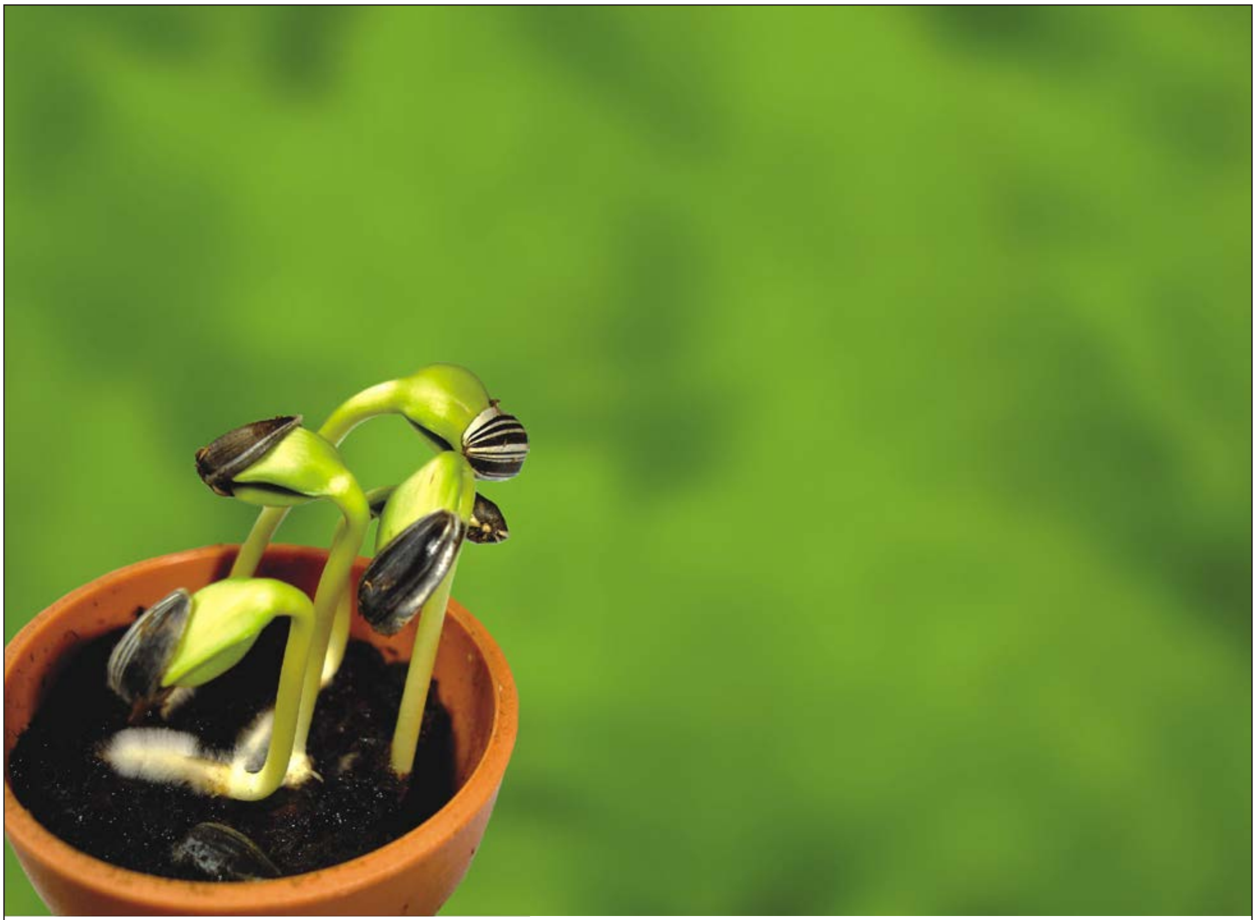

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Path Analysis of the Relationships Between Single Plant Seed Yield and Some Morphological Traits in Sesame (Genera *Sesamum* and *Ceratotheca*)

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ABSTRACT

This study was explored in order to determine the effects of various agronomic traits on single plant seed yield in sesame using correlation and path coefficient analysis. Nine diverse accessions of sesame were grown in a two-year potted field experiment and were completely randomized with twelve replicates. Simple correlation and path analysis were carried out in order to determine the relationships between agronomic characters and estimate their direct and indirect influences on the single plant seed yield. Positive and statistically significant ($p<0.01$) relationships were established between single plant seed yield (g) and leaf nodes per plant, number of pods per plant, number of pods per main stem, breadth of pod, number of seeds per pod, 1000-seed weight and number of seeds per plant. Path analysis revealed that the number of seeds per plant and 1000-seed weight had the highest direct influence (i.e., 1.325 and 0.578, respectively) on single plant seed yield while the number of pods per plant had the highest indirect effect (1.175) through the number of seeds per plant. These results indicate that number of seeds per plant, 1000-seed weight and number of pods per plant can be good selection criteria for single plant seed yield in sesame.

Key words: Correlation, direct effect, path coefficient, seed yield, sesame

INTRODUCTION

Sesame plant is an important seed crop whose oil is commercially and nutritionally desirable because of its high stability and quality compared to other vegetable oils. It is one of the world's most important and oldest oilseed crops known to man (Abou-Gharbia *et al*., 2000). Its meal is notable for high protein content which is rich in methionine and tryptophan, amino acids that are rarely found in other sources of vegetable protein, such as soya. Thus, sesame meal or flour is added to recipes to give a better nutritional balance to health food products (Anonymous, 2002). Compared to other oilseeds, sesame production is insufficient and its seed yield is comparatively low necessitating breeding for improvement (Furat and Uzun, 2010).

The determination of seed and oil yield components and suitable character combinations that maximise yield are important in formulating an effective breeding programme. Moreover, an analysis of association between various plant characters helps in identifying the most important ones. This may subsequently assist the researcher to identify and select suitable donors for a potential and successful breeding programme (Kumaresan and Nadarajan, 2002). Correlation study provides reliable information on the nature, extent and direction of selection as it measures the magnitude of relationship between various plant characters and determines the component character on which selection can be based (Iqbal *et al.*, 2006). However, this may not give satisfactory results because its analytical resolution is limited to the identification of mutual associations among parameters.

In crop breeding, path analysis has been widely used to identify traits that have a significant effect on yield for potential use in selection (Vidya and Sunny, 2002; Surek and Beser, 2003; Mohammadi *et al.*, 2003; Singh *et al.*, 2004; Mahasi *et al.*, 2006; Sumathi *et al.*, 2007; Biabani and Pakniyat, 2008). This technique is useful in determining the direct influence of one variable on another and also separates the correlation coefficient into direct effect (path coefficient) and indirect effects (effects exerted through other independent variables) (De Rodriguez *et al.*, 2001; Yucel, 2004).

The correlation between yield components and the partitioning of the correlation coefficient into its components of direct and indirect effects have been extensively studied for sesame. For instance in sesame, Muhamman *et al.* (2010) reported positive correlations for seed yield per plant with number of branches per plant and plant height. Positive and significant associations had been established between morphological characters like plant height, number of branches per plant, number of capsules, capsule length and number of seeds per capsule with seed yield in the mutated population of three genotypes (Tamina and Tapash, 2011). According to Solanki and Gupta (2000), seed yield per plant showed significantly positive correlations with characters such as 1000-seed weight, capsule-bearing plant height, number of capsules per plant and plant height. Sarwar *et al.* (2005) however, observed highly significant and positive phenotypic correlations between the number of branches and capsules per plant with seed yield.

The objectives of this study were to evaluate associations between yield components and related traits with grain yield and to determine the direct and indirect effects of these traits on single plant seed yield in diverse accessions of sesame.

MATERIALS AND METHODS

Nine morphologically distinct sesame accessions used in this research work were selected from thirty-three collections obtained from various locations in Nigeria in 2003 (Table 1). They were grown on a demonstration farm at the back of the Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria during the growing seasons of

Table 1: Name of sesame accessions studied, place of collection and germplasm type

Code/Accession No/Local name	Collection locality	Botanical name	Germplasm type
AYK (Ayigba)	Kabah	*Sesamum radiatum*	Black seeds
IBS (Eku Ile)	Bode saadu	*Ceratotheca sesamoides*	Black seeds
ALO (Eku gogoro)	Ogbomoso	*Sesamum radiatum*	Black seeds
EVA	NCRI Badeggi/FAO, Italy	*Sesamum indicum*	White seeds
S530	NCRI Badeggi	*Sesamum indicum*	Dirty white seeds
65-8B	IAR&T Ibadan	*Sesamum indicum*	Mixture of seeds
C-K2	NCRI Badeggi	*Sesamum indicum*	Brown seeds
PACH	NCRI Badeggi/FAO, Italy	*Sesamum indicum*	White seeds
69B-882	NCRI Badeggi	*Sesamum indicum*	Mixture of seeds

2005 and 2006. The experimental site is located on latitude 80°N and longitude 4°E and it is characterized by both wet and dry seasons with mean monthly temperature of around 28°C.

Seeds of each accession were first raised in a nursery and then transplanted after two weeks (two plant-stands each) into 50 cm diameter black polythene bags filled with homogenized, agriculturally rich topsoil. The polythene bags were replicated twelve times and were arranged using a complete randomised design, while within rows of 0.5 m apart was adopted. Foliar spraying against leaf eating insect larvae, using a broad spectrum insecticide (i.e., Karate 2.5°C at the rate of 0.1 mL of the product per litre of water), was carried out three weeks after planting and every fortnight thereafter.

The following characters were observed and measured at physiological maturity (i.e., when the lower pods and leaves started to turn yellow) on eight randomly tagged plants; plant height at first fruit(s) maturity, number of leaf nodes per plant, number of primary branches, lower leaf area, number of days to maturity, length of fruiting nodes and number of pods per main stem. The number of pods per plant were counted before harvesting while the length and breadth of the pods, the number of seeds per pod, the 1000-seed weight, the number of seeds per plant, the single plant seed yield (g), the seed oil content (%) and the seed protein content (%) were determined at or after harvesting. The seed oil and protein contents were determined as described by Azeez and Morakinyo (2011) and AOCS method 5-38 (AOCS, 1989), respectively. Crude protein was calculated using a nitrogen conversion factor of 6.25.

Statistical analysis: Simple phenotypic correlation coefficients between all observed components were first calculated by the statistical programme SPSS (version 10) to study the interrelationships between them. The correlation coefficients were separated into direct and indirect effects, through path coefficient analysis of Dewey and Lu (1959) to estimate the actual contribution of each attribute and its influence through other characters. Here, single plant seed yield (g) was used as the dependent variable while the other characters were considered as independent variables. The significant levels of the statistical analysis were described at the probability of 0.05 and 0.01.

RESULTS

Interrelationships between characters for the nine populations of sesame accessions (Table 2) showed that plant height at first fruit(s) maturity had significant positive correlations ($p = 0.05$, $p = 0.01$) with the number of primary branches ($r = 0.24$), the number of pods per main stem ($r = 0.46$), the length of the pod ($r = 0.35$), the length of the fruiting nodes ($r = 0.79$) and the seed protein content ($r = 0.24$). However, Plant height at first fruit(s) maturity showed a significant negative correlation with the seed oil content ($r = -0.50$). Significant positive correlations were observed between leaf nodes per plant and number of primary branches ($r = 0.70$), number of pods per plant ($r = 0.58$), number of days to maturity ($r = 0.51$), single plant seed yield ($r = 0.27$) and number of seeds per plant ($r = 0.53$), while significant negative correlations were shown by leaf nodes per plant with number of pods per main stem ($r = -0.28$), length of the pod ($r = -0.17$) and length of the fruiting nodes ($r = -0.30$).

Number of primary branches had significant positive correlations with number of pods per plant ($r = 0.45$), number of days to maturity ($r = 0.51$), number of seeds per plant ($r = 0.38$) and seed oil content ($r = 0.19$) but significant negative ones with lower leaf area ($r = -0.36$), length of the pods ($r = -0.28$), breadth of pod ($r = -0.31$) and 1000-seed weight ($r = -0.33$). Number of pods per plant had significant positive correlations with number of pods per main stem ($r = 0.19$), number of days

Table 2: Correlation coefficients of vegetative and yield traits of nine accessions of sesame in the early rains seasons of 2005 and 2006

Traits	PHM	LNP	NPB	NPP	NPS	LLA	LOP	BOP	SPP	NDM	TSW	SWP	NSP	LFN	POC
LNP	0.11	1.00													
NPB	0.24**	0.70**	1.00												
NPP	0.10	0.58**	0.45**	1.00											
NPS	0.46**	-0.28**	-0.13	0.19*	1.00										
LLA	0.06	-0.16	-0.36**	0.01	0.12	1.00									
LOP	0.35**	-0.17*	-0.28**	-0.32**	0.11	0.23**	1.00								
BOP	-0.12	0.10	-0.31**	-0.01	0.05	0.41**	0.37**	1.00							
SPP	0.08	-0.08	-0.16	-0.14	0.18*	0.19*	0.54**	0.44**	1.00						
NDM	0.16	0.57**	0.51**	0.43**	-0.03	-0.01	-0.20*	-0.03	-0.26**	1.00					
TSW	-0.02	-0.12	-0.33**	-0.19*	0.05	0.16	0.39**	0.47**	0.36**	-0.15	1.00				
SWP	0.07	0.27**	0.05	0.46**	0.27**	0.17*	0.16	0.44**	0.48**	0.11	0.58**	1.00			
NSP	0.16	0.53**	0.38**	0.89**	0.31**	0.09	-0.10	0.18*	0.27**	0.32**	-0.04	0.69**	1.00		
LFN	0.79**	-0.30**	-0.05	-0.09	0.62**	0.07	0.47**	-0.03	0.30**	-0.19*	0.11	0.10	0.06	1.00	
POC	-0.50**	0.12	0.19*	0.26**	-0.38**	-0.28**	-0.55**	-0.36**	-0.47**	0.01	-0.29**	-0.21**	0.02	-0.50**	1.00
PPC	0.24**	0.09	0.08	0.05	0.21*	-0.14	0.01	0.07	0.01	0.20*	0.04	0.14	0.05	0.14	-0.49**

** Correlation is significant at $p<0.01$. * Correlation is significant at $p<0.05$; PHM: Plant height at maturity; LNP: Leaf nodes per plant; NPB: No. of primary branches; LLA: Lower leaf area; NDM: No. of days to maturity; LFN: Length of the fruiting nodes; NPS: No. of pods per main stem; NPP: No of pods per plant; LOP: Length of pods; BOP: Breadth of pods; SPP: No. of seeds per pod; TSW: 1000-seed weight; NSP: No. of seeds per plant; SWP: Single plant seed yield (g), POC: Seed oil content and PPC: Seed protein content.

to maturity (r = 0.43), single plant seed yield (r = 0.46), number of seeds per plant (r = 0.89) and seed oil content (r = 0.26), while the correlations of number of pods per plant with length of the pods (r = -0.32) and 1000-seed weight (r = -0.19) were negative and significant. Correlations between number of pods per main stem and the number of seeds per pod (r = 0.18), single plant seed yield (r = 0.27), number of seeds per plant (r = 0.31), length of the fruiting nodes (r = 0.62) and seed protein content (r = 0.21) were positive and significant, while a significant negative correlation was observed between number of pods per main stem and seed oil content (r = -0.38).

Lower leaf area showed significant positive correlations with length of the pods (r = 0.23), breadth of the pods (r = 0.41), number of seeds per pod (r = 0.19) and single plant seed yield (r = 0.17) while its correlation with seed oil content (r = -0.28) was negative and significant. Significant positive correlations were observed between length of the pods and breadth of the pods (r = 0.37), number of seeds per pod (r = 0.54), 1000-seed weight (r = 0.39) and length of the fruiting nodes (r = 0.47) while significant negative correlations were shown by length of the pods with number of days to maturity (r = -0.20) and seed oil content (r = -0.55). Breadth of the pods had significant positive correlations with number of seeds per pod (r = 0.44), 1000-seed weight (r = 0.47), single plant seed yield (r = 0.44) and number of seeds per plant (r = 0.18) but its correlation with seed oil content was negative and significant (r = -0.36).

Correlations between number of seeds per pod and 1000-seed weight (r = 0.36), single plant seed yield (r = 0.48), number of seeds per plant (r = 0.27) and length of the fruiting nodes (r = 0.30) were significantly positive while number of seeds per pod showed significant negative correlations with number of days to maturity (r = -0.26) and seed oil content (r = -0.47). Number of days to maturity had significant positive correlations with number of seeds per plant (r = 0.32) and seed protein content (r = 0.20). However, significant negative correlations were shown by number of days to maturity with length of the fruiting nodes (r = -0.19). The 1000-seed weight had a

Table 3: Path analysis of direct and indirect effects of fifteen traits on single plant seed yield in pooled data

Traits	PHM	LNP	NPB	LLA	NDM	LFN	NPS	NPP	LOP	BOP	SPP	TSW	NSP	POC	PPC	TE
PHM	0.0263	-0.0077	0.0097	0.0018	-0.0027	-0.0706	0.0036	-0.0661	-0.0070	-0.0012	-0.0081	-0.0133	0.2107	-0.0424	0.0341	0.0670
LNP	0.0030	-0.0685	0.0280	-0.0050	-0.0094	0.0265	-0.0022	-0.3730	0.0034	0.0009	0.0089	-0.0664	0.7048	0.0100	0.0120	0.2730
NPB	0.0064	-0.0479	0.0400	-0.0115	-0.0084	0.0047	-0.0010	-0.2863	0.0056	-0.0030	0.0172	-0.1883	0.4995	0.0158	0.0113	0.0540
LLA	0.0015	0.0106	-0.0143	0.0324	0.0002	-0.0063	0.0008	-0.0051	-0.0046	0.0040	-0.0200	0.0941	0.1166	-0.0239	-0.0201	0.1660
NDM	0.0043	-0.0393	0.0205	-0.0004	-0.0164	0.0172	-0.0002	-0.2748	0.0041	-0.0003	0.0276	-0.0866	0.4240	0.0010	0.0284	0.1090
LFN	0.0208	0.0203	-0.0021	0.0023	0.0032	-0.0893	0.0048	0.0591	-0.0094	-0.0003	-0.0323	0.0641	0.0768	-0.0420	0.0200	0.0960
NPS	0.0120	0.0191	-0.0052	0.0034	0.0005	-0.0551	0.0078	-0.1226	-0.0023	0.0005	-0.0194	0.0283	0.4054	-0.0324	0.0300	0.2700
NPP	0.0027	-0.0398	0.0179	0.0003	-0.0070	0.0082	0.0015	-0.6420	0.0065	-0.0001	0.0149	-0.1086	1.1752	0.0223	0.0070	0.4590
LOP	0.0091	0.0115	-0.0111	0.0073	0.0033	-0.0415	0.0009	0.2074	-0.0202	0.0036	-0.0583	0.2270	-0.1365	-0.0469	0.0004	0.1560
BOP	-0.0031	-0.0065	-0.0123	0.0133	0.0005	0.0027	0.0004	0.0090	-0.0075	0.0097	-0.0480	0.2686	0.2319	-0.0308	0.0103	0.4380
SPP	0.0020	0.0056	-0.0064	0.0060	0.0042	-0.0267	0.0014	0.0886	-0.0109	0.0043	-0.1081	0.2062	0.3524	-0.0402	0.0006	0.4790
TSW	-0.0006	0.0079	-0.0131	0.0053	0.0025	-0.0099	0.0004	0.1207	-0.0080	0.0045	-0.0386	0.5776	-0.0543	-0.0247	0.0053	0.5750
NSP	0.0042	-0.0364	0.0151	0.0028	-0.0053	-0.0052	0.0024	-0.5694	0.0021	0.0017	-0.0288	-0.0237	1.3249	0.0020	0.0066	0.6930
POC	-0.0132	-0.0081	0.0074	-0.0091	-0.0002	0.0442	-0.0030	-0.1688	0.0112	-0.0035	0.0511	-0.1681	0.0305	0.0849	-0.0694	-0.2140
PPC	0.0064	-0.005	0.0032	-0.0046	-0.0033	-0.0127	0.0017	-0.0321	-0.0001	0.0007	-0.0004	0.0219	0.0623	-0.0419	0.1407	0.1360

PHM: Plant height at maturity; LNP: Leaf nodes per plant; NPB: No. of primary branches; LLA: Lower leaf area; NDM: Number of days to maturity; LFN: Length of the fruiting nodes; NPS: Number of pods per main stem; NPP: No. of pods per plant; LOP: Length of pods; BOP: Breadth of pods; SPP: No. of seeds per pod; TSW: 1000-seed weight; NSP: No. of seeds per plant; POC: Percentage oil content; PPC: Percentage protein content; TE (D+ID), Total Effect (Direct +Indirect) significant positive correlation with single plant seed yield (r = 0.58) and a significant negative correlation with seed oil content (r = -0.29). Single plant seed yield showed positive and significant correlation with number of seeds per plant (r = 0.69) but negative and significant correlation with seed oil content (r = -0.21). Correlations between seed oil content and length of the fruiting nodes (r = -0.50) and seed protein content (r = -0.49) were also negative and significant.

A detailed study of the relationships obtained by path analysis (Table 3) showed different results from those of the simple analysis of correlation (Table 2). Path coefficient analysis across the two years of evaluation (2005-2006) shows that number of seeds per plant had the greatest direct (1.325) and total (0.693) effects on single plant seed yield in sesame. However, the indirect effects of number of seeds per plant through all other traits were generally poor. So also, 1000-seed weight had large total and direct effects of 0.575 and 0.578, respectively on single plant seed yield but its indirect effect through number of pods per plant was small (0.121). Number of seeds per pod had a total effect on single plant seed yield that was quite large (0.479). Its direct effect was however very small and negative (-0.108), while its indirect effects through number of seeds per plant and 1000-seed weight were small but positive (0.352 and 0.206).

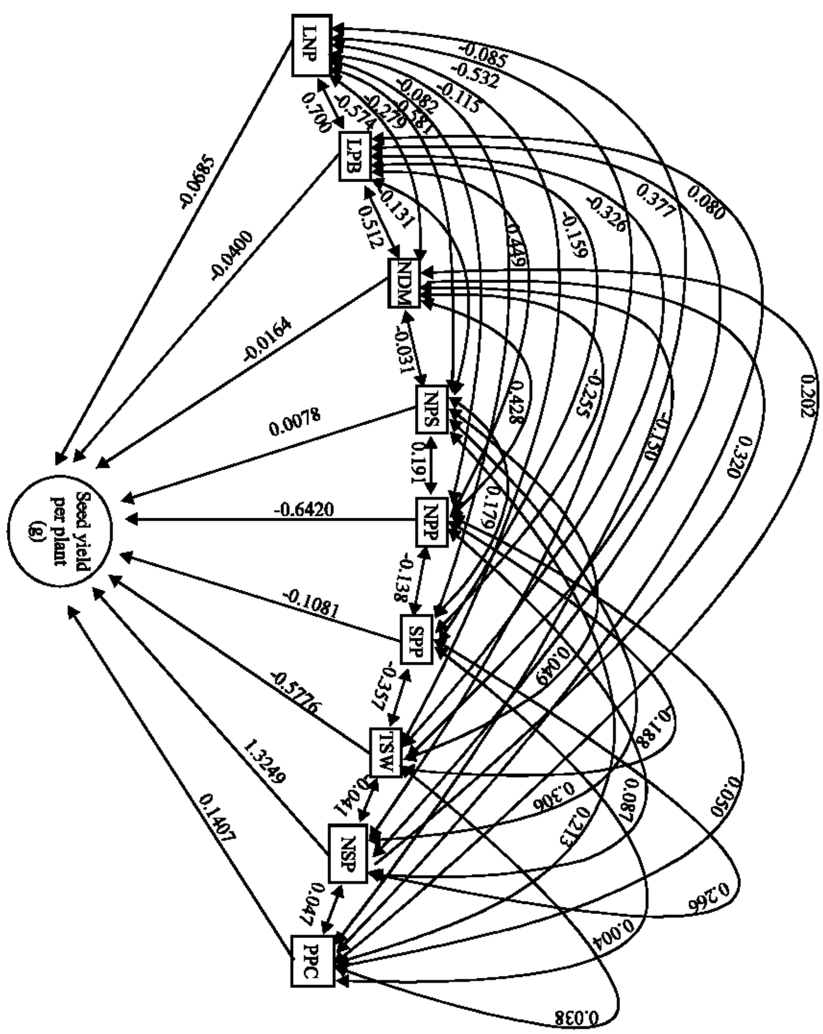

Fig. 1: Path coefficient diagram of nine selected components of yield in sesame

Number of pods per plant also had a total effect on single plant seed yield that was quite large (0.459). However, its direct effect was large and negative (-0.642), while its indirect effect through number of seeds per plant was very high (1.175). Although number of pods per main stem had a negligible positive, direct effect (0.008) and a total effect of 0.270 on single plant seed yield, its indirect effect through number of seeds per plant was quite large (0.405). Leaf nodes per plant also had a negligible negative direct effect (-0.069) and a small, positive total effect (0.273) on single plant seed yield. Its indirect effect on number of seeds per plant however, was large and positive (0.705) (Table 3). Other characters, such as seed protein content, length of the pod, length of the fruiting nodes, number of days to maturity, lower leaf area, number of primary branches and plant height at maturity, had either small or negligible direct or total direct effects on single plant seed yield and were therefore not used in the path diagram (Fig. 1).

DISCUSSION

The results of character associations in this study suggest that any increase in number of seeds per plant, the 1000-seed weight (g), the number of seeds per pod, the number of pods per plant, the number of pods per main stem, pod breadth, leaf nodes per plant and lower leaf area will lead to an improvement in single plant seed yield. Yol *et al.* (2010) obtained positive and significant correlations between seed yield and the number of capsules per plant and number of seeds per pod, which are similar to the present findings. In the study of Sarwar *et al.* (2007), Arshad *et al.* (2003) and Atta *et al.* (2008), significant positive correlations were observed for seed yield (g) with the number of capsules per plant.

The significant positive associations were observed between the height of the plant at maturity and leaf nodes per plant, the number of primary branches, the number of pods per main stem, length of pod, length of fruiting nodes and the number of days to maturity. These are indicative of the strong relationship between the plant growth phase at which pods are initiated and the final height at which the entire crop life is completed. This is in agreement with the findings of Akinyele and Osekita (2006) for okra. Mahajan *et al.* (2007) reported positive and significant correlation between plant height and the number of capsules per plant, while Yucel *et al.* (2006) obtained high positive correlation between plant height and full pod number and 1000-seed weight. However, the correlation between plant height and the number of capsules per plant and seed yield in this study was positive but not significant. This is consistent with the finding of Bidgoli *et al.* (2006) in safflower for seed yield and plant height.

The 1000-seed weight (g) showed positive and significant correlations with pod length, pod breadth and the number of seeds per pod which suggests that improvements in these yield components will bring about increase in seed size and number. The seed oil content was significantly and negatively correlated with plant height, number of pods per main stem, lower leaf area, length of pods, breadth of pods, number of seeds per pod, 1000-seed weight, seed yield and protein content. Cama *et al.* (2005) and Arslan (2007) in safflower found similar results for seed oil content and plant height, while Pahlavani (2005) for seed yield and seed oil content. Also, Solanki and Gupta (2000) reported similar result in sesame for seed oil content and protein content. However, a contrasting relationship between oil content and seed yield was observed by Basalma (2008) in winter rapeseed.

The major goal of sesame breeders is to achieve an increase in seed yield. Yield and its components are multigenic traits which are strongly under the influence of environment and other factors both known and yet to be identified. Therefore, the present study suggests that characters, such as number of seeds per plant, number of pods per plant and 1000-seed weight, may play significant roles in selection for yield improvement.

In the path analysis, the importance of the components of yield was strongly emphasized. The number of seeds per plant had the highest positive direct effect on single plant seed yield, followed by the 1000-seed weight while number of pods per plant had large negative direct effect but highest indirect effect through number of seeds per plant on single plant seed yield. This is slightly different from the result obtained by correlation analysis where number of seeds per plant, number of pods per plant and 1000-seed weight showed highly significant and positive correlations with seed yield.

According to Okuyama *et al.* (2004), the apparent difference between these two concepts is due to the analytical approach, in the sense that while correlation simply identifies the mutual associations between the parameters, path analysis allows determination of the relative magnitudes of each effect. It was further reported that when the objective is to establish relationships between the variables that affect grain yields, path coefficient analysis is a more efficient method than the correlation analysis. It is common to find the number of pods providing reliable criteria for selection in pod or capsule bearing crops (Twari *et al.*, 2001; Mahanta *et al.*, 2001; Singh *et al.*, 2003; Singh and Mishra, 2002; Sengupta and Datta, 2004; Arya *et al.*, 2004; Singh and Singh, 2005, 2006; Avci and Ceyhan, 2006; Singh *et al.*, 2011).

Yingzhong and Yishou (2002) found that the number of capsule per plant was the most important contributor to seed yield per plant. A similar study by Shim *et al.* (2001) indicated that culm length and number of capsules per plant had the highest direct effects on grain yield in sesame. Yucel *et al.* (2006) reported that seed number per plant and full pod number exerted the highest direct influence on seed yield per plant in chickpea. According to Chowdhury *et al.* (2010), the total capsules per plant had substantial positive and direct contribution to oil yield. In this investigation, highly significant and positive correlation coefficients as well as high direct effects of the number of seeds per plant and 1000-seed weight on single plant seed yield have indicated that these two components in co-operation are simultaneously the most reliable components for selecting high-yielding sesame accessions.

CONCLUSION

This study has established that characters such as the number of seeds per plant, the 1000-seed weight (g), the number of seeds per pod, the number of pods per plant, the number of pods per main stem, the pod breadth, the number of leaf nodes per plant and the lower leaf area positively influence single plant seed yield in sesame. Of these, the number of seeds per plant had the highest direct effect on single plant seed yield, followed by the 1000-seed weight (g). The number of pods per plant had the highest indirect effect through the number of seeds per plant. Therefore, the number of seeds per plant and the 1000-seed weight (g) are good indicators of single plant seed yield in sesame. Indirect effect of the number of pods per plant should also be considered and the three parameters could serve as selection criteria in breeding for yield improvement.

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