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Correlation and path coefficient analysis of seed yield and yield components in lentil (*Lens culinaris* Medik.) genotype in Ethiopia

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Knowledge of correlation among different traits and further partitioning of the correlation coefficients into direct and indirect effects on yield is one of the approaches to understand the nature and extent of the relationship among characters. The objective of this study was to determine the degree of associations between seed yield and yield components of lentil. In this study, 228 genotypes from diversified origin were considered. The experiment was conducted at three locations using randomized complete block design and augmented design. Significant strong positive phenotypic and genotype correlations were observed between seed yield and biomass, seed weight per plant, number of seed per plant and number of pods per plant. These four yield-contributing characters had also strong positive correlations with each other. The path coefficient analysis is in harmony, with the phenotypic and genotypic correlation, that is, seed weight per plant, followed by number of pods per plant, biomass yield and 100 seed weight have a considerable positive direct effect on lentil seed yield. However, days to 50% flowering, days to 90% maturity and rust disease severity score had negative phenotypic correlation and negative direct effect on seed yield.

Key words: Genotype correlation coefficient, lentil, path analysis, phenotype correlation coefficient.

INTRODUCTION

Lentil is a short and slender annual cool-season food legume, which was, domesticated early in the Fertile Crescent of the Near East (Sarker et al., 2010). Lentil provides sufficient amounts of the most essential amino acids to meet the nutrient requirements of humans. It is also a cash crop fetching a lot of money in domestic

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markets as compared to all other food legumes and major cereals (Geletu et al., 1996). Because of its significant economic roles and social contribution, lentil production has recently been expanding both in stressed and non-stressed environments (Asnake and Geletu, 2006). The global lentil productivity is about 0.9 t/ha, while in Africa it is about 0.6 t/ha (FAO, 2013) and in Ethiopia about 1.2 t/ha (CSA, 2012). In many traditional lentil-producing countries, most of the lentil production area is covered by the local landraces that are vulnerable to a range of biotic and abiotic factors and produced lower yield and seed quality (Sarker et al., 2003).

Characterizing crop genotypes for agronomic morphological traits have immense importance in crops breeding. Some of the traits are easy to select due to its visual nature but its scientific understanding is important for its manipulation. To facilitate selection in breeding for high yield, it is important to examine the association of various yield components and give more attention to those having greatest influence on yield. Gomez and Gomez (1984) showed that in order to determine important components of crop performance among their variables, it is essential to examine association between primary and secondary traits. Falconer and Mackey (1996) also indicated correlation coefficients measures the degree of association between characters and relative influence of various characters on yield and amongst themselves. Since breeding is commonly aimed at multiple traits, it is essential to know the correlated responses in primary traits like seed yield through selection of secondary traits (Borojevic, 1990).

Knowledge of correlation among different traits and further partitioning of the correlation coefficients into direct and indirect effects is one of the approaches to understand the nature and extent of such relationship among the characters in both local and introduced genotypes. As more traits are considered for correlation study, the indirect associations between traits become more complex, less obvious and somewhat perplexing. The path coefficient analysis, a method developed by Wright (1921) and later elaborated by Dewey and Lu (1959), provides an effective means of partitioning direct and indirect effect of association. Path coefficient is simply a standardized partial regression coefficient, measures the direct influence of one variable upon another, and permits the separation of correlation coefficient into components of direct and indirect effects This technique allows identifying major yield contributing characters, and specific traits producing a given correlation (Rao et al., 1997).

Researchers in Ethiopia and elsewhere have reported association yield and yield components traits of lentil germplasm, and the information was not comprehensive and exhaustive (Erskine et al., 1989; Ramgiry et al., 1989; Geletu et al., 1996; Abebe et al., 2001; Tigest, 2003; Edossa et al., 2010; Roy, et al., 2013). Besides, the value of correlation coefficients and the contribution of different components vary in different environments and, in different population and the magnitude of correlation coefficient can often be influenced by the choice of individuals upon which the observations are made (Jatasra and Paroda 1978; Dabholkar, 1992). It is therefore, advisable to consider large number of genotypes and use the correlation to establish an index in deciding the direction of selection. Hence, understanding of such an important association is necessary to conduct effective selection activities. An understanding of the genetic relationships of different yield components and their direct and indirect effect is imperative for Ethiopian lentil, in relation to lentil from exotic origin. The objective of this study was to determine the degree and nature of associations among seed yield and yield components in local and exotic lentil genotypes under the Ethiopia conditions.

MATERIALS AND METHODS

Description of the study site

The field experiment was conducted on selected hot spot locations for rust. The locations included Sirinka Agricultural Research Center (SRARC) in the northeastern part of Ethiopia for two seasons (2011 and 2012), Chefe Donsa in the central part of Ethiopia and Sinana Agricultural Research Center (SARC) in southeastern parts of Ethiopia during the 2011/12 cropping season (Table 1 and Figure 1).

Plant materials

The experiments consist of 228 genotypes collected from Ethiopian Biodiversity Institute (EBI) and DebreZeit Agricultural Research Station (DZARC), Ethiopia, and the International Center for Agricultural Research in Dry Areas (ICARDA). Name of genotype number of genotype, source of origin, and breeding status of the genotypes were presented in Table 1. In 2010/2011 cropping season, 158 genotypes were planted for morphological evaluation at SRARC. In the 2011/12 cropping season, 228 genotypes including recombinant inbreed lines (RIL) were included (Table 1) in the study across three locations: Sirinka, Chefe Donsa and Sinana.

Experimental layout and design

A randomized complete block design (RCBD) with three replications, at SRARC in the 2010/11 cropping season, and an augmented design with five blocks were used in 2011/12 cropping season over the three locations. The genotypes were planted in July in a two rows plot size of 0.8 m^2. The row to row distance was 20 cm. The distance between two plots was 50 cm and the distance between two blocks was 100 cm. Eight checks were replicated within each block. Planting was done in the first week of July at SRARC, in August at Chefe Donsa and in mid-September at SARC. The recommended agronomic packages at each location were applied for raising a successful crop.

Data collection

Data were recorded on 10 important phonological, yield and yield

Table 1. List of genotypes used in this study and their origin.

Source of origin	No. of genotypes	Name of genotype	Breeding status of the genotypes
Tigray	8	Acc. no. 219957,235383, 237503,237504, 241785, 242604, 243447	Landrace
Amhara	54	Acc. no. 36003, 36025, 36028, 36039, 36041, 36061, 36071, 36085, 36088, 36089, 36097, 36103, 36104, 36105, 36137, 36139, 36150, 36162, 36165, 36168, 207258, 207274, 207287, 207309, 212745, 215248, 215249, 223221, 228242, 229179, 229182, 229183, 231247, 235013, 235015, 235016, 235017, 236484, 236486, 236487, 237502, 238978, 238979, 241784, 241786, 243433, 243436, 243440, 243443, 244606, 244610, 244615, 244619, 244623	Landrace
Oromya	29	Acc. no. 36001, 36007, 36009, 36013, 36015, 36019, 36023, 36029, 36033, 36042, 36048, 36058, 36110, 36120, 36131, 203141, 215806, 216877, 228809, 230521, 230833, 230834, 230837, 231248, 235698, 236438, 236892, 237027, 238971	Landrace
SNNP	2	Acc. no. 36147 and Acc. No.,228243	Landrace
Somali	1	Acc. no. 230832	Landrace
DZARC	6	/ILL4225 x ILL4605/ /ILL 6821/ Alemaya, /ILL 1 x ILL 1169//ILL 6027/ ADAA, /ILL 7978/ Teshale, / Alemaya x FLIP88-41L/ DERASH, /ILL 7981/ *Aleme Tena* and P160/ILL 2704/ / Chekol/	Commercial varieties
Unknown	10	Acc. no. 36134, 207260, 211062,211078, 211110, 220120, 211131, 233349, 233973, 241782	Landrace
ICARDA	22	X2003S 222/ILL 213/, X2003S 238 /ILL 4605/, X2006S 128/ILL 5480/, L-9-12, X2002S 219 /ILL 6821/, X2006S 129 /F2/, X2005S 215 /ILL 6002/, X2006S 133/FLIP87-21L/ /ILL 4349 x ILL4605//ILL 6211/, X2006S 130/FLIP 93-46L/ /ILL 7547/, FLIP-2004-7L, X2003S 223, X2003S 195/ILL 7115/, X2006S 130/FLIP 96-46 L//ILL 7978/, X2002S 221/FLIP 96-47 L//7979/, X2002S 221 /7980/, X2003S 233 /ILL 8009/, X2006S 134/ILL8174/, 2006S 122 /FLIP 2003-43L/ /ILL 7010 x ILL 1939/ /ILL 9932/, /FLIP 2003-56L/ /ILL 9945/X2006S 127, /ILL 2573 x ILL 7537/ /FLIP 2003-62 L/ /ILL 9951/X2006S 122, X2002S 219 /shehor-74/ /ILL 7554/, 2003S 236	Parent
DZARC	11	EL-142 /ILL 5071/, EXOTIC #DZ/2008 AK, R-186XFLIP-86-38L-24, ILL-358 X ILL-2573-2-2000, 87S-93549XEL-1O3-4, 87s-93549XEL-03-5, Chekol X R-186-1, R-186X FLIP-86-38L, Chekol x R-186-2, EL-142 X R-186-2, EL-142 X R-186-3	Breeding line
ICARDA	15	ILL-590/NEL 590/, FLIP-2006-60L, FLIP-97-68L, FLIP-04-26L, ILL-28501, FLIP-2006-20L, FLIP-87-68L, /ILL 6037 x ILX 87062/ FLIP2005-24L/ ILL-10045, FLIP-97-16L/ILL 8078, ILL-10680, FLIP-2004-37L, FLIP-84-95L /ILL 5722, FLIP-97-61L, L-830, Precoze/ILL 4605/	Breeding line
ICARDA	70	RIL1- RIL70	RIL

Unknown: Originated from Ethiopia but site of collection not mentioned RIL: Recombinant inbred line.

components and reaction to rust disease. The data were recorded in randomly selected plants on plant and plot basis (Table 2).

Data analysis

The data were subjected to statistical analysis using GenStat Release 15.1 statistical software (VSN International Ltd., 2012). The correlation and path coefficient was analyzed based on the row data value for each agro-morphological trait. The phenotypic and genotypic correlation coefficients were calculated for data from RCBD by the following formula as suggested by Miller et al. (1959). Only the phenotypic correlation coefficients were calculated for augmented design using the formula adopted by Singh and Chudhary (1977) on Genstat 15 Release 4.2 software. Path coefficient analysis was carried out to partition the phenotypic and genotypic correlation coefficients into direct and indirect effects of yield attributing traits (independent characters) on grain yield (dependent character) using the general formula suggested by Wright (1921) and worked out by Dewey and Lu (1959). For augmented design, path coefficient analysis was calculated using the formula and syntax developed by Singh and Chudhary (1977) on Genstat 15 Release 4.2 software.

RESULTS AND DISCUSSION

Phenotypic and genotypic correlation

Significant positive phenotypic correlation was observed between number of pods per plant and seed weight per plant (r_p = 0.9), seed yield and above ground biomass (r_p = 0.7), seed weight per plant (r_p = 0.6), number of seed per plant (r_p = 0.5) and number of pods per plant (r_p = 0.5). In addition, numbers of seeds per pod, plant height and 100 seed weight have significant ($P \leq 0.05$) positive association with seed yield at Sirinka (Table 3).

Highly significant strong positive correlations were observed between number of pods per plant and seed weight per plant (r_p = 0.9), seed weight per plant and

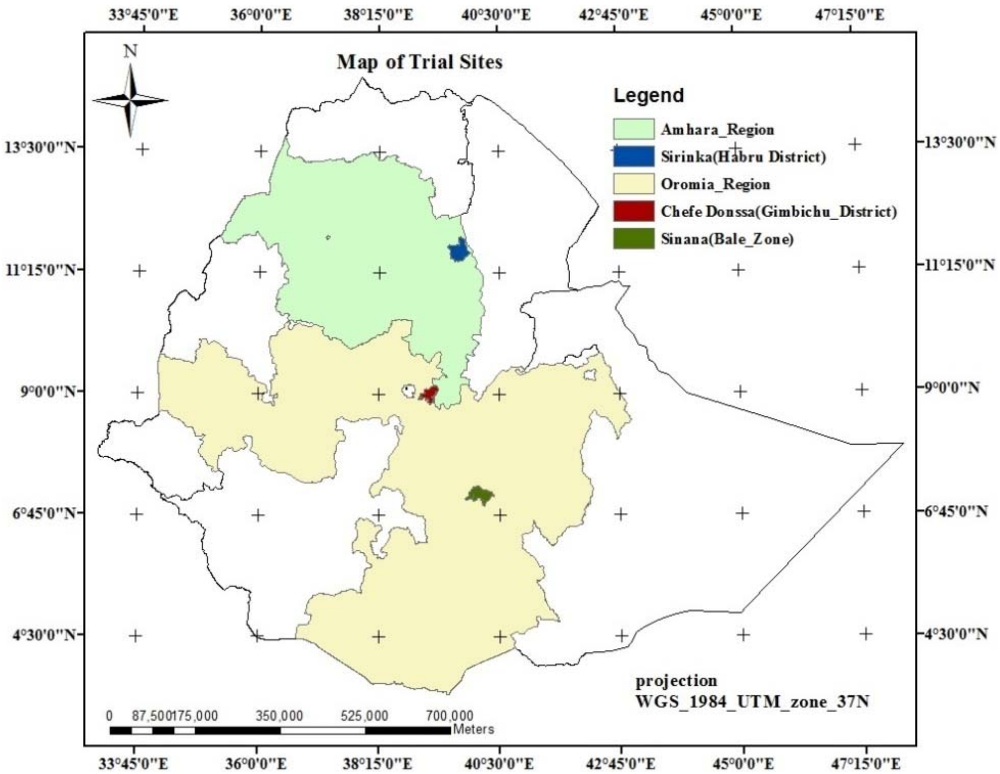

Figure 1. Geographical position of the experimental sites.

Table 2. List of agro-morphological, phonological traits and rust severity score collected for the study.

Traits	Description
Number of pods/plant (NPPP)	Mean of pods from ten randomly selected plants
Number of seeds/ Pod (NS)	Average number of seeds per pods counted from 10 randomly sampled pods of 10 different plants.
Seed weight per plant (SWPP)	The average matured seed weight from 10 randomly selected plants.
Number of seeds per plant (NSPP)	Mean of number of seeds counted from 10 randomly selected plants
100-seed weight (SW)	Weight of 100 seeds taken from the bulk harvest in gram (g)
Plant height (PH)	The height from the ground surface to the top of the main stem at physiological maturity in centimeter (cm)
Days to flowering (DFF)	Days from planting to flowering of 50% plant
Days to maturity (DM)	Days from planting to physiological maturity of 75% plant
Biomass per plant (BI)	Above ground biomass of the mean yield of two harvestable rows in gram
Seed yield per plant (SY)	Mean seed yield in gram of two harvestable rows in gram
Rust disease severity score after flowering (RDSAF)	The RILs and the accession were scored for rust severity quantitative scale developed by Chen (2007) had 1–9 scale, whereby 1 = 0–10% leaf area infected, 3 = 11–30% leaf area infected, 5 = 31–50% leaf area infected, 7 = 51–70% leaf area infected, 9 = more than 70% leaf area infected.

number of seeds per plant (r_p = 0.8), number of pods per plant and number of seeds per plant (r_p = 0.8). Whereas intermediate significant positive correlations were observed between days to 50% flowering and days to 90% maturity (r_p = 0.6), seed weight per plant and above ground biomass (r_p = 0.6), plant height and above ground biomass (r_p = 0.6) and number of seeds per plant and above ground biomass (r_p = 0.5) at Sirinka in 2010/11 (Table 3).

Significant ($P \leq 0.05$) negative phenotypic correlation

Table 3. Genotypic correlation in above diagonal and phenotypic correlation in below diagonal of yield and yield component characters in lentil genotypes at Sirinka in 20110/11.

Trait	DFF	DM	NPPP	NS	SWPP	NSPP	PH	SW	BI	AY
DFF		0.8**	0.1	-0.3**	-0.1	0.3*	0.3*	-0.1	0.5**	0.2
DM	0.6**		-0.1	-0.8**	-0.3**	0.1	-0.1	0.1	0.3**	0.04
NPPP	0.05	-0.2*		0.1	0.8*	0.8**	0.3**	-0.3**	0.4**	0.4**
NS	-0.2**	-0.5**	0.1*		0.4**	0.5**	0.1	-0.07	0.2**	0.3**
SWPP	-0.1	-0.2**	0.9**	0.2**		0.8**	0.2	0.20*	0.6**	0.6**
NSPP	0.06	-0.04	0.8**	0.4**	0.8**		0.3**	-0.3**	0.4**	0.**
PH	0.2*	-0.2*	0.4**	0.001	0.3**	0.3**		-0.14	0.6**	0.3**
SW	-0.06	0.2*	-0.07	-0.03	0.2**	-0.2**	-0.1*		0.2*	0.2*
BI	0.3**	0.2*	0.5**	0.13*	0.6**	0.5**	0.6**	0.2**		0.7**
AY	0.02	-0.07	0.5**	0.2**	0.5**	0.5**	0.3**	0.2**	0.66**	

DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield,
** and * =Significant at 0.01and 0.05 probability levels.

Table 4. Pearson's phenotype correlations of yield and yield component characters in lentil genotypes at Sirinka 2011/12.

Trait	DF	DM	NPPP	NS	NSPP	SW	SWPP	PH	BI	SY
DF	-									
DM	0.70**	-								
NPPP	0.002	-0.16**	-							
NS	0.20**	0.17	0.03	-						
NSPP	0.03	-0.15*	0.62**	0.32**	-					
SW	-0.02	0.22	-0.19**	-0.02	-0.22**	-				
SWPP	0.07	-0.01	0.51	0.19**	0.83**	0.11	-			
PHH	0.20**	-0.06	0.31	0.10	0.47**	-0.11	0.41**	-		
BI	0.26**	0.14*	0.39**	0.19**	0.57**	0.03	0.65**	0.57**	-	
SY	0.05	-0.10	0.43**	0.13*	0.64**	0.04	0.72**	0.41**	0.77**	-

DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield,
** and * =Significant at 0.01and 0.05 probability levels.

coefficients were observed between days to 90% maturity and number of seeds per pods (r_p = -0.5), plant height and number of pods per plant and 100 seed weight and number of seeds per plant (Table 3).

Similarly, significant phenotypic correlation was observed between seed yield and number of pods per plant, number of seeds per pods, number of seeds per plant, seed weight per plant and plant height at Sirinka, Chefe Donsa and Sinana in 2011/12 cropping season (Tables 4, 5 and 6). However, negative significant correlations were observed between seed yield and days to 50% flowering, and rust disease score with seed yield at Chefedonsa and Sinana locations (Tables 5 and 6). Above ground biomass showed significant positive phenotypic correlation with all characters except rust disease severity score (Tables 4, 5 and 6). Significant positive correlations were observed between days to 50% flowering and days to 90% maturity, and between days to 90% maturity and 100 seed weight in all the three environments; significant phenotypic correlations were observed between number of pods per plant and seed weight per plant at Sirinka (r_p = 0.51) and Chefe Donsa (r_p = 0.85), and number of pods per plant and number of seeds per plant at Sirinka (r_p = 0.62), Chefe Donsa (r_p = 0.94) and Sinana (r_p = 0.92). Seed weight per plant and number of seeds per plant (r_p = 0.83) at Sirinka, seed weight per plant with plant height (r_p = 0.41) at Sirinka and number of seeds per plant with plant height (r_p = 0.47) at Sirinka. Highly significant phenotypic correlation was observed between seed weight per plant and above

Table 5. Pearson's phenotype correlations of yield and yield component characters in lentil genotypes at Chefe Donsa 2011/12.

Traits	DF	DM	NPPP	NS	NSPP	SW	SWPP	PH	BI	SY
DF	-									
DM	0.54**	-								
NPPP	-0.15*	-0.19**	-							
NS	-0.26**	-0.38**	0.10	-						
NSPP	-0.21**	-0.26**	0.94**	0.40**	-					
SW	0.15*	0.45**	-0.22**	-0.25**	-0.26**	-				
SWPP	-0.12	-0.06	0.85**	0.18**	0.83**	0.08	-			
PH	0.27**	0.21**	0.02	-0.05	0.01	-0.02	0.01	-		
BI	0.30**	0.39**	0.07	0.05	0.06	0.14*	0.17**	0.44**	-	
SY	-0.15*	-0.18*	0.45**	0.22**	0.47**	-0.09	0.54**	0.25**	0.51**	-

DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield,
** and * =Significant at 0.01and 0.05 probability levels.

Table 6. Pearson's phenotype correlations of yield and yield component characters in lentil genotypes at Sinana in 2011/12.

Trait	DF	DM	NPPP	NS	NSPP	SW	PHH	BI	SY	RDSBF	RDSAF
DF	-										
DM	0.2**	-									
NPPP	-0.14*	0.2**	-								
NS	-0.03	0.07	0.14*	-							
NSPP	-0.10	0.2**	0.9**	0.5**	-						
SW	0.15*	0.3**	0.2**	0.01	0.2**	-					
PH	0.09	-0.01	-0.02	0.11	0.05	0.09	-				
BI	0.02	0.11	0.03	0.06	0.07	0.13*	0.2**	-			
SY	-0.09	0.2**	0.5**	0.03	0.4**	0.5**	0.2**	0.3**	-		
RDSBF	-0.2**	-0.3**	-0.2**	0.01	-0.2**	-0.3**	0.04	0.06	-0.3**	-	
RDSAF	-0.06	-0.4**	-0.3**	0.02	-0.2**	-0.5**	0.00	-0.12*	-0.5**	0.40	-

RDSBF= rust disease severity score before flower, RDSAF= rust disease severity score after flower, DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield, ** and * =Significant at 0.01and 0.05 probability levels.

ground biomass (r_p = 0.65) at Sirinka (Table 4). Negative phenotypic correlations were observed between days to 90% maturity and rust disease score before and after flowering (r_p = 0.3 and 0.4) at Sinana (Table 6). Negative phenotypic correlations were observed between days to 90% maturity and number of pods per plant, number of seed per plant and seed weight per plant at Sirinka and ChefeDonsa (Tables 4 and 5). Hundred seed weight also showed significant negative phenotypic correlation with number of seeds per plant at Sirinka and ChefeDonsa but not at Sinana (Tables 4, 5 and 6).

Seed yield per plant positively and significantly correlated with biomass (r_g = 0.7), seed weight per plant (r_g = 0.6), number of seeds per plant (r_g = 0.5), number of pods per plant (r_g = 0.4) (Table 3). Significant positive genotypic correlation coefficient were also observed among yield component traits including number of pods per plant with seed weight per plant (r_g = 0.8) and number of seeds per plant (r_g = 0.8), seed weight per plant with number of seeds per plant (r_g = 0.8), days to 50% flowering with days to 90% maturity (r_g = 0.8). However, negative and significant genotypic correlation coefficients were observed between days to 90% maturity and number of seeds per pod (r_g = -0.8), number of pods per plant with 100 seed weight (r_g = - 0.3), number of seeds per plant and 100 seed weight (r_g = -0.3), days to 50% flowering and number of seeds per pod (r_g = -0.3).

Estimates of direct and indirect effects of yield component traits on seed yield

In the present study, seed yield (SY) was considered as

Table 7. Phenotypic direct effects on main diagonal (bold) and indirect effects of different agronomic traits on seed yield of lentil genotypes at Sirinka in 2010/11.

Traits	DF	DM	NPPP	NS	SWPP	NSPP	PHH	SW	PSS
DF	**-0.06**	-0.12	0.03	0.03	0.11	-0.04	0.05	0.03	-0.02
DM	0.04	**-0.19**	-0.03	0.03	0.12	-0.01	-0.01	0.11	-0.02
NPPP	0.01	0.02	**0.31**	0.00	0.36	-0.22	0.05	-0.04	0.00
NS	0.01	-0.02	0.00	**0.21**	0.15	-0.13	0.01	-0.01	-0.01
SWPP	0.01	-0.04	0.23	0.07	**0.48**	-0.22	0.04	0.05	-0.003
NSPP	0.01	-0.003	0.25	0.10	0.39	**-0.27**	0.05	-0.03	-0.002
PHH	0.02	0.01	0.10	0.02	0.10	-0.08	**0.17**	-0.03	0.002
SW	0.01	-0.09	-0.05	-0.01	0.10	0.04	-0.02	**0.22**	-0.001
PSS	-0.02	0.06	0.00	-0.03	-0.03	0.01	0.01	-0.01	**0.05**

Contribution of residuals in the variability = 0.57. DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS = number of seeds per pod, SWPP = seed weight per plant, NSPP = number of seeds per plant, PH = plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield, **, * = Significant at 0.01 and 0.05 probability levels.

effect dependent on nine independent variables, which were considered as causes. The independent characters were: days to 50% flowering (DFF), days to 90% maturity (DM), number of pods per plant (NPPP), number of seeds per pods (NS), number of seeds per plant (NSPP), seed weight per plant (SWPP), plant height (PH), 100 seed weight (SW) and rust disease severity score.

The path analysis revealed that seed weight per plant (0.48) followed by number of pods per plant (0.31) and 100 seed weight (0.22) had exerted positive direct effects on seed yield at Sirinka in 2010/11 (Table 7). In addition, numbers of seeds per pod and plant height have positive direct effects on seed yield. However, number of seeds per plant (-0.27) and days to 90% maturity (-0.19) had negative direct effects on seed yield. With the exception of seed weight per plant and number of seeds per plant, the indirect effects of all traits on seed yield via other traits were small and negligible. The contribution of all traits in explaining the variability of seed yield was lower than the residual effect (0.57). More than 50% of the variability of seed yield at Sirinka 2011/12 was accounted for by seed weight per plant and number of pods per plant followed by the interaction of seed weight per plant and number of pods per plant, the rest of the traits had very little effect on the variability of seed yield.

Result of the path analysis are consistent with the phenotypic and genotype correlation coefficients which showed that seed weight per plant and number of pods per plant had highly significant genotypic and phenotypic correlation coefficients with seed yield (Table 3). Number of seeds per plant had significant positive correlation with seed yield and had a substantially high negative direct effect (-0.27). The positive indirect effects of number of seeds per plant via seed weight per plant, number of pods per plant and number of seeds per pod, might counter-balance the final positive correlation with seed yield (Table 7). Path coefficient analysis at Sirinka in 2011/12 cropping season, gave essentially similar pattern of relationship between yield and yield components with that of Sirinka in 2010/11. Seed weight per plant, plant height and numbers of pods per plant had strong positive direct effect on seed yield. These characters had positive indirect influence via seed weight per plant, days to 90% maturity, number of pods per plant, number of seeds per plant and 100 seed weight on seed yield (Table 8).

At Chefe Donsa, seed weight per plant (0.62), plant height (0.32), and number of pods per plant (0.28) had positive direct effect on seed yield. Number of seeds per pod, number of seeds per plant, and 100 seed weight had significant positive indirect effect on seed yield via seed weight per plant and plant height. The strong direct effects of these three characters on seed yield is consistent with the phenotypic correlation coefficient of these traits with seed yield (r_p = 0.54, 0.25 and 0.45, respectively) (Table 5). Number of seeds per plant had negative direct effect on seed yield but it had a significant phenotypic correlation coefficient (r_p= 0.47) with seed yield. This may be due to the indirect positive effect of this character on seed yield via seed weight per plant, number of pods per plant, number of seeds per pod, 100 seed weight and days to 50% flowering and 90% maturity that counter balanced the final correlation in the positive direction (Table 9). Rust disease score, days to 50% flowering and 90% maturity and 100 seed weight in gram had considerable negative direct and indirect effects on seed yield via days to 50% flowering, days to 90% maturity, number of pods per plant, number of seeds per pod, plant height and 100 seed weight (Table 9). The direct and indirect effect of the casual variables considered in this study were higher than the residual effects

Table 8. Phenotypic direct effects on main diagonal (bold) and indirect effects of different agronomic traits on seed yield of lentil genotypes at Sirinka in 2011/12.

Trait	DF	DM	NPPP	NS	SWPP	NSPP	PHH	SW
DF	**-0.04**	-0.023	-0.001	-0.001	0.027	-0.001	0.018	-0.0001
DM	-0.021	**-0.045**	-0.006	-0.001	-0.01	-0.01	-0.004	-0.002
NPPP	0.001	0.005	**0.056**	0.001	0.303	0.027	0.033	0.001
NS	-0.006	-0.008	0.002	**-0.01**	0.116	0.014	0.012	0.0002
SWPP	-0.002	0.0004	0.026	-0.001	**0.641**	0.038	0.044	-0.001
NSPP	0.001	0.005	0.033	-0.002	0.533	**-0.046**	0.051	0.002
PHH	-0.007	0.002	0.017	-0.001	0.256	0.021	**0.11**	0.001
SW	-0.001	-0.01	-0.011	0.001	0.072	-0.01	-0.01	**-0.007**

Contribution of residuals in the variability = 0.4195. DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS = number of seeds per pod, SWPP = seed weight per plant, NSPP = number of seeds per plant, PH = plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield, **, *Significance at 0.01 and 0.05 probability levels.

Table 9. Phenotypic direct effects on main diagonal (bold) and indirect effects of different agronomic traits on seed yield of lentil genotypes at Chefe Donsa in 2011/12.

Trait	DF	DM	NPPP	NS	SWPP	NSPP	PHH	SW	RDSAF
DF	**-0.09**	-0.1	-0.01	-0.02	-0.08	0.04	0.08	-0.02	0.03
DM	-0.05	**-0.19**	-0.02	-0.03	-0.05	0.05	0.06	-0.05	0.06
NPPP	0.02	0.04	**0.28**	0.01	0.52	-0.16	0	0.03	-0.01
NS	0.02	0.08	0.01	**0.07**	0.11	-0.06	-0.01	0.03	-0.03
SWPP	0.01	0.02	0.07	0.01	**0.62**	-0.14	0.006	-0.01	0.01
NSPP	0.02	0.06	0.07	0.03	0.51	**-0.17**	0.002	0.03	-0.02
PHH	-0.02	-0.04	0.001	0.003	0.01	0	**0.32**	0.01	0.01
SW	-0.02	-0.09	-0.02	-0.02	0.03	0.05	-0.01	**-0.11**	0.06
RDS	0.02	0.08	0.01	0.02	-0.04	-0.03	-0.03	0.05	**-0.13**

Contribution of residuals in the variability = 0.4905. DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield, ** and * =Significant at 0.01 and 0.05 probability levels.

(0.49) which explain its effect on seed yield. More than 50% of seed yield response was explained by seed weight per plant followed by plant height at Chefe Donsa in 2011/12.

At Sinana in the 2011/12 cropping season, the highest positive direct effect were shown by number of pods per plant (0.49), followed by 100 seed weight in gram (0.28) (Table 10). Plant height (0.18) showed the third largest positive direct effect on seed yield. In addition to its direct effect, the indirect influence of number of pods per plant via number of seeds per plant was substantially important for final contribution to seed yield (P_r=0.4). However, rust disease severity score (-0.25), number of seeds per plant (-0.171) and days to 50% flowering (-0.12) showed negative direct effects on seed yield.

In general, from path analysis result of the four environments, we can deduce that seed weight per plant, number of pods per plant and plant height had consistently strong direct effects on seed yield. These traits had also average strong phenotypic correlation coefficient values (r_p = 0.64, 0.47 and 0.29, respectively) with seed yield. However, days to 50% flowering, days to 90% maturity, rust disease severity score and number of seeds per plant had negative direct effect on seed yield at the four environments. Phenotypic correlation coefficients also revealed that these traits had negative association with seed yield of lentil except for number of seeds per plant with an average value of r_p = -0.023, -0.26 and -0.055, respectively. Despite, negative direct effect of number of seeds per plant on seed yield, it had an average strong phenotypic correlation coefficient (r_p= 0.54) with seed yield. This may be due to the significant positive indirect effect of this character via number of pods per plant, seed weight per plant, number of seeds per pod, 100 seed weight in gram, days to 50% flowering and 90% maturity, and plant height that substantially step

Table 10. Phenotypic direct effects on main diagonal (bold) and indirect effects of different agronomic traits on seed yield of lentil genotypes at Sinana in 2011/12.

Trait	DF	DM	NPPP	NSPP	PHH	SW	RDSAF
DF	**-0.12**	-0.012	-0.094	0.023	0.014	0.05	0.025
DM	-0.03	**0.042**	0.093	-0.04	0.009	0.09	0.121
NPPP	0.02	-0.008	**0.493**	-0.16	-0.002	0.06	0.07
NSPP	0.02	-0.009	0.451	**-0.17**	0.014	0.06	0.061
PHH	-0.01	-0.002	-0.007	-0.01	**0.18**	0.03	0.011
SW	-0.02	-0.014	0.104	-0.03	0.017	**0.28**	0.125
RDSAF	0.01	0.02	-0.14	0.042	-0.008	-0.14	**-0.25**

Contribution of residuals in the variability = 0.5398. DFF = days to 50% flowering, DM = days to 90% maturity, NPPP = number of pods per plant, NS= number of seeds per pod, SWPP = Seed weight per Plant, NSPP = Number of Seeds per Plant, PH = Plant height in cm, SW = 100-seed weight in gram, BI = above ground biomass, SY = seed yield, ** and * = Significant at 0.01and 0.05 probability levels.

down the final correlation in the positive direction (Tables 8, 9 and 10).

DISCUSSION

Seed yield is a complex quantitative character governed by polygene, and is highly influenced by the environment. To improve yield, study of association of yield and yield components is of paramount importance. To increase yield, the breeder has to give sufficient attention to yield components that are favorably correlated with seed yield. Studies on correlation provide an opportunity for critically assessing the relationship of the component characters with seed yield. At Sirinka in 2010/11 cropping season, the magnitudes of genotypic correlation coefficients between all traits were higher than their phenotype correlation coefficients except for number of pods per plant, signifying that the association among various characters were of genetic causes rather than environmental effects. A similar trends were reported by Singh et al. (1999) and Tyagi and Khan (2011), genotypic correlation were of higher magnitude than their phenotypic counter parts in lentil.

Significant positive correlations were observed between seed yield and biomass, number of pods per plant, seed weight per plant, number of seed per plant and plant height at the four environments (Tables 3, 4 and 5). Other investigators also reported that seed yield was positively correlated with number of pods per plant, number of seeds per pods, seed weight per plant and biological yield in lentil (Dixit and Dubey, 1984; Balayan and Singh, 1986; Esmail et al., 1994; Bhattacharya, 1999; Naji et al., 2003; Singh et al., 2003). In another study, Abo-Shetaia et al. (1997) showed similar report both with highly significant phenotypic and genotypic association between lentil seed yield and number of pods per plant, and number of seeds per plant, the genotype correlation coefficient of seed yield with number of seeds per pod being negative in their study.

Number of pods per plant, number of seed per plant, seed weight per plant and above ground biomass had strong positive correlations among each other. Kumar and Sapra (1984) and Singh et al. (2003) reported that seed weight per plant was directly linked with number of pods per plant. Sinha and Singh (2002), Tigest (2003) and Ketema (2007) reported that number of seeds per plant was strongly and positively associated with number of pods per plant in lentil. This implies that genotype with larger number pods per plant produce higher number of seeds per plant. The relationship between seed yield and number of pods per plant, number of seeds per plant, seed weight per plant and above ground biomass suggested that selection based on these component characters would result in maximum yield in lentil. From this, we can infer that selection for either character increases the other traits and has to be considered as selection index for seed yield of lentil.

In support of our recommendation, Hamdi et al. (1991) and Khattab (1999) observed that pods per plant, seeds per plant and seed weight and biomass yield were the most important characters that contributed to grain yield. In addition to these, number of seeds per pods, plant height and 100 seed weight had significant ($p \leq 0.05$) positive phenotypic association with seed yield in all location except with 100 seed weight at Chefe Donsa. Vir et al. (2001) and Tyagi and Khan (2011) had reported such positive correlation between seed yield with plant height and 100-seed weight in lentil. Sinha and Singh (2002) and Sing et al. (2003) also reported in agreement with our findings that seed yield was significantly correlated with plant height, number of seeds per pods and seed weight. Hundred seed weight has negative phenotypic association with number of seeds per plant, number of pods per plant and number of seeds per pods at all the environments except at Sinana. Such observation was also made by others (Tyagi and Sharma, 1985; Sharma et al., 1993; Tyagi and Khan, 2011). However, as opposed to our finding, Sinha and Singh (2002) reported that 100 seed weight was strongly and positively associated with number of seeds per plant and number of pods per plant in lentil.

Days to 50% flowering and 90% maturity and rust disease severity score showed significant negative phenotypic correlation with seed yield at all locations, except at Sinana where positive association was observed between days to 90% maturity and seed yield. At Sirinka and Chefe Donsa where terminal drought is a common phenomena, earliness is favorable characters for better performance in such location however, at Sinana, incidence of terminal drought is not common, late maturing genotype may better perform for seed yield. Others also reported that seed yield had negative correlation with time to flowering, days to 90% maturity and seed weight in moisture deficit environments (Kumar and Sapra, 1984; Mia et al., 1986; Esmail et al., 1994; Tyagi and Khan, 2011). In another high potential environment, Manara and Manara (1988) found positive correlation of seed yield with days to 90% maturity, suggesting that seed yield could be increased by selecting late maturing genotypes with greater number of pods per plant whenever there is no terminal drought. These findings are also strengthened by Tyagi and Sharma (1985) and Dutta et al. (1993) who reported that above ground biomass and seed yield were negatively correlated with earliness.

Two characters may show correlation just because they are correlated with a common third one. In such cases, it becomes necessary to study a method that takes into account the causal relationship between the variables in addition to the degree of such relationship. The phenotypic and genotypic correlations were further subjected to path coefficient analysis, which involves partitioning of the correlation coefficients into direct and indirect effects via alternative characters (Falconer and Mackay, 1996). Since correlations provide only limited information ignoring complex interrelationships among traits, further partitioning of genetic correlations into direct and indirect effects using the path-coefficient analysis provides better picture of the relationship of predictor variables with the response variable (Rao et al., 1997). Seed yield being a complex outcome contributed by different component traits, it was considered to be the resultant variable, while days to 50% flowering, days to maturity, number of pods per plant, number of seeds per pods, pod weight per plant, number of seeds per plant, seed weight per plant, plant height and 100 seed weight were causal variables.

Path coefficient analysis for seed yield over the two seasons at Sirinka revealed that seed weight per plant, number of pods per plant, and plant height had consistently strong direct effects on seed yield. Therefore, for selecting high yielding genotypes, the breeder should give more emphasis to plants with higher seed weight per plant, and more number of pods per plant. Phenotypic and genotype correlation coefficients of seed weight per plant and number of pods per plant were also high with seed yield at Sirinka 2010/11. Dixit and Dubey (1984), Balayan and Singh (1986), Tikka et al. (1997), Hamdi et al. (2003), Verma et al. (2004) and Tyagi and Khan (2011) also reported that number of pods per plant, plant height and seed weight per plant were the highest direct contributors towards better seed yield in their respective studies. In addition, Jain et al. (1991) and Begum and Begum (1996) reported that a combination of two or three variables, viz. plant height, number of branches per plant and pods per plant were found to be better than other combination of characters for the improvement of seed yield in lentil.

However, days to 50% flowering and days to 90% maturity, which had negative phenotypic correlation coefficients with seed yield, had also substantial negative direct effects on seed yield. In spite of the negative direct effect of number of seeds per plant it had high genotypic and phenotype correlation coefficient with seed yield, and this association was due to positive indirect effect of this character via seed weight per plant, number of pods per plant, days to 50% flowering and 90% maturity, plant height and 100 seed weight that step down the final association in the positive direction (Table 7). Verma et al. (2004) also reported that number of seeds per plant has significant correlation with seed yield but it had a negative direct effect on seed yield under rain fed condition. The path analysis residual values, at Sirinka in 2010/11 was high indicating that some other factors, which have not been considered need to be included in the analysis to fully account for the variation in seed yield (Annex 1). The contribution of all traits in the variability of seed yield was higher than the residual effects (0.42) in 2011/1 (Table 8). More than 50% of seed yield variability was contributed by the effect of seed weight per plant (Annex 1, 2 and 3).

At Chefe Donsa and Sinana 2012, almost similar results were obtained in terms of both magnitude and direction. The highest positive direct effects were shown by number of pods per plant (0.49), followed by 100 seed weight (0.281) (Table 9). Plant height (0.18) showed the third largest positive direct effect on seed yield. These results were consistent with results from other studies (Khattab, 1999; Bhattacharya, 1999; Singh et al., 2003; Çokkizgin, 2007).

Days to 90% maturity, rust disease score and days to 50% flowering had negative direct effects on seed yield at the four environments, except positive direct effects of days to 90% maturity at Sirinka in 2010/11. The same traits had also negative phenotypic correlation coefficients with seed yield of lentil. This was obvious for a dry land site like Sirinka where terminal drought is a common phenomena, genotypes which had long flowering period and late maturing genotypes with their physiological seed sinking process would be disturbed and fail to bring better seed yields. Whereas genotypes possessing early flowering and maturity attributes do well in these kinds of environments by escaping the terminal drought.

However, at Sinana where we do not have the incidence of terminal drought, late maturing genotype perform better in seed yield. Similar observation were reported by Kumar and Sapra (1984) and Tyagi and Khan (2011). However, Dutta et al. (1993) and Kumar et al. (2004) observed that days to 50% flowering and 90% maturity had the highest direct effects on seed yield, and could justify that increased seed yield were due to a long crop growing season that may affect an increase sink sites, not to impaired grain development during high temperature in the latter part of the season.

Conclusion

This study clearly showed that for selecting high yielding genotypes, the breeder should give more emphasis to plants with higher seed weight per plant, more number of pods per plant and higher number of seeds per plant, and plants with higher above ground biomass. The path coefficients were consistent with phenotypic and genotype correlation coefficients in that seed weight per plant and number of pods per plant showed not only significant positive genotypic and phenotypic correlation coefficients with seed yield but also higher direct effects. On the other hand, days to 50% flowering and 90% maturity and rust disease severity score showed both negative phenotypic correlation coefficient and negative direct effects on seed yield except for the positive direct effect of days to 90% maturity with seed yield at Sinana. From phenotypic, genotypic and path coefficients it could be conclude that traits like seed weight per plant, number of pods per plant, above ground biomass, number of seeds per plant and plant height had a considerable role as selection criteria to improve lentil seed yield.

Conflict of Interests

The author(s) have declared that there is no conflict of interests.

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Annex 1. Contribution of direct and indirect effects of agro-morphological traits on seed yield variability of lentil at Sirinka 2011 cropping season.

Trait	DFF	DM	NP	NSS	SWPP	TNSPP	PH	SW
DFF	0.003							
DM	-0.014	0.035						
NP	0.003	0.011	0.095					
NSS	0.004	-0.009	0	0.046				
SWPP	0.012	-0.043	0.221	0.062	0.233			
TNSPP	-0.005	0.002	-0.135	-0.054	-0.214	0.074		
PH	0.005	0.004	0.032	0.006	0.035	-0.028	0.028	
SW	0.003	-0.039	-0.024	-0.005	0.045	0.017	-0.01	0.048

Contribution of residuals in the variability = 0.5713.

Annex 2. Contribution of direct and indirect effects of agro-morphological traits on seed yield variability of lentil at Sirinka 2012 cropping season.

Trait	DFF	DM	NP	SWPP	TNSPP	PH	SW
DFF	0.00163						
DM	0.00188	0.00206					
NP	0.00011	0.00055	0.00309				
SWPP	-0.00221	0.00054	0.03364	0.41112			
TNSPP	0.00008	0.00049	0.00304	0.04878	0.00209		
PH	-0.00144	0.00036	0.00365	0.0565	0.00463	0.01215	
SW	0.00001	0.00014	0.00015	-0.00099	0.00014	0.00017	0.00005

Contribution of residuals in the variability = 0.4195.

Annex 3. Contribution of direct and indirect effects of agro-morphological traits on seed yield variability of lentil at Chefe Donsa 2012 cropping season.

Trait	DFF	DM	NP	NS	SWPP	TNSPP	PH	SW	RDSAF
DFF	0.009								
DM	0.019	0.037							
NP	0.002	0.006	0.006						
NS	0.003	0.011	0.001	0.005					
SWPP	0.014	0.019	0.081	0.015	0.385				
TNSPP	-0.007	-0.018	-0.024	-0.009	-0.169	0.027			
PH	-0.015	-0.024	0.001	-0.001	0.004	-0.001	0.105		
SW	0.003	0.020	0.004	0.004	-0.006	-0.010	0.002	0.013	
RDSAF	-0.006	-0.023	-0.002	-0.004	0.012	0.007	0.008	-0.013	0.018

Contribution of residuals in the variability = 0.4905.

Annex 4. Contribution of direct and indirect effects of agro-morphological traits on seed yield variability of lentil at Sinana 2012 cropping season.

Trait	DFF	DM	NP	NSPP	PH	SW	RSBF	RSAF
DFF	0.015							
DM	0.003	0.002						
NP	0.023	-0.008	0.243					
NSPP	-0.006	0.003	-0.154	0.029				
PH	-0.003	-0.001	-0.002	-0.005	0.032			

Annex 4. Contd.

SW	-0.011	-0.008	0.059	-0.019	0.009	0.079		
RSBF	-0.001	-0.001	0.005	-0.002	0.000	0.004	0.001	
RSAF	-0.006	-0.010	0.069	-0.021	0.004	0.070	0.005	0.061

Contribution of residuals in the variability = 0.4905.