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RESEARCH PAPER

Trait dynamics through association and path analysis across temperature regimes in chickpea (*Cicer arietinum* L.)

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Abstract: Chickpea (*Cicer arietinum* L.) is an important food legume, grown across more than fifty countries in the world. There has been constant improvement on the yield levels of the crop, however, its yield potential is constrained by several stresses including heat, particularly during flowering and pod development. This study aimed to assess the trait dynamics through character associations along with direct and indirect effects of independent traits on yield under timely sown and late sown conditions. Forty genotypes were evaluated under two sowing regimes *viz*., timely sown (October) and late sown (January). Under timely sown condition, seed yield per plant had significantly positive correlation with number of pods per plant (0.734), plant biomass (0.684), total chlorophyll content (0.737), pollen viability (0.402) and canopy temperature depression (0.578). Path coefficient analysis indicated that plant biomass (0.2840) and number of pods per plant had the higher direct contributions to seed yield per plant. On the other hand, negative correlations were noted with days to maturity (-0.238) and plant height (-0.422). In the late sown condition, seed yield per plant showed significant positive correlation with pollen viability (0.686), number of pods per plant (0.757), canopy temperature depression (0.682), plant biomass (0.936) and total chlorophyll content (0.611) while Path analysis revealed substantial direct effect (0.3409) of plant biomass on yield, whereas days to fifty per cent flowering (-0.407), days to maturity (-0.625) and plant height (-0.361) had negative associations. These results highlight the critical role of key traits across different temperature regimes, with plant biomass and number of pods per plant contributing significantly under normal conditions, while pollen viability, canopy temperature depression and biomass were pivotal under heat stress in buffering productivity. The knowledge on such aspects might be very useful in breeding programmes aimed at climate resilience towards making informed and précised decisions.

Key words: Association, Chickpea, Climate resilience, Heat stress

Introduction

Chickpea (*Cicer arietinum* L.) is a self-pollinating diploid (2n=2x=16) food legume with a relatively small genome size of 740 Mbp (Varshney *et al*., 2013) and the most important pulse crop globally. It is not only a vital source of dietary protein for humans but also contributes significantly to sustainable agriculture by improving soil fertility through atmospheric nitrogen fixation. Despite its importance, chickpea cultivation faces significant challenges due to its sensitivity to high temperatures, particularly during the reproductive phase and pod development. The exposure of chickpea to temperatures exceeding 30-35°C during these critical stages can lead to severe yield losses (Kaushal and Wani *et al*., 2016). The success of developing high yielding cultivars depends on effective selection of criterion traits and understanding the relationships between yield and its attributing traits. Analysing the strength and nature of the associations between such traits helps to assign proper importance to the traits during selection and also to formulate selection indices. It is also important to understand the genetic diversity in the crop species which can help to select the potential parents for breeding programme to attain the anticipated improvement in grain yield (Soumyashree *et al.,* 2021, Aishwarya *et al*., 2021).

Climate change is posing several challenges to agriculture as a whole and specifically to the crops which are majorly grown as rainfed, due to seasonal changes, erratic, unevenly distribution of rains and temperature dynamics (Ashwini *et al.,* 2021). These challenges are becoming increasingly relevant and alarming in the context of rising temperatures which are expected to further worsen and impact chickpea production. Breeders and plant scientists are under pressure to improve existing crops and develop high yielding, more nutritious, pest and disease resistant and climate resilient crop varieties at rapid pace (Nandigavi, 2022). While developing the trait specific cultivars, especially biotic or abiotic stress tolerance, it is crucial to evaluate the genotypes under specific target conditions. It helps to isolate the genotypes which perform well under such stress conditions. Further, it also aids to understand the important contributing traits for the stress tolerance which in turn helps to formulate selection indices considering such traits. In doing so, correlation among the traits gives insights on association between the traits while, path coefficient analysis, introduced by Wright in 1921, helps to dissect the relationship between the traits with insights on direct and indirect effects of independent traits on dependent trait *ie* yield. These are important parameters being applied by plant breeders to understand the relation between traits and also to break down total correlations into direct and indirect effects of various independent traits on yield. This method clarifies the causal relationships between traits, supporting the prediction of responses to selection and aiding in the identification of superior genotypes for yield improvement.

Material and methods

The present study was conducted at Regional Agricultural Research Station (RARS), Vijayapur campus in Northern Dry Zone of Karnataka (Zone-3) during *rabi* 2023-24. The experiment consisted of forty chickpea genotypes involving advanced breeding lines and appropriate check varieties.

The genotypes were assessed under two temperature regimes through different dates of sowing *viz*., timely sown (October) and late sown (January) during *rabi* 2023-24. The mean and range of temperatures during the reproductive phase differed significantly between the two sowing conditions. During the reproductive phase, the temperature in the timely sown condition ranged from 13.4°C to 31.0°C, with a mean of 23.2°C, whereas in the late sown condition, it ranged from 20.6°C to 38.0°C, with a mean of 30.1°C. This highlights the substantial difference in temperature stress experienced during critical reproductive stages under late sown conditions. The experiment was laid out in randomized complete block design (RCBD) with two replications across both the temperature regimes. The crop was sown with spacing of 30cm x 10cm and recommended package of practices were followed to raise the good crop.

Correlation studies help to identify trait associations that inform selection criteria for targeted trait improvement. Understanding the magnitude and direction of these associations aids in achieving breeding goals more effectively. In this study, correlation analysis was conducted to examine the relationships between morpho-phenological, physiological and yield related traits. To gain deeper insights into trait dynamics and understand the influence of independent traits on productivity, path coefficient analysis was carried out. This method was employed to understand both the direct and indirect effects of different traits on the overall yield, offering insights on how these traits interact and contribute to crop performance. Path coefficients were calculated for thirteen independent traits, with seed yield per plant as the dependent variable, to formulate crop improvement strategies.

Results and discussion

Correlation analysis

In the present investigation, genotypic correlation coefficients among fourteen morpho-phenological, physiological and yield related traits (Table 1) were estimated to understand the association between the component traits across temperature regimes *viz*., timely (normal) and late sown (heat stress) conditions.

Under timely sown condition, seed yield per plant exhibited a positive correlation with days to fifty per cent flowering (0.120) and the number of primary branches (0.056). A significant positive correlation of seed yield with pollen viability (0.402), number of pods per plant (0.734), yield per plot (0.970), plant biomass (0.684), canopy temperature depression (0.578), per cent membrane leakage (0.796) and total chlorophyll content (0.737) was also evident. In contrast, negative correlations were found between plant yield and days to maturity (-0.238), number of seeds per pod (-0.038), hundred seed weight (-0.078), while yield showed significant negative correlation with plant height (-0.422). There was a significant positive correlation (0.633) between days to fifty per cent flowering and days to maturity and between pollen viability and number of pods per plant (0.714). Plant height showed a significant positive correlation with days to maturity (0.447) and the number of primary branches (0.320) while number of pods per plant was significantly positively correlated (0.458) with plant biomass. Conversely, hundred seed weight had a significant negative correlation with the number of seeds per pod (-0.424).

Under late sown (heat stress) condition, seed yield per plant recorded significant positive correlations with pollen viability (0.686), number of pods per plant (0.757), yield per plot (0.966),

Table 1. Correlation coefficients between morpho-phenological traits, physiological and yield attributes under timely (normal) and late sown (heat stress) conditions

	DFF	PV	DM	NPB	PH	NSPP	NPPP	HSW	SYPP	YPP	PB	CTD	PML	TCC
DFF	1.00	0.246	0.633**	0.278	0.510**	0.066	-0.023	0.135	0.120	0.070	0.382*	-0.002	-0.141	0.327*
PV	-0.592**	1.00	-0.017	-0.056	0.080	0.493**	0.714**	0.067	0.402*	0.476**	0.252	0.302	0.079	0.366*
DM	0.763**	-0.578**	1.00	0.186	0.447**	0.017	-0.249	0.169	-0.238	-0.317	-0.034	-0.334*	-0.229	-0.043
NPB	0.195	-0.244	0.457**	1.00	0.320*	0.560**	0.207	-0.583**	0.056	0.051	0.163	0.364*	-0.214	0.211
PH	0.534**	-0.337*	0.828**	0.533**	1.00	0.220	-0.316*	0.083	-0.422**	-0.426**	0.229	-0.247	-0.626**	-0.140
NSPP	-0.211	0.031	-0.275	0.048	-0.138	1.00	0.023	-0.424**	-0.038	0.029	-0.085	0.482**	-0.403**	0.079
NPPP	-0.585**	0.615**	-0.636**	-0.262	-0.477*	*0.059	1.00	-0.250	0.734**	0.876**	0.458**	0.723**	0.525**	0.667**
HSW	0.267	0.259	-0.046	-0.117	0.155	-0.041	0.122	1.00	-0.078	-0.109	0.150	-0.370*	0.070	-0.308
SYPP	-0.407**	0.686**	-0.625**	-0.206	-0.361*	0.152	0.757**	0.260	1.00	0.970**	0.684**	0.578**	0.796**	0.737**
YPP	-0.347*	0.702**	-0.718**	-0.218	-0.444**	0.154	0.633**	0.243	0.966**	1.00	0.588**	0.776**	0.905**	0.833**
PB	-0.166	0.692**	-0.412**	-0.207	-0.196	0.082	0.598**	0.455**	0.936**	0.820**	1.00	0.568**	0.447**	0.570**
CTD	-0.721**	0.765**	-0.544**	-0.136	-0.060	-0.004	0.412**	0.165	0.682**	0.710**	0.504**	1.00	0.612**	0.651**
PML	0.516**	-0.718**	0.175	-0.145	-0.285	-0.094	-0.041	-0.021	-0.126	-0.162	-0.083	-0.736**	1.00	0.780**
TCC	0.082	0.364*	-0.310	-0.149	-0.268	0.054	0.445**	0.200	0.611**	0.585**	0.658**	0.240	0.137	1.00

NOTE: * and ** defines significance at 5 per cent and 1 per cent probability, respectively.

DFF-Days to 50% flowering, PV- Pollen viability, DM- Days to maturity, NPB-No. of primary branches, PH-Plant height, NSPP- No. of seeds per pod, NPPP- No. of pods per plant, HSW- Hundred seed weight, SYPP- Seed yield per plant, YPP- Yield per plot, PB- Plant biomass, CTD- Canopy temperature depression, PML- Per cent membrane leakage, TCC- Total chlorophyll content.

Values above diagonal: Timely sown condition; Values below diagonal- Late sown condition biomass (0.936), canopy temperature depression (0.682) and total chlorophyll content (0.611), whereas significant negative correlations were noticed for days to fifty per cent flowering (-0.407), days to maturity (-0.625) and plant height (-0.361). Pollen viability showed a significant positive association with the number of pods per plant (0.615), further, days to maturity also exhibited significant positive correlation with days to fifty per cent flowering (-0.407) and plant height (0.828). The number of pods per plant had significant negative correlations with days to fifty per cent flowering (-0.585) and days to maturity (-0.636) while canopy temperature depression exhibited significant negative correlation with per cent membrane leakage (-0.736).

The trait associations, that too, significant ones under both growing conditions provide valuable insights for breeding heat tolerant chickpea genotypes. Under normal condition, number of pods per plant, plant biomass and total chlorophyll content were found to be critical and may be considered in formulating selection indices in achieving higher yields. Whereas, under heat stress condition, pollen viability, canopy temperature depression and early maturity become noteworthy towards isolating promising genotypes. These outcomes align with the findings of Mohan and Thiyagarajan (2019) and Yadav *et al*. (2020) who also reported on biological yield showing significant association with primary branches per plant, pods per plant, seeds per pod and harvest index.

Path coefficient analysis

Deciphering the trait association into direct and indirect effect provides more relevant and useful information and helps to decide on criterion traits. In the current study, the direct and indirect effects of morpho-phenological and yield attributing traits on yield under both normal and heat stress conditions are analysed and same is presented in Table 2a and Table 2b respectively.

Under timely sown conditions, yield per plot exhibited the highest direct effect (0.3957) and an indirect effect (0.2712) through the number of pods per plant on seed yield per plant, followed by plant biomass with a direct effect of 0.2840 and an indirect effect of 0.1236 through the number of pods per plant on seed yield per plant. The number of pods per plant had a direct effect of 0.1355 and an indirect effect of 0.0929 through yield per plot while days to fifty per cent flowering showed a direct effect of 0.1249 and an indirect effect of 0.075 on seed yield per plant through days to maturity. Number of primary branches, total chlorophyll content, pollen viability, hundred seed weight and canopy temperature depression had direct effects of 0.0498, 0.0433, 0.0162, 0.0094 and 0.0063, respectively. In contrast, days to maturity (-0.0963), plant height (-0.2385) and number of seeds per pod (-0.0289) displayed negative direct effects on seed yield per plant (Table 2a). The path diagram is depicted in Fig. 1.

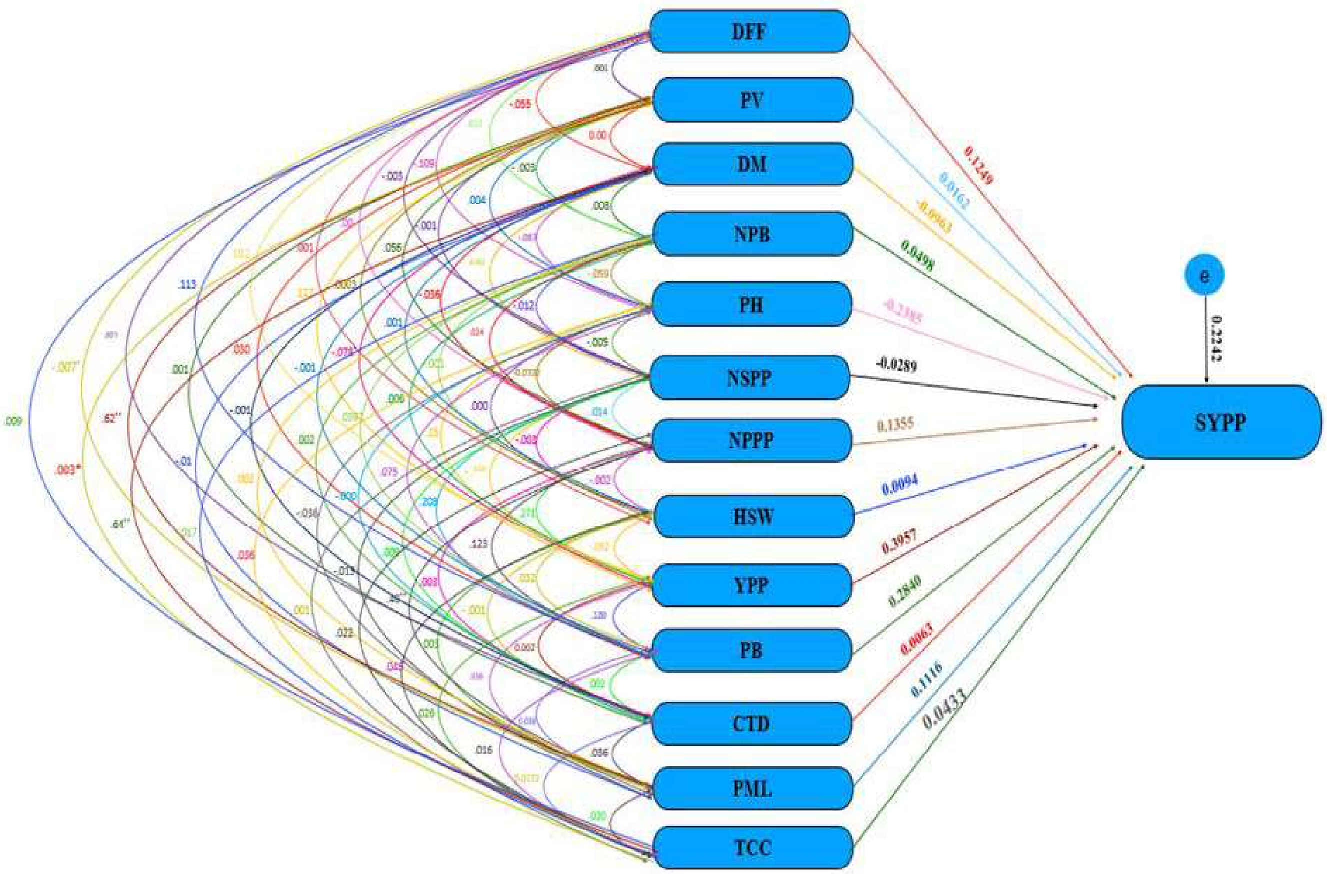

Fig 1. Path diagram showing the direct and indirect effects of thirteen characters on seed yield per plant under timely sown (normal) condition

Table 2a. Direct and indirect effects of morpho-phenological, physiological and yield components on yield under timely sown (normal) condition

	DFF	PV	DM	NPB	PH	NSPP	NPPP	HSW	YPP	PB	CTD	PML	TCC
DFF	0.1249	0.0014	-0.0552	0.0118	-0.1097	-0.0039	0.0008	0.0011	0.0127	0.1131	0.0001	-0.0076	0.0098
PV	0.0107	0.0162	0.0003	-0.003	0.0047	-0.0019	0.0563	0.0003	0.1272	0.0309	0.0014	-0.0004	0.0039
DM	0.0715	0.0001	-0.0963	0.0085	-0.0865	0.0011	-0.036	0.0013	-0.0786	-0.0011	-0.0015	-0.0181	-0.0009
NPB	0.0296	-0.0012	-0.0164	0.0498	-0.0591	-0.0122	0.0246	-0.0046	0.006	0.0397	0.002	-0.0107	0.0083
PH	0.0574	-0.0003	-0.035	0.0124	-0.2385	-0.0052	-0.0322	0.0007	-0.1068	0.0759	-0.0007	-0.0367	-0.0046
NSPP	0.0168	0.0012	0.0037	0.0212	-0.0427	-0.0289	0.0148	-0.003	-0.0182	0.0208	0.0013	-0.0131	0.0013
NPPP	0.0007	0.0067	0.0256	0.009	0.0566	-0.0031	0.1355	-0.002	0.2712	0.1236	0.0031	0.0485	0.0225
HSW	0.0146	0.0006	-0.0131	-0.0244	-0.0184	0.0092	-0.0289	0.0094	-0.0528	0.0324	-0.0013	0.0032	-0.008
YPP	0.004	0.0052	0.0191	0.0008	0.0644	0.0013	0.0929	-0.0013	0.3957	0.1209	0.0027	0.0569	0.0262
PB	0.0497	0.0018	0.0004	0.007	-0.0637	-0.0021	0.059	0.0011	0.1684	0.2840	0.0024	0.0389	0.0161
CTD	0.0022	0.0035	0.0231	0.0157	0.0275	-0.0058	0.0679	-0.002	0.1697	0.1068	0.0063	0.036	0.0172
PML	-0.0085	-0.0001	0.0157	-0.0048	0.0784	0.0034	0.0589	0.0003	0.2019	0.0991	0.002	0.1116	0.0202
TCC	0.0284	0.0015	0.002	0.0095	0.0255	-0.0009	0.0703	-0.0017	0.2395	0.1057	0.0025	0.052	0.0433

NOTE: Diagonal values represent the direct effect of a respective trait on yield per plant. TS- Timely sown, LS- Late sown, DFF-Days to 50% flowering, PV- Pollen viability, DM- Days to maturity, NPB-No. of primary branches, PH-Plant height, NSPP- No. of seeds per pod, NPPP- No. of pods per plant, HSW- Hundred seed weight, SYPP- Seed yield per plant, YPP-Yield per plot, PB- Plant biomass, CTD- Canopy temperature depression, PML- Per cent membrane leakage, TCC- Total chlorophyll content. Residual= 0.2242

The direct and indirect effects of independent traits on yield under late sown conditions showed different pattern wherein, yield per plot had the highest direct effect (0.4690) and an indirect effect (0.3161) through plant biomass on yield per plant, followed by plant biomass with a direct effect of 0.3409 and an indirect effect of 0.2289 on yield per plant. The number of pods per plant showed a direct effect (0.2679) and an indirect effect (0.1493) through yield per plot on seed yield per plant. Plant height along with direct effect (0.1000) exhibited indirect effect (0.0612) through days to maturity. Per cent membrane leakage (0.0645), number of seeds per pod (0.0485), canopy temperature depression (0.0517), pollen viability (0.0296) and total chlorophyll content (0.0296) also had positive direct effects on seed yield per plant. However, days to fifty per cent flowering, days to maturity, number of primary branches and hundred seed weight showed negative direct effects of -0.0100, -0.0059, -0.0058 and -0.0750, respectively, on seed yield per plant. The path diagram illustrating direct effects and correlations is shown in Fig. 2.

In comparative analysis, it is evident that under timely sown conditions, seed yield per plant was mainly influenced by plant biomass and the number of pods, with yield per plot having the highest direct effect while under late sown conditions, plant biomass and the number of pods observed to be key contributors, with membrane leakage, canopy temperature depression and pollen viability also being major yield attributing traits with buffering effect for stress adaptation. Other similar attempts of dissecting direct and indirect effects through path analysis by Paul *et al.* (2018), Varshini *et al.* (2019) and Velpula and Gaibriyal (2022) also revealed findings where number of pods per plant, seed yield per plant and days to fifty per cent flowering had positive direct effects on seed yield per plot analogous to the present study.

Table 2b: Direct and indirect effects of morpho-phenological, physiological and yield components on yield under late sown (heat stress) condition

	DFF	PV	DM	NPB	PH	NSPP	NPPP	HSW	YPP	PB	CTD	PML	TCC
DFF	-0.0100	-0.0123	-0.0035	-0.0012	0.0313	-0.0077	-0.1227	-0.0124	-0.1471	-0.0463	-0.027	0.0246	0.0021
PV	0.0041	0.0296	0.0028	0.0012	-0.0074	0.0009	0.1149	-0.0136	0.2514	0.181	0.0311	-0.0288	0.0092
DM	-0.006	-0.0143	-0.0059	-0.0025	0.0612	-0.0098	-0.1437	0.0019	-0.2862	-0.1299	-0.025	0.0066	-0.0079
NPB	-0.002	-0.0059	-0.0025	-0.0058	0.041	0.0012	-0.0566	0.0073	-0.1004	-0.0459	-0.0076	-0.0071	-0.004
PH	-0.0031	-0.0022	-0.0036	-0.0024	0.1000	-0.008	-0.0981	-0.0042	-0.1572	-0.0498	-0.006	-0.0065	-0.0039
NSPP	0.0016	0.0005	0.0012	-0.0001	-0.0166	0.0485	0.0118	0.0022	0.0736	0.0204	0.0027	-0.0056	0.0008
NPPP	0.0046	0.0127	0.0032	0.0012	-0.0366	0.0021	0.2679	-0.0112	0.2614	0.158	0.0146	-0.0013	0.0111
HSW	-0.0017	0.0054	0.0002	0.0006	0.0055	-0.0014	0.0401	-0.0750	0.1077	0.1169	0.0066	0.0007	0.0052
YPP	0.0031	0.0159	0.0036	0.0012	-0.0335	0.0076	0.1493	-0.0172	0.4690	0.2298	0.0324	-0.008	0.0152
PB	0.0014	0.0157	0.0022	0.0008	-0.0146	0.0029	0.1241	-0.0257	0.3161	0.3409	0.0243	-0.0064	0.0135
CTD	0.0052	0.0178	0.0028	0.0009	-0.0116	0.0026	0.0755	-0.0095	0.2939	0.1605	0.0517	-0.0289	0.0098
PML	-0.0038	-0.0132	-0.0006	0.0006	-0.01	-0.0042	-0.0054	-0.0008	-0.0582	-0.0337	-0.0361	0.0645	0.0139
TCC	-0.0007	0.0092	0.0016	0.0008	-0.0133	0.0013	0.1009	-0.0133	0.2419	0.1562	0.0056	0.0064	0.0296

NOTE: Diagonal values represent the direct effect of a respective trait on yield per plant. TS- Timely sown, LS- Late sown, DFF-Days to 50% flowering, PV- Pollen viability, DM- Days to maturity, NPB-No. of primary branches, PH-Plant height, NSPP- No. of seeds per pod, NPPP- No. of pods per plant, HSW- Hundred seed weight, SYPP- Seed yield per plant, YPP-Yield per plot, PB- Plant biomass, CTD- Canopy temperature depression, PML- Per cent membrane leakage, TCC- Total chlorophyll content. Residual= 0.1069

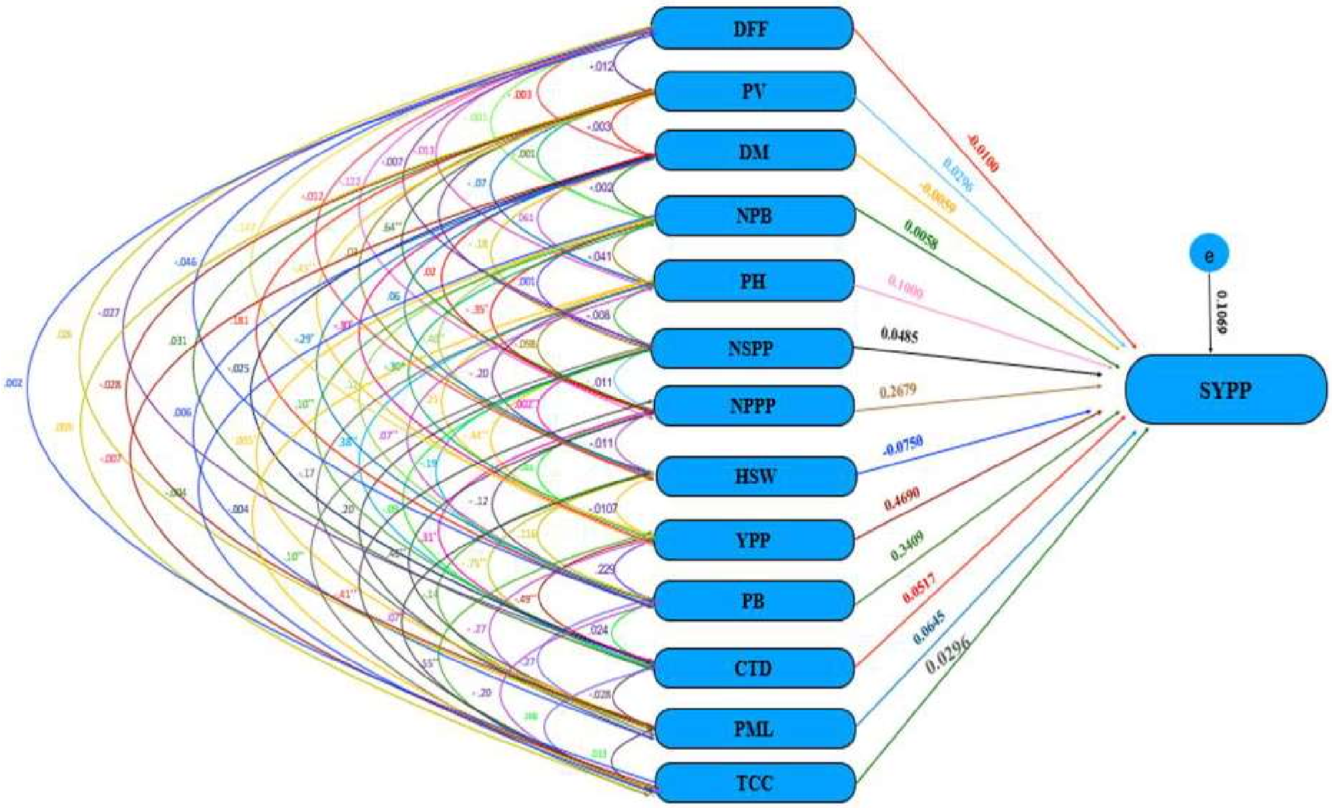

Fig 2. Path diagram showing the direct and indirect effects of thirteen characters on seed yield per plant under late sown (heat stress) condition

Conclusion

The study brought out the useful information on the key traits that influence seed yield in chickpea under different temperature regimes, normal and heat stress conditions, aiding in the development of heat tolerant genotypes. Under optimal conditions, plant biomass, number of pods per plant and yield per plot emerged as the most significant contributors to yield, indicating that overall plant productivity and pod development play a crucial role in achieving higher yields. In contrast, under late sown (heat stress) conditions, pollen viability, canopy temperature depression and plant biomass were critical for maintaining yield, suggesting the importance of these traits in adapting to heat stress. The positive impact of canopy temperature depression highlights its importance in stress tolerance mechanisms. These findings emphasize on prioritization of these traits in breeding programmes aimed at improving chickpea resilience and yield stability across varying temperature regimes, towards ensuring more stable performance across normal and high temperature environments.

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