.0012	0.0065	-0.0032
RWC at 60 DAS	**RF**	0.0000	-0.0001	-0.0007	-0.0008	0.0003	-0.0003	-0.0011	-0.0008	-0.0003	0.0011
	IR	0.0034	-0.0003	-0.0054	-0.0041	0.0025	0.0022	-0.0011	0.0026	0.0010	-0.0046
proline	**RF**	0.0011	-0.0015	0.0037	0.0058	0.0021	0.0000	0.0005	0.0014	-0.0006	-0.0013
	IR	-0.0057	-0.0060	0.0032	0.0063	0.0048	-0.0017	0.0019	0.0072	-0.0068	-0.0019
protein	**RF**	0.0012	-0.0004	0.0014	0.0023	0.0027	-0.0019	-0.0007	-0.0013	-0.0018	0.0041
	IR	-0.0009	-0.0014	-0.0019	-0.0007	-0.0016	-0.0016	-0.0006	0.0001	-0.0006	0.0007
SY/plot	**RF**	**-0.1468**	**-0.6050****	**-0.6217****	**-0.5960****	**0.0503**	**-0.4860****	**-0.2395***	**0.4373****	**0.0775**	**-0.0510**
	IR	**-0.3449****	**-0.6189****	**-0.2395***	**-0.3030****	**-0.0431**	**-0.5402****	**-0.3279****	**0.0773**	**-0.4155****	**0.1804**

Table.4 (cont.)

		NPP	BY	HI	100 SW	RWC (30)	RWC(60)	Proline	Protein
APP	**RF**	0.0012	0.0009	0.0007	-0.0013	-0.0024	0	0.0004	0.0004
	IR	0.005	0.0048	0.0044	-0.0028	-0.0014	0.0036	-0.003	-0.0017
HFP	**RF**	-0.0070	-0.0062	-0.0109	-0.0021	-0.0021	-0.0004	0.0015	0.0004
	IR	-0.0019	-0.0057	-0.0094	-0.0005	0.0009	0.0003	0.0029	0.0024
DFF	**RF**	0.0062	0.0011	0.0193	0.0088	0.0011	0.0033	0.0047	0.0016
	IR	-0.0017	-0.0005	0.0138	0.0100	-0.0035	-0.0124	0.0036	-0.0077
DM	**RF**	-0.0179	0.0014	-0.0491	-0.0190	0.0007	-0.0097	-0.0182	-0.0064
	IR	0.0012	-0.0054	-0.0102	-0.0067	0.0027	0.0082	-0.0063	0.0023
DRP	**RF**	0.0004	0.0006	-0.0001	-0.0017	0.0009	0.0003	-0.0006	-0.0006
	IR	-0.0034	0.0017	-0.0013	0.0012	0.0003	0.0024	0.0023	-0.0029
PH	**RF**	-0.0005	-0.0007	-0.0012	0.0003	-0.0002	-0.0001	0.0000	0.0002
	IR	-0.0049	-0.0073	-0.0106	0.0036	0.0020	-0.0029	0.0011	0.0036
NPB	**RF**	-0.0008	-0.0007	0.0018	0.0004	0.0000	0.0008	0.0001	-0.0001
	IR	-0.0007	-0.0001	0.0028	0.0008	0.0009	-0.0003	0.0003	-0.0003
NSB	**RF**	0.0001	0.0000	0.0002	0.0001	0.0000	-0.0001	0.0000	0.0000
	IR	0.0000	-0.0002	-0.0009	-0.0014	0.0005	0.0017	0.0024	0.0001
SCMR	**RF**	-0.0001	0.0053	-0.0028	0.0034	0.0007	-0.0010	0.0004	0.0013
	IR	0.0077	0.0037	0.0128	-0.0049	0.0062	0.0016	-0.0052	-0.0015
SLA	**RF**	0.0043	-0.0005	0.0011	0.0055	0.0015	-0.0035	-0.0012	0.0034
	IR	-0.0003	0.0008	0.0051	-0.0034	0.0026	0.0062	0.0013	-0.0017
NPP	**RF**	**0.0260**	0.0113	0.0090	0.0022	0.0077	-0.0029	-0.0006	0.0034
	IR	**-0.0279**	-0.0091	-0.0080	0.0115	-0.0048	-0.0017	0.0025	0.0045
BY/plot	**RF**	0.2576	**0.5902**	0.0240	-0.0387	0.1087	-0.1556	-0.0075	0.1425
	IR	0.2206	**0.6765**	0.1949	-0.0704	0.0548	0.1944	0.0555	0.0051
HI	**RF**	0.2811	0.0331	**0.8144**	0.3117	0.0720	-0.0298	0.1188	0.1112
	IR	0.1680	0.1699	**0.5899**	0.0544	0.1425	0.0707	-0.0537	0.0026
100 SW	**RF**	0.0004	-0.0003	0.0017	**0.0043**	0.0005	-0.0001	0.0008	0.0008
	IR	-0.0107	-0.0027	0.0024	**0.0260**	0.0000	-0.0035	0.0036	0.0059
RWC at 30 DAS	**RF**	-0.0086	-0.0054	-0.0026	-0.0032	**-0.0292**	-0.0021	-0.0023	-0.0041
	IR	-0.0044	-0.0021	-0.0062	0.0000	**-0.0257**	-0.0015	0.0038	0.0000
RWC at 60 DAS	**RF**	-0.0006	-0.0014	-0.0002	-0.0001	0.0004	**0.0052**	0.0015	-0.0001
	IR	-0.0009	-0.0045	-0.0019	0.0021	-0.0009	**-0.0156**	-0.0010	-0.0016
Proline	**RF**	0.0004	0.0002	-0.0028	-0.0038	-0.0015	-0.0056	**-0.0194**	-0.0013
	IR	0.0029	-0.0026	0.0029	-0.0044	0.0047	-0.0021	**-0.0316**	0.0029
Protein	**RF**	-0.0028	-0.0053	-0.0030	-0.0042	-0.0031	0.0006	-0.0015	**-0.0218**
	IR	0.0014	-0.0001	0.0000	-0.0020	0.0000	-0.0009	0.0008	**-0.0088**
SY/plot	**RF**	**0.5393****	**0.6237****	**0.7995****	**0.2627***	**0.1541**	**-0.2006**	**0.0773**	**0.2306***
	IR	**0.3498****	**0.8173****	**0.7805****	**0.0132**	**0.1817**	**0.2482***	**-0.0209**	**0.0034**

Residual effect (RF: 0.086, IR: 0.062)

APP = angle of primary branch
HFP = Height of the first pod
DFF = Days to 50 % flowering
DM= Days to maturity
DRP = Duration of reproductive phase
PH= Plant height
NPB = Number of primary branches per plant
NSB = Number of secondary branches per plant
SCMR = SPAD Chlorophyll meter readings
SLA = Specific leaf area
NPP = Number of pods per plant
BY/ plot = Biological yield per plot
HI = Harvest index
100 SW = 100 seed weight
RWC at 30 DAS = Relative water content at 30 Days After sowing
RWC at 60 DAS = Relative water content at 60 Days After sowing
Proline = proline content
Protein = protein content
seed yield = seed yield per plot

Table.5 Genotypic Path coefficients among 19 characters in 30 chickpea genotypes under rainfed and irrigated condition during *rabi* 2018-19

		APP	HFP	DFF	DM	DRP	PH	NPB	NSB	SCMR	SLA	NPP	BY	HI	100 SW	RWC (30)	RWC(60)	Proline	Protein
APP	**RF**	**-0.0121**	-0.0015	-0.0006	-0.0015	0.0001	-0.0027	0.003	0.0039	0.0001	-0.0001	0.0023	0.0022	0.0016	-0.0024	-0.0060	0.0008	0.0005	0.0017
	IR	**-0.0201**	-0.0105	0.0005	0.0037	0.0054	-0.0133	0.0018	0.0088	-0.0054	0.0041	0.0099	0.0085	0.0057	-0.0039	-0.0027	0.0061	-0.0043	-0.0022
HFP	**RF**	-0.003	**-0.024**	-0.0167	-0.0117	0.0025	-0.0197	-0.0097	0.0081	-0.0017	0.0004	0.0088	0.0086	0.0141	0.0026	0.0043	0.0021	-0.0018	-0.0028
	IR	-0.1935	**-0.3712**	-0.1832	-0.168	0.066	-0.3148	-0.1857	0.1455	-0.1671	0.0591	0.0891	0.1977	0.2617	0.0152	-0.0260	0.0108	-0.0877	-0.0674
DFF	**RF**	0.0026	0.0339	**0.0487**	0.0415	0.0150	0.0260	0.0308	-0.0267	0.0071	0.0019	-0.0128	-0.0014	-0.0401	-0.0177	-0.0034	-0.0100	-0.0107	-0.0069
	IR	0.0014	-0.0276	**-0.0558**	-0.0466	-0.0172	-0.0181	-0.0424	0.0263	-0.0200	-0.0032	-0.0085	0.0030	0.0227	0.0160	-0.0041	-0.0349	0.0055	-0.0135
DM	**RF**	0.0250	0.0990	0.1730	**0.2028**	0.0377	0.0694	0.1392	-0.0951	0.0428	0.0127	-0.0618	0.0048	-0.1760	-0.0667	-0.0061	-0.0568	-0.0640	-0.0453
	IR	-0.0265	0.0646	0.1191	**0.1428**	0.0257	0.0349	0.0999	-0.0458	0.0481	0.0176	0.0097	-0.0320	-0.0497	-0.0316	0.0165	0.0755	-0.0361	0.0118
DRP	**RF**	0.0003	0.0063	-0.0190	-0.0114	**-0.0615**	0.0050	0.0037	0.0286	0.0087	-0.0133	-0.0061	-0.0122	0.0042	0.0259	-0.0152	-0.0039	0.0080	0.0224
	IR	0.0185	0.0123	-0.0212	-0.0124	**-0.0690**	0.0112	-0.0141	0.0042	0.0052	0.0038	-0.0181	0.0000	-0.0054	0.0075	-0.0037	0.0161	0.0164	-0.0176
PH	**RF**	0.0062	0.0224	0.0146	0.0094	-0.0022	**0.0273**	0.0083	-0.0050	-0.0016	-0.0060	-0.0049	-0.0097	-0.0125	0.0029	-0.0029	0.0003	0.0000	0.0050
	IR	0.1760	0.2247	0.0857	0.0648	-0.0430	**0.2650**	0.0797	-0.0788	0.1331	-0.0401	-0.0928	-0.1365	-0.1573	0.0495	0.0393	-0.0904	0.0205	0.0621
NPB	**RF**	0.0331	-0.0533	-0.0836	-0.0908	0.0081	-0.0402	**-0.1322**	0.0062	-0.0471	0.0312	-0.0264	-0.0265	0.0824	0.0180	0.0062	0.0478	0.0053	-0.0173
	IR	-0.0076	0.0430	0.0654	0.0601	0.0175	0.0259	**0.0860**	-0.0085	0.0403	-0.0151	0.0010	-0.0075	-0.0640	-0.0191	-0.0214	0.0049	-0.0089	0.0127
NSB	**RF**	-0.0030	-0.0032	-0.0052	-0.0044	-0.0044	-0.0017	-0.0004	**0.0094**	0.0013	0.0006	0.0034	0.0009	0.0050	0.0036	-0.0026	-0.0026	-0.0010	0.0007
	IR	-0.0031	-0.0028	-0.0033	-0.0023	-0.0004	-0.0021	-0.0007	**0.0070**	-0.0022	0.0007	0.0000	0.0004	0.0010	0.0012	-0.0010	-0.0022	-0.0026	-0.0005
SCMR	**RF**	-0.0006	0.0048	0.0098	0.0142	-0.0095	-0.0040	0.0239	0.0089	**0.0671**	0.0085	0.0007	0.0290	-0.0142	0.0174	0.0001	-0.0041	0.0022	0.0094
	IR	-0.0348	-0.0585	-0.0464	-0.0438	0.0098	-0.0653	-0.0609	0.0408	**-0.1300**	0.0303	0.0522	0.0291	0.0790	-0.0277	0.0492	0.0269	-0.0386	-0.0100
SLA	**RF**	-0.0004	0.0006	-0.0016	-0.0026	-0.0088	0.0090	0.0096	-0.0026	-0.0051	**-0.0407**	0.0113	-0.0012	0.0036	0.0148	0.0014	-0.0198	-0.0029	0.0193
	IR	0.0101	0.0080	-0.0029	-0.0061	0.0027	0.0076	0.0088	-0.0049	0.0117	**-0.0500**	0.0009	-0.0029	-0.0133	0.0082	-0.0057	-0.0311	-0.0063	0.0057
NPP	**RF**	-0.0184	-0.0361	-0.0258	-0.0300	0.0097	-0.0177	0.0196	0.0353	0.0010	-0.0273	**0.0984**	0.0506	0.0365	0.0091	0.0381	-0.0229	-0.0022	0.0222
	IR	-0.0079	-0.0038	0.0024	0.0011	0.0042	-0.0056	0.0002	0.0000	-0.0064	-0.0003	**0.0160**	0.0096	0.0059	-0.0096	0.0054	0.0067	-0.0030	-0.0045
BY	**RF**	-0.0932	-0.1835	-0.0150	0.0122	0.1014	-0.1822	0.1023	0.0479	0.2207	0.0154	0.2628	**0.5113**	0.0440	-0.0480	0.1990	-0.1928	-0.0126	0.2203
	IR	-0.1864	-0.2335	-0.0234	-0.0982	0.0003	-0.2260	-0.0382	0.0255	-0.0981	0.0253	0.2615	**0.4386**	0.1861	-0.0439	0.0906	0.1888	0.0708	0.0350
HI	**RF**	-0.1165	-0.5352	-0.7456	-0.7864	-0.0625	-0.4158	-0.5648	0.4795	-0.1912	-0.0808	0.3360	0.0780	**0.9060**	0.3649	0.0849	-0.0346	0.1513	0.2029
	IR	-0.1781	-0.4402	-0.2538	-0.2174	0.0486	-0.3707	-0.4646	0.0888	-0.3793	0.1658	0.2308	0.2649	**0.6243**	0.0575	0.2045	0.1762	-0.0767	0.0078
100 SW	**RF**	-0.0108	0.0060	0.0201	0.0182	0.0232	-0.0058	0.0075	-0.0210	-0.0144	0.0201	-0.0051	0.0052	-0.0222	**-0.0552**	-0.0081	0.0007	-0.0113	-0.0209
	IR	-0.0013	0.0003	0.0018	0.0014	0.0007	-0.0012	0.0014	-0.0011	-0.0014	0.0011	0.0038	0.0006	-0.0006	**-0.0064**	0.0000	0.0015	-0.0008	-0.0016
RWC at 30 DAS	**RF**	-0.0196	0.0071	0.0028	0.0012	-0.0097	0.0042	0.0018	0.0107	-0.0001	0.0013	-0.0152	-0.0153	-0.0037	-0.0058	**-0.0393**	0.0034	-0.0061	-0.0154
	IR	-0.0011	-0.0006	-0.0006	-0.0010	-0.0004	-0.0012	0.0020	0.0012	0.0031	-0.0009	-0.0028	-0.0017	-0.0027	0.0000	**-0.0082**	-0.0017	0.0014	0.0001
RWC at 60 DAS	**RF**	0.0002	0.0003	0.0006	0.0009	-0.0002	0.0000	0.0011	0.0009	0.0002	-0.0015	0.0007	0.0012	0.0001	0.0000	0.0003	**-0.0031**	-0.0018	0.0001
	IR	-0.0020	-0.0002	0.0042	0.0035	-0.0016	-0.0023	0.0004	-0.0021	-0.0014	0.0041	0.0028	0.0029	0.0019	-0.0015	0.0013	**0.0066**	0.0019	0.0014
proline	**RF**	-0.0013	0.0023	-0.0067	-0.0097	-0.0040	0.0000	-0.0012	-0.0033	0.0010	0.0022	-0.0007	-0.0008	0.0051	0.0063	0.0048	0.0178	**0.0306**	0.0052
	IR	0.0287	0.0316	-0.0130	-0.0338	-0.0318	0.0103	-0.0138	-0.0491	0.0397	0.0169	-0.0246	0.0216	-0.0164	0.0176	-0.0225	0.0382	**0.1336**	-0.0081
protein	**RF**	0.0019	-0.0015	0.0019	0.0030	0.0049	-0.0025	-0.0017	-0.0010	-0.0019	0.0063	-0.0030	-0.0057	-0.0030	-0.0050	-0.0052	0.0005	-0.0023	**-0.0133**
	IR	0.0034	0.0056	0.0075	0.0026	0.0079	0.0073	0.0046	-0.0024	0.0024	-0.0035	-0.0087	0.0025	0.0004	0.0077	-0.0005	0.0063	-0.0019	**0.0310**
SY/plot	**RF**	**-0.2097**	**-0.6556**	**-0.6484**	**-0.6452**	**0.0397**	**-0.5514**	**-0.3592**	**0.4847**	**0.0869**	**-0.0692**	**0.5883**	**0.6189**	**0.8311**	**0.2646**	**0.2503**	**-0.2773**	**0.0812**	**0.3873**
	IR	**-0.4241**	**-0.7588**	**-0.3174**	**-0.3494**	**0.0253**	**-0.6584**	**-0.5355**	**0.1555**	**-0.5275**	**0.2155**	**0.5221**	**0.7987**	**0.8794**	**0.0367**	**0.3109**	**0.4042**	**-0.0168**	**0.0421**

APP=Angle of primary branch, HFP=Height of the first pod, DFF=Days to 50% flowering, DM=Days to Maturity, DRP= Duration of reproductive phase, PH=Plant height, NPB=No. of primary branches, NSB=No. Of secondary branches, SCMR=SPAD Chlorophyll meter readings, SLA=Specific leaf area, NPP=No. of pods per plant, BY/plot=Biological Yield per plot, HI=Harvest index, 100 SW=100 Seed Weight, RWC=Relative water content (30 DAS=30 Days after sowing, 60 DAS=60 Days after sowing), Proline= Proline content, Protein=Protein content

The cause and effect relationship of traits correlated with seed yield under both rainfed and irrigated conditions was studied through path analysis (Tables 4 and 5). Under both rainfed and irrigated conditions, significant positive correlation with seed yield was observed with three traits *viz*., number of pods per plant, biological yield per plot and harvest index. Biological yield per plot had high direct effect on seed yield under both rainfed and irrigated conditions similar to the findings of Naveed *et al.,* (2012), Kuldeep *et al.,* (2014) and Tadesse *et al.,* (2016). High positive direct effects of harvest index was responsible for significant positive correlations with seed yield under both rainfed and irrigated condition according to Khorgade *et al.,* (1995), Raval and Dobariya (2004) and Gohil and Patel (2010). The direct effect of number of pods per plant on seed yield was negligible but indirect effects *via* biological yield and harvest index were moderate to high similar to the findings of Paneliya *et al.*, (2017).

Days to 50 % flowering, days to maturity and number of primary branches per plant showed significant negative correlation with seed yield under both rainfed and irrigated conditions. Days to 50 % flowering exhibited negligible direct effects but harvest index with moderate to high negative indirect effects indirectly resulted in negative correlation. Negative direct effect of days to 50 % flowering was similar to earlier findings of Renukadevi and Subbalakshmi (2006). On the other hand, days to maturity with positive negligible to moderate direct effects exhibited significant negative correlation with seed yield *via* harvest index with high indirect effects under rainfed and low to moderate indirect effects under irrigated conditions. Positive direct effects of days to maturity *via* moderate effects through harvest index were reported earlier by Renukadevi and Subbalakshmi (2006) and Parhe *et al.,* (2014).

Number of primary branches per plant exhibited significant negative correlation with seed yield under both rainfed and irrigated conditions where direct effects were low to negligible. Harvest index with high and negative indirect effects was responsible for negative association. This result was supported by findings of Arshad *et al.,* (2004).

Under rainfed condition, though number of secondary branches per plant, 100 seed weight and Protein content had significant positive correlation with seed yield but its direct effects were negligible but harvest index with high and positive effects contributed indirectly.

SCMR and RWC at 60 DAS which exhibited significant negative correlation and positive correlation with seed yield under irrigated condition respectively also had indirect contribution *via* harvest index and biological yield respectively.

Among the traits related to mechanical harvesting, height of the first pod and plant height exhibited negligible direct effects but contributed indirectly *via* biological yield with low to moderate value and through harvest index with high indirect effects thereby exhibiting significant negative correlation with seed yield under both rainfed and irrigated conditions. Under irrigated condition, angle of primary branch had negative correlation with seed yield due to indirect effects of biological yield and harvest index.

Residual effects obtained from path analysis were negligible under rainfed condition (P_p = 0.086) and irrigated condition (P_p = 0.062) indicating that most of the characters studied were accounted for cause and effect relationships on seed yield.

In conclusion the results of present study indicated that seed yield was positively correlated with DTI under both rainfed and irrigated conditions. Biological yield per plot and harvest index were positively correlated with seed yield as well as DTI under both the conditions. In addition to these traits, 100 seed weight and number of pods per plant under rainfed condition were positively correlated with DTI and seed yield. However, most of these correlations were established through direct and indirect effects of two attributes *viz*., biological yield and harvest index. Several researchers revealed that an increased shoot biomass production at maturity is the means for drought tolerance (Serraj and Sinclair, 2002 and Krishnamurthy *et al.*, 2013). Consistency in correlations of biological yield and harvest index across environments and their direct effects and indirect effects established through other correlated traits *viz*., number of pods per plant, number of primary branches per plant, days to 50 % flowering, days to maturity, height of first pod and plant height suggest that increased shoot biomass and greater harvest index will contribute to drought tolerance. Across environments, number of primary branches per plant, mechanical harvestable traits as such height of the first pod and plant height exhibited negative correlation with seed yield and DTI. Phenological traits, days to 50 % flowering and days to maturity were also negatively correlated with seed yield and DTI. Chickpea, being a self pollinated crop, presence of linkage blocks and inverse relations of the correlated characters are more common. Further negative association among yield components coupled with high G x E interactions prevent full exploitation of genetic variability for characters like yield. Under such circumstances, biparental mating in an appropriate segregating population is effective in breaking larger linkages blocks and provides more chances of recombination than the selfing series (Gill, 1987). Though implementation of population improvement programme in chickpea is difficult due difficulty in crossing, a small number of studies reported increased variability in biparental populations (Kampali *et al.*, 2002 and Nijagun, 2006).

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