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PS Zade
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

SP Pole
Junior Breeder, Oilseeds Research Station, Latur, VNMKV Parbhani, Maharashtra, India

MV Dhuppe
Oilseeds Specialist, Oilseeds Research Station, Latur, VNMKV Parbhani, Maharashtra, India

TA Narkhede
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

G Singh
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

NP Sonawane
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

AG Rajput
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

Corresponding Author:
PS Zade
M.Sc. (Agri.), Department of Genetics and Plant Breeding, College of Agriculture, Latur, Maharashtra, India

Character Association and Path Analysis for seed yield in Sunflower (*Helianthus annuus* L.)

PS Zade, SP Pole, MV Dhuppe, TA Narkhede, G Singh, NP Sonawane and AG Rajput

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Abstract
The present investigation was carried out to assess the relationships among seed yield and its contributing traits in 40 diverse genotypes of Sunflower (*Helianthus anuus* L.). The genotypes were evaluated under a randomized block design with two replications at the Research farm, Oilseeds Research Station, Latur, VNMKV Parbhani (Maharashtra) during *Kharif* season 2024-25. Observations were recorded on ten quantitative traits including days to 50 per cent flowering, days to maturity, plant height (cm), head diameter (cm), Seed filling (%), 100 seed weight (g), volume weight (g/100ml), hull content (%), seed yield per plant (g) and oil content (%). Days to 50 per cent flowering and days to maturity observations were recorded on plot basis only once.
Plant height, head diameter, seed filling percentage and oil content recorded highly significant positive correlation with seed yield per plant at both phenotypic and genotypic levels and days to 50 percent flowering and days to maturity recorded significant negative correlation with seed yield per plant. Path coefficient analysis at both phenotypic and genotypic level indicated that the traits plant height, head diameter, seed filling percentage and volume weight exerted a positive direct effect on seed yield per plant.

Keywords: Sunflower, correlation analysis, path coefficient analysis, character association

Introduction
In India's agricultural sector, oilseeds hold significant importance after food grains. Among the major oilseed crops, sunflower (*Helianthus annuus* L.) stands out following groundnut, rapeseed-mustard and soybean. It is especially valued for its heart-healthy edible oil, which maintains a steady market demand. The main goal of sunflower breeding programs is to develop cultivars with high yields and enhanced yield-related traits. However, seed yield in sunflower is a complex quantitative trait that is greatly influenced by environmental conditions. Hence, a thorough understanding of both genetic and non-genetic sources of variability is crucial for designing an effective and well-structured breeding strategy.
In India, sunflower is primarily cultivated in states such as Punjab, Haryana, Karnataka, Gujarat, Maharashtra, Uttar Pradesh, West Bengal, Odisha, Rajasthan, Tamil Nadu and Andhra Pradesh. At present, the crop covers an area of 3,64,000 hectares yielding a total production of 3.63 million tonnes with an average productivity of 996 kg per hectare. Karnataka, Maharashtra, and Andhra Pradesh together represent 70% of the total area under sunflower cultivation (Anonymous, 2023) [2].
Correlation analysis provides an estimate of the degree and direction of association between traits, but it does not explain the direct and indirect effects. Path coefficient analysis, introduced by Wright (1921) [11], allows the partitioning of correlation coefficients into their direct and indirect effects on yield. This dual analysis provides a better understanding of trait interdependencies and aids in identifying the most important yield-contributing characters.
The present study was undertaken to determine the correlation and path coefficients among yield and its component traits in bread wheat genotypes. The objective was to identify the key traits that can serve as reliable selection indices for enhancing grain yield in future breeding programs.

Materials and Methods

The experiment was conducted using genotypes of sunflower laid out in a randomized block design (RBD) with two replications during the *kharif* season (2023-24) at the farm of Oilseeds Research Station Latur, VNMKV Parbhani (Maharashtra). Thirty eight Inbreds along with two standard check varieties were sown in two replications. Two to three seeds were dibbled per hill. One single line included 15 dibbles, following spacing of 60 cm between row to row and 30 cm between plant to plant. Standard agronomic practices were followed throughout the cropping season to ensure uniform crop management, and appropriate plant protection measures were undertaken when necessary. Data were recorded for ten quantitative traits: days to 50 per cent flowering, days to maturity, plant height, head diameter, seed filling percentage, 100 seed weight, volume weight, hull content, seed yield per plant and oil yield.

Phenotypic and genotypic correlation coefficients were computed following the method described by Al-Jibouri *et al*. (1958). Path coefficient analysis was carried out as per Wright (1921) and Dewey & Lu (1959) [11, 3], taking seed yield per plant as the dependent variable.

Results and Discussion

Correlation Analysis

The phenotypic and genotypic correlation coefficients between yield and its related components are presented in (Table 1 & Table 2).

Phenotypic correlation coefficient

Highly significant and positive correlation was observed for seed yield per plant with seed filling (0.8733), head diameter (0.607), plant height (0.4992), oil content (0.3275) and highly significant negative correlation with days to maturity (-0.3792) and days to 50 per cent flowering (-0.3255). Seed yield per plant recorded positive non-significant correlation with 100 seed weight (0.2098) and volume weight (0.1129) and negative non-significant correlation with hull content (-0.0945). These results were in agreement with reports of Kulkarni *et al.* (2022) [6] for plant height, 100 seed weight and volume weight, Gangavati and kulkarni (2021) [5] for head diameter and oil content, for seed filling percentage and hull content, Kholghi *et al.* (2011) [4] for days to 50 per cent flowering, Vivek *et al.* (2023) [10] for days to maturity.

Days to 50 per cent flowering had highly significant and positive correlation with days to maturity (0.8697) and highly significant and negative correlation with seed yield per plant (-0.3255), seed filling percentage (-0.2559) and head diameter (-0.2272) but had non-significant positive correlation with hull content (0.2191), oil content (0.1595) and volume weight (0.0232) and had a non-significant negative correlation with remaining characters like plant height (-0.104) and 100 seed weight (-0.2176). Plant height was highly significant and positively correlated with seed yield per plant (0.4992), head diameter (0.6499), seed filling percentage (0.4503) and oil content (0.3061). It showed non-significant positive association with volume weight g/100 ml (0.212) and 100 seed weight (0.1634) while, non-significant negative association was observed with hull content (-0.0613). Head diameter showed highly significant and positive association with seed yield per plant (0.607), seed filling percentage (0.531) and oil content (0.3203). It showed positive, non-significant correlation with 100 seed weight (0.1999) and volume weight (0.1026) and it was negatively and non-significantly correlated with hull content (-0.156). Seed filling percentage exhibited positive and significant correlation with seed yield per plant (0.8733), oil content (0.4581) and 100 seed weight (0.2822). It showed positive and non-significant correlation with volume weight (0.0388) and negative, non-significant correlation with hull content (-0.1003). 100 seed weight recorded highly significant negative correlation with hull content (-0.57) and non-significant positive correlation with seed yield per plant (0.2098), oil content (0.0829) and volume weight (0.0615). Volume weight exhibited non-significant positive correlation with oil content (0.1325) and seed yield per plant (0.1129) and non- significant and negative with hull content (-0.1716). Hull content showed negative and non-significant correlation with oil content (-0.1029) and seed yield per plant (-0.0945).

Genotypic correlation coefficient

Seed yield per plant showed strong positive associations with several yield components. It was highly significantly correlated with plant height (0.5368), head diameter (0.6502), seed filling percentage (0.9523) and oil content (0.3417). Positive but non-significant correlations were observed with 100 seed weight 0.2124) and volume weight (0.1307). In contrast, It was negatively correlated with days to 50 per cent flowering (-0.3672) and days to maturity (-0.4318) and had a non-significant negative correlation with hull content (-0.0951). These results were similar with results of Binod *et al*. (2008) for days to 50 per cent flowering and 100 seed weight, for volume weight and hull content, Gangavati and Kulkarni *et al*. (2021) [5] for plant height, head diameter and oil content, Shankar *et al*. (2006) for seed filling percentage and Vivek *et al*. (2023) [10] for days to maturity.

Days to 50 per cent flowering was almost perfectly positively correlated with days to maturity (0.9983), reflecting that genotypes that flower later also mature later. It had non-significant positive correlations with hull content (0.2525), oil content (0.215) and volume weight (0.0354) and non-significant negative correlations with plant height (-0.0765), head diameter (-0.2351), seed filling percentage (-0.2671) and 100 seed weight (-0.2362). Notably, days to 50 per cent flowering was significantly negatively correlated with seed yield (-0.3672). Days to maturity was significantly negatively correlated with seed yield (-0.4318), seed filling percentage (-0.4016) and 100 seed weight (-0.3629). It had non-significant positive correlations with hull content (0.3004) and oil content (0.0718) and volume weight (0.0367). It had non-significant negative correlations with plant height (-0.094), head diameter (-0.2421). Plant height showed strong positive correlations with several traits. It was highly significantly associated with head diameter (0.6818), seed filling percentage (0.4942) and seed yield per plant (0.5368). A modest but significant positive correlation also existed with oil content (0.3246). Correlations with 100seed weight (0.166) and volume weight (0.2325) were positive but non-significant. Hull content showed negative and non-significant correlation (-0.0606). Head diameter showed highly significant positive correlations with seed filling percentage (0.5856) and seed yield per plant (0.6502) indicating that larger flower heads produce more filled seeds and higher yield. A significant positive correlation was also found with oil content (0.3475). Its correlations with 100

seed weight (0.2104) and volume weight (0.1203) were positive but not significant. Hull content was negatively correlated with head diameter (-0.1666). Seed filling percentage had a highly significant positive correlation with seed yield per plant (0.9523) and oil content (0.4955) and a significant positive association was also found with 100 seed weight (0.3239). Its correlations with volume weight (0.0286) was positive but not significant and hull content (0.1197) was negative non-significant. These results indicate that genotypes with better grain filling tend to produce heavier seeds and higher yield. 100 seed weight exhibited a highly significant negative correlation with hull content (-0.5824). It was positively but non-significantly correlated with seed yield per plant (0.2124). Its associations with volume weight (0.0658) and oil content (0.0845) were also positive but not significant. Volume weight showed a non-significant positive correlation with seed yield per plant (0.1307) and oil content (0.1416) and a non-significant negative correlation with hull content (-0.1838). Hull content showed generally weak negative correlations with the other traits. It had a non-significant negative correlation with oil content (-0.1096) and with seed yield per plant (-0.0951).

Path Analysis

Path coefficient analysis was carried out to estimate the direct and indirect effects of yield-contributing traits on seed yield per plant at both phenotypic and genotypic levels Presented in (Table 3 & 4).

Phenotypic path coefficient analysis

Days to 50 per cent flowering had negative direct effect (-0.0617) on seed yield per plant. 100 seed weight (0.0172) and volume weight (0.0017) showed positive indirect effects, whereas days to maturity (-0.0139), plant height (-0.0047), head diameter (-0.0392), seed filling percentage (-0.2064), hull content (-0.0020) and oil content (-0.0166) had negative indirect effects on seed yield per plant through days to 50 per cent flowering. Days to maturity had negative direct effect (-0.0537) on seed yield per plant. 100 seed weight (0.0255) and volume weight (0.0018) showed positive indirect effects, whereas days to 50 per cent flowering (-0.0537), plant height (-0.0044), head diameter (-0.0372), seed filling percentage (-0.2874), hull content (-0.0026) and oil content (-0.0055) had negative indirect effect on seed yield per plant through days to maturity. Plant height (cm) had positive direct effect (0.0448) on seed yield per plant. Days to 50 per cent flowering (0.0064), days to maturity (0.0155), head diameter (0.1120), seed filling percentage (0.3632), volume weight (0.0156) and hull content (0.0006) showed positive indirect effects, whereas 100 seed weight (-0.0130) and oil content (-0.0319) had negative indirect effects on seed yield per plant through plant height. Head diameter (cm) had positive direct effect (0.1724) on seed yield per plant. Days to 50 per cent flowering (0.014), days to maturity (0.0034), plant height (0.029), seed filling percentage (0.4283), volume weight (0.0075) and hull content (0.0014) showed positive indirect effects, whereas 100 seed weight (-0.0158) and oil content (-0.0334) had negative indirect effects on seed yield per plant though head diameter. Seed filling (%) had positive direct effect (0.8065) on seed yield per plant. Days to 50 per cent flowering (0.0158), days to maturity (0.0057), plant height (0.0208), head diameter (0.0915), volume weight (0.0029) and hull content (0.0009) showed positive indirect effects, whereas 100 seed weight (-0.0224) and oil content (-0.0478) had negative indirect effects on seed yield per plant through seed filling (%). 100 seed weight (g) had negative direct effect (-0.0793) on seed yield per plant. Days to 50 per cent flowering (0.0134), days to maturity (0.0051), plant height (0.0073), head diameter (0.0345), seed filling percentage (0.228), volume weight (0.0045) and hull content (0.0053) showed positive indirect effects, whereas oil content (-0.0086) had negative indirect effects on seed yield per plant through 100 seed weight. Volume weight (g/100ml) had positive direct effect (0.0735) on seed yield per plant. Plant height (0.0095), head diameter (0.0177), seed filling percentage (0.0313) and hull content (0.0016) showed positive indirect effects, whereas days to 50 per cent flowering (-0.0014), Days to maturity (-0.0004), 100 seed weight (-0.0049) and oil content (-0.0138) had negative indirect effects on seed yield per plant through volume weight. Hull content (%) had negative direct effect (-0.0093) on seed yield per plant. 100 seed weight (0.0452) and oil content (0.0107) showed positive indirect effects, whereas days to 50 per cent flowering (-0.0135), days to maturity (-0.0045), plant height (-0.0028), head diameter (-0.0269), seed filling percentage (-0.0809) and volume weight (-0.0126) had negative indirect effects on seed yield per plant through hull content. Oil content (%) had negative direct effect (-0.1043) on seed yield per plant. plant height (0.0137), head diameter (0.0552), seed filling percentage (0.3695), volume weight (0.0097) and hull content (0.001) showed positive indirect effects, whereas days to 50 per cent flowering (-0.0099), Days to maturity (-0.0008), 100 seed weight (-0.0066) had negative indirect effects on seed yield per plant through oil content.

Genotypic path coefficient analysis

Days to 50 per cent flowering had positive direct effect (0.4884) on seed yield per plant. It had positive indirect effect through 100 seed weight (0.0556) and volume weight (0.0043), whereas other characters like days to maturity (-0.5502), plant height (-0.0022), head diameter (-0.0423), seed filling percentage (-0.2508), hull content (-0.0132) and oil content (-0.0567) showed negative indirect effect. Days to maturity had negative direct effect (-0.5511) on seed yield per plant. It had positive indirect effect through days to 50 per cent flowering (0.4876), 100 seed weight (0.0854) and volume weight (0.0045), whereas other characters like plant height (-0.0027), head diameter (-0.0435), seed filling percentage (-0.3771), hull content (-0.0157) and oil content (-0.0190) showed negative indirect effect. Plant height (cm) had positive direct effect (0.0290) on seed yield per plant. It had positive indirect effect through days to maturity (0.0518), head diameter (0.1226), seed filling percentage (0.4641), volume weight (0.0283) and hull content (0.0032), whereas other characters like days to 50 per cent flowering (-0.0374), 100 seed weight (-0.0390) and oil content (-0.0857) showed negative indirect effect. Head diameter (cm) had positive direct effect (0.1798) on seed yield per plant. It had positive indirect effect through days to maturity (0.1335), plant height (0.0197), seed filling percentage (0.5499), volume weight (0.0146) and hull content (0.0087), whereas other characters like days to 50 per cent flowering (-0.1149), 100 seed weight (-0.0495) and oil content (-0.0917) showed negative indirect effect. Seed filling (%) had positive direct effect (0.9390) on seed yield per plant. It

had positive indirect effect through days to maturity (0.2214), plant height (0.0143), head diameter (0.1053), volume weight (0.0035) and hull content (0.0063), whereas other characters like days to 50 per cent flowering (-0.1305), 100 seed weight (-0.0762) and oil content (-0.1308) showed negative indirect effect. 100 seed weight (g) had negative direct effect (-0.2352) on seed yield per plant. It had positive indirect effect through days to maturity (0.2000), plant height (0.0048), head diameter (cm) (0.0378), seed filling percentage (0.3041), volume weight (0.0080) and hull content (0.0305), whereas other characters like days to 50 per cent flowering (-0.1154) and oil content (-0.0223) showed negative indirect effect. Volume weight (g/100ml) had positive direct effect (0.1216) on seed yield per plant. It had positive indirect effect through days to 50 per cent flowering (0.0173), plant height (0.0067), head diameter (0.0216), seed filling percentage (0.0269) and hull content (0.0096), whereas other characters like days to maturity (-0.0202), 100 seed weight (-0.0155) and oil content (-0.0374) showed negative indirect effect. Hull content (%) had negative direct effect (-0.0524) on seed yield per plant. It had positive indirect effect through days to 50 per cent flowering (0.1233), 100 seed weight (0.1370) and oil content (0.0289), whereas other characters like days to maturity (-0.1656), plant height (-0.0018), head diameter (-0.0300), seed filling percentage (-0.1124) and volume weight (-0.0224) showed negative indirect effect. Oil content (%) had negative direct effect (-0.2639) on seed yield per plant. It had positive indirect effect through days to 50 per cent flowering (0.1050), plant height (0.0094), head diameter (0.0625), seed filling percentage (0.4653), volume weight (0.0172) and hull content (0.0057), whereas other characters like days to maturity (-0.0396) and 100 seed weight (-0.0199) showed negative indirect effect.

The present results were in agreement with the observations of Sanju *et al.* (2018) [7] for days to 50 per cent flowering, plant height, head diameter, seed filling percentage, volume weight, hull content and oil content, for days to maturity and those of Gangavati and Kulkarni (2021) [5] concerning 100 seed weight.

Table 1: Phenotypic correlation for yield and yield contributing traits in Sunflower

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	1 **	0.8697 **	-0.104	-0.2272 *	-0.2559 *	-0.2176	0.0232	0.2191	0.1595	-0.3255 **
Days to maturity		1 **	-0.0974	-0.2156	-0.3563 **	-0.3226 **	0.0248	0.2817 *	0.0524	-0.3792 **
Plant height (cm)			1 **	0.6499 **	0.4503 **	0.1634	0.212	-0.0613	0.3061 **	0.4992 **
Head diameter (cm)				1 **	0.531 **	0.1999	0.1026	-0.156	0.3203 **	0.607 **
Seed filling (%)					1 **	0.2822 *	0.0388	-0.1003	0.4581 **	0.8733 **
100 seed weight (g)						1 **	0.0615	-0.57 **	0.0829	0.2098
Volume weight (g/100ml)							1 **	-0.1716	0.1325	0.1129
Hull content (%)								1 **	-0.1029	-0.0945
Oil content (%)									1 **	0.3275 **
Seed yield per plant (g)										1 **

** - Significant at p = 0 .01 * - Significant at p = 0. 05

Table 2: Genotypic correlation for yield and yield contributing traits in sunflower

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	1 **	0.9983 **	-0.0765	-0.2351	-0.2671	-0.2362	0.0354	0.2525	0.215	-0.3672 *
Days to maturity		1 **	-0.094	-0.2421	-0.4016 *	-0.3629 *	0.0367	0.3004	0.0718	-0.4318 **
Plant height (cm)			1 **	0.6818 **	0.4942 **	0.166	0.2325	-0.0606	0.3246 *	0.5368 **
Head diameter (cm)				1 **	0.5856 **	0.2104	0.1203	-0.1666	0.3475 *	0.6502 **
Seed filling (%)					1 **	0.3239 *	0.0286	-0.1197	0.4955 **	0.9523 **
100 seed weight (g)						1 **	0.0658	-0.5824 **	0.0845	0.2124
Volume weight (g/100ml)							1 **	-0.1838	0.1416	0.1307
Hull content (%)								1 **	-0.1096	-0.0951
Oil content (%)									1 **	0.3417 *
Seed yield per plant (g)										1 **

** - Significant at p = 0 .01 * - Significant at p = 0. 05

Table 3: Path analysis for different characters at phenotypic level in sunflower

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	-0.06173	-0.01385	-0.00466	-0.03916	-0.20639	0.01724	0.0017	-0.00203	-0.01664	-0.3255 **
Days to maturity	-0.05369	-0.01592	-0.00436	-0.03716	-0.28736	0.02555	0.00182	-0.00261	-0.00548	-0.3792 **
Plant height (cm)	0.00642	0.00155	0.04478	0.11201	0.36317	-0.01295	0.01557	0.00057	-0.03193	0.4992 **
Head diameter (cm)	0.01403	0.00343	0.02911	0.17235	0.42826	-0.01584	0.00754	0.00144	-0.03341	0.607 **
Seed filling (%)	0.0158	0.00567	0.02017	0.09152	0.80651	-0.02236	0.00285	0.00093	-0.04778	0.8733 **
100 seed weight (g)	0.01343	0.00514	0.00732	0.03445	0.2276	-0.07928	0.00452	0.00528	-0.00865	0.2098
Volume weight (g/100ml)	-0.00143	-0.00039	0.00949	0.01768	0.03129	-0.00487	0.07345	0.00159	-0.01381	0.1129
Hull content (%)	-0.01353	-0.00449	-0.00275	-0.02689	-0.08089	0.04516	-0.0126	-0.00926	0.01073	-0.0945
Oil content (%)	-0.00985	-0.00084	0.01371	0.0552	0.36946	-0.00657	0.00972	0.00095	-0.1043	0.3275 **

** - Significant at p = 0 .01 * - Significant at p = 0. 05 Residual effect= 0.0035

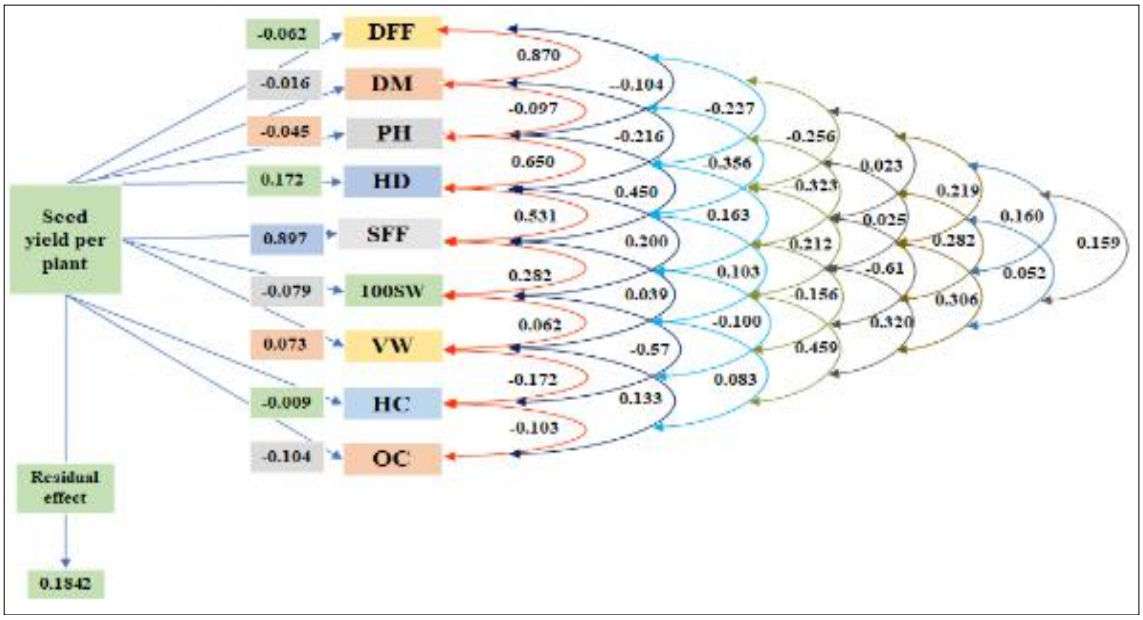

Fig 1: Phenotypical path diagram for seed yield per plant

Table 4: Path analysis for different characters at genotypic level in sunflower

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	0.48843	-0.55018	-0.00221	-0.04227	-0.25084	0.05555	0.0043	-0.01322	-0.05673	-0.3672 *
Days to maturity	0.48759	-0.55112	-0.00272	-0.04353	-0.37715	0.08536	0.00446	-0.01573	-0.01895	-0.4318 **
Plant height (cm)	-0.03737	0.05181	0.02895	0.12256	0.46411	-0.03903	0.02827	0.00317	-0.08566	0.5368 **
Head diameter (cm)	-0.11485	0.13345	0.01974	0.17976	0.5499	-0.04948	0.01463	0.00872	-0.09171	0.6502 **
Seed filling (%)	-0.13048	0.22135	0.01431	0.10527	0.93902	-0.07617	0.00348	0.00627	-0.13075	0.9523 **
100 seed weight (g)	-0.11535	0.20003	0.0048	0.03782	0.30411	-0.2352	0.008	0.03049	-0.02231	0.2124
Volume weight (g/100ml)	0.01729	-0.02022	0.00673	0.02162	0.02689	-0.01548	0.12159	0.00962	-0.03737	0.1307
Hull content (%)	0.12333	-0.16555	-0.00175	-0.02995	-0.11238	0.13697	-0.02235	-0.05235	0.02893	-0.0951
Oil content (%)	0.105	-0.03958	0.0094	0.06247	0.46526	-0.01989	0.01722	0.00574	-0.2639	0.3417 *

** - Significant at p = 0 .01 * - Significant at p = 0. 05 Residual effect= 0.3394

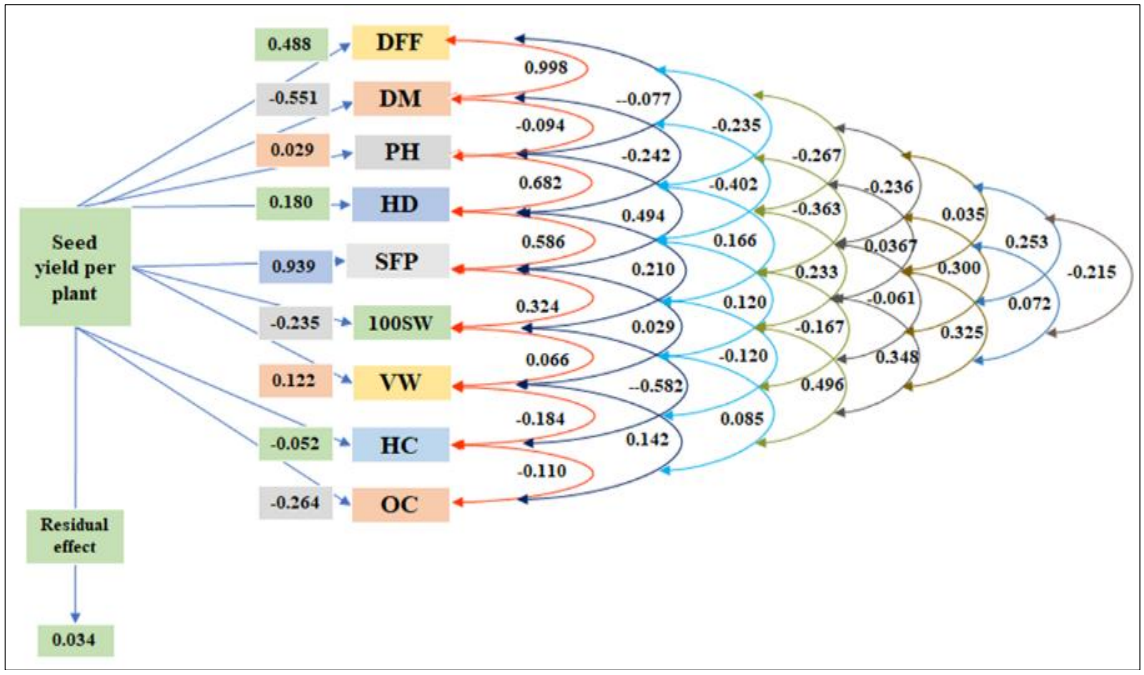

Fig 2: Genotypical path diagram for seed yield per plant

Conclusion

Correlation studies reveal that genotypic correlation coefficients were greater than phenotypic correlation coefficients for most of the traits under study. Plant height, head diameter, seed filling percentage and oil content recorded highly significant positive correlation with seed yield per plant at both phenotypic and genotypic levels and days to 50 percent flowering and days to maturity recorded significant negative correlation with seed yield per plant. 100 seed weight and volume weight recorded non-significant positive correlation with seed yield per plant and hull content recorded non-significant negative correlation with seed yield per plant at both phenotypic and genotypic levels.

Path coefficient analysis at both phenotypic and genotypic level indicated that the traits plant height, head diameter, seed filling percentage and volume weight exerted a positive direct effect on seed yield per plant and traits such as days to maturity, 100 seed weight, hull content and oil content exerted a negative direct effect on seed yield per plant. whereas, days to 50 per cent flowering exerted negative direct effect at phenotypic level and positive direct effect at genotypic level on seed yield per plant. The results from both correlation and path analyses highlight the significant association of various traits with seed yield, thereby emphasizing the importance of these characters in the selection and improvement of sunflower genotypes.

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