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Correlation and co-heritability studies of yield and yield-associating characters in apple (*Malus domestica*)*

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Apple *(Malus* × *domestica* Borkh) belongs to family Rosaceae, an important temperate fruit crops, it covers 52.10% area and 79% production of total temperate fruits. Jammu and Kashmir leads in area, production and productivity. More than 10,000 apple cultivars are available in the world (Way *et al.* 1990). In Jammu and Kashmir hardly dozen apple varieties are being commonly grown. Out of total cultivars being grown, Delicious group represents more than 85% area which results complex problem like poor fruit set, glut in the market and other associating impediments. Productivity of apple in advanced countries have been recorded more than 60–70 tonnes/ha where as in India it is very low (9.73 tonnes/ha) as compared to world average 14.9 tonnes/ha (Anonymous 2010). In order to improve the yield potential in India. Improvement of yield in apple requires knowledge of the magnitude of variation in available varieties, interdependence of quantitative characters with yield and the heritability of the genotypic material. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection than heritability estimates alone. Correlation coefficient is a statistical measure to find out the degree (strength) and direction of relationship between two and more variables. Phenotypic correlations can be measured directly and the inherent or heritable association between two variables is known as genotypic correlation and it is due to pleiotropic gene action as well as linkage or both (Singh and Narayanam 2009a). Co-heritability takes both genotypic as well as phenotypic covariance into account and helps in understanding changes taking place in pairs of polygenic characters. Hence, an experiment was undertaken to understand the inheritance of yield and its components and their interdependence in apple.

The present was carried out at Research Farm of Central Institute of Temperate Horticulture, Srinagar during 2008–10. Thirteen apple cultivars Benoni, Red Gold, Golden Delicious, Starking Delicious (Royal Delicious), Red Delicious, Vance Delicious, Red Chief, Top Red, Gala Mast, Red Fuji, Oregon Spur, Vista Bella, Silver Spur budded on Maharaji apple root stock and planted at 4 m × 4 m spacing were taken for study. The experiment was laid out in randomized block design with three replications and two plant/unit and all the cultural operations were followed uniformly for all the tree under study.The observations on the tree height and trunk girth were measured by measuring tape and vernier calliper. Tree spread was measured by (N-S) and (E-W) by measuring tape and tree volume was calculated as per the formulae suggested by Westwood (1996). Annual extension growth was recorded at end of growing season. Number of fruits/tree counted visually fruit weight by digital balance and yield/tree were estimated at final harvest time. Analysis of variance was carried out as suggested by Panse and Sukhatme (1995) were used for calculating other genetic parameters. Simple correlation coefficient, genotypic and phenotypic covariance for paired characters and co-heritability were calculated by statistical software SPAR-2.

The analysis of variance indicated high difference among varieties for most of the characters. Highly significant differences were noted in trunk girth, number of primary and secondary scaffold, tree volume, annual extension growth, number of fruits/tree, fruit weight and yield/tree were noted for both the years. However, tree height and spread were non-significant in both the years (Table 1). All the traits except tree height, number of primary scaffold and tree spread exhibited wide range of variability during both the years. The genotypic and phenotypic variances were maximum for number of fruits/tree in both the years (1079.0–

*Short note

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Table 1 Range, mean, heritability, genetic advance, mean and sum of square of apple in various characters for yield and yield-associating characters in apple

Characters	Mean and sum of square of apple in various characters						Range, mean, heritability and genetic advance for yield and yield-associating characters in apple													
	Replication		Treatment		Error		Range		Mean		Variance				Coefficient variance				Heritability in broad sense%		Genetic advance	
											G	P	G	P	G	P	G	P				
	2009	1010	2009	1010	2009	1010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tree height (m)	0.12	0.024	0.28	0.28	0.052	0.04	1.70–2.57	1.84–2.62	2.135	2.23	0.07	0.12	0.07	0.02	12.98	16.91	12.71	15.85	59.0	64.21	42.11	45.82
Trunk girth (mm)	127.87	9.25	311.84	73.67	12.29	11.62	82.20–110.57	23–42.33	96.39	33.00	99.85	112.1	20.68	32.3	10.82	11.47	14.60	18.18	89.04	64.63	1942.37	750.0
No. of primary scaffold	1.10	1.72	3.81	0.75	0.82	1.47	6.33–9.70	7.67–9.33	8.01	8.50	0.99	1.82	0.23	1.2	12.76	17.25	5.74	13.07	54.70	-19.2	152.01	-43.32
No. of secondary scaffold	7.87	71.26	18.08	56.94	3.60	49.84	9.33–17.30	15.33–32.3	13.31	23.81	4.84	8.40	2.36	52.2	16.65	21.96	8.07	37.92	57.60	4.5	343.89	66.98
Tree spread (m^2)	0.03	0.06	0.26	0.27	0.03	0.03	1.25–1.95	1.22–2.24	1.60	1.73	0.07	0.10	0.08	0.11	17.38	20.07	18.38	21.62	75.00	72.31	48.85	49.40
Tree volume (m^3)	6.33	7.03	24.53	23.84	1.70	2.33	2.75–10.14	3.52–11.80	6.46	7.66	7.61	9.29	7.16	9.51	46.39	51.24	45.23	52.08	81.97	75.41	514.67	479.0
Anuual ext. growth (cm)	57.90	22.25	1502.73	288.50	196.12	116.45	61.10–14.1	88–123.3	30.57	105.65	435.5	631.6	57.35	173.8	19.28	23.21	7.59	13.21	68.95	33.00	3569.76	894.13
No of fruit/plant	1400.0	274.79	3894.2	2041.35	657.30	343.71	176–285.7	124.33–225.33	230.85	174.83	1079.0	1736.2	565.8	909.6	14.56	18.47	12.45	15.79	62.14	62.21	5321.91	3865.0
Fruit weight (g)	250.70	250.68	766.43	766.42	102.43	102.43	114–172.5	121.29–146.40	143.25	133.84	221.3	221.3	221.3	323.8	11.05	13.37	11.05	13.37	68.36	68.36	2533.84	2534.0
Yield/tree (kg)	58.33	2.01	162.05	94.42	17.10	16.05	21.37–46.0	15.14–38.58	33.68	26.86	48.3	65.4	26.12	42.18	22.77	26.50	19.54	24.83	73.90	61.92	1231.21	828.42

1736.27) and (565.8–909.6) respectively. The PCV value had higher estimate than corresponding GCV for all the characters in both the years. The small difference between PCV and GCV was observed for trunk girth (2009) and fruit weight (2010) that the difference was due to genotypic differences on the contrary environmental influences were predominated for remaining characters. The PCV and GCV were very high for tree volume for both the years (51.24, 46.39) and (52.08, 45.23). Further low PCV and GCV for any characters indicated less scope of its selection. Heritability in broad sense ranged from 54.70% to 89.04% in 2009 and –19.2% to 75.41% in 2010.The tree spread and tree volume had high heritability during both the years. Number of fruit/tree, fruit weight and yield/tree registered 76.2% heritability in both the years. Very high genetic advance was registered for number of fruits/plants during both the years 5321.91 and 3865.00 respectively. Further fruit weight, yield/tree, trunk girth registered very high genetic advance in both the years. Tree height and tree spread had low genetic advance for both the years, moderate to low heritability indicates that improvement for these characters through simple selections would be limited. High heritability alone does not guarantee large gain from selection unless sufficient genetic advance attributable to additive gene action is present. High heritability coupled with high genetic advance for tree volume, number of fruits/tree, fruit weight, yield/tree and trunk girth during both years indicative of additive gene effects. These results are in-conformity with the finding of Samal *et.al.* (1996) and Mir *et al.* (2006). High heritability coupled with low G A, low heritability with high G A or low heritability and low G A offers less scope for selection, as they were more influenced by environment and accounted for non-additive gene effects. High heritability coupled with high genetic advance is indicative of greater proportion of additive genetic variance and consequently a high genetic gain is expected from selection (Singh and Rai 1981).

Genotypic and phenotypic correlation coefficient was estimated from variances and co-variances. Simple correlation gives an idea about co-variation or co-inheritance of two characters. High positive co-variance for both genotypic and phenotypic level showed by tree height with trunk girth. Trunk girth with tree spread and tree volume showed high positive co-variance (genotypic and phenotypic) level. Number of fruit/tree showed high positive co-variance with fruit weight and fruit yield/tree. Similarly fruit weight and fruit yield/tree, number of primary scaffold and secondary scaffold showed positive co-variance with tree spread and tree volume and also showed positive (genophytic co-variance Table 2) for 2009. Co-variance measure inheritance of two characters simultaneously, both genotypic and phenotypic co-variance measures co-heritability (Singh and Narayanam, 2009b). High positive co-variance for genotypic and phenotypic level exhibited by tree height with trunk girth in second year also. Genotypic co-variance were higher than the corresponding phenotypic covariance for trunk girth with tree volume. Number of primary scaffold with number of secondary scaffold and number of fruit/tree and tree spread with number of fruit/plant. It is obvious from co-variance table that very high positive phenotypic co-variance recorded for annual extension growth with number of fruit/plant, fruit weight and yield/tree. Similarly high phenotypic and genotypic co-variance for number of fruit/plant with trunk girth and yield registered during 2010.

The co-heritability estimates of character combinations are presented in Table 3 of various traits with tree height, revealed that number of fruits/tree and trunk girth and tree height with trunk girth and tree spread had higher co-heritability during 2009 and 2010 respectively. Number of secondary scaffold and tree volume had high co-heritability with yield/tree for both the years (Table 3). High heritability values were observed for trunk girth with all the traits except number of fruits/tree, during 2009 and number of secondary scaffold for 2010.This suggests that selection for either of these attributes may result in simultaneous selection for other co-herited characters. Smaller magnitude of co-heritability estimates are expected due to high magnitude of environmental variance, hence resulting poor response to selection. Co-heritability helps in understanding changes taking place in pair of polygenic characters. High value of co-heritability estimates suggest that increase in one polygene trait will lead to simultaneous increase in another co-heritable characters. All possible correlation coefficient between yield/tree in apple and its components were estimated at genotypic and phenotypic levels and have been presented in Table 4. In general, the genotypic correlation coefficient for most of the association except tree height with number of primary scaffold and number of secondary scaffold with tree volume and tree spread and tree volume with annual extension growth was high. High positive genotypic and phenotypic correlation of tree height were observed with tree spread and tree volume. Trunk girth also had high positive correlations with tree spread. Tree spread exhibited high significant positive genotypic and phenotypic correlation with tree volume. Number of fruit/plant showed positive correlation with fruit weight and yield/tree. Fruit weight had positive correlation with yield/tree. The magnitude of genotypic correlation with corresponding phenotypic correlations were high for all the characters except tree height, trunk girth and number of primary scaffold with annual extension growth and tree height and number of primary scaffold with number of fruit/plant. High positive genotypic and phenotypic correlation were observed with tree spread and tree volume. Tree spread showed significant correlation with tree volume for genotypic and phenotypic levels. Number of fruit/tree had positive correlation with fruit weight and yield/tree and fruit weight with yield/tree and similar trend on correlation recorded to previous year.

Table 2 Phenotypic and genotypic covariance for paired characters

Character	Year	Tree height (m)		Trunk girth (mm)		No. of primary scaffolds		No. of secondary scaffold		Tree spread (m^2)		Tree volume (m^3)		Annual extension growth (cm)		No. of fruit/ plant		Fruit weight (g)		Yield/ tree (kg)	
		G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P
Tree height (m)	2009			1.98	1.63	0.06	0.14	–0.07	–0.07	0.05	0.05	0.62	0.74	–1.13	–1.03	1	0.24	–0.72	0.07	–0.09	0
	2010			0.86	0.75	–.0.03	–0.05	0.27	–0.01	0.04	0.04	0.52	0.56	0.5	1.23	1.1	2.04	–0.75	0.2	0.09	0.36
Trunk girth (mm)	2009					0.99	0.27	–0.75	–1.47	1.96	1.96	21.06	19.96	–37.59	–37.88	–11.14	–15.45	–26.42	–34.08	–9.08	–7.13
	2010					–0.5	–1.8O	–6.1	0.78	0.62	0.5	6.34	4.65	–2.24	–16.3	–8.97	–16.2	–10.3	–10.27	–5.34	–4.63
No. of primary scaffolds	2009							–0.55	–0.13	0.09	0.14	1	1.6	–9.3	–11.54	5.23	–0.17	–34.08	4.1	–7.13	1.77
	2010							1.54	0.44	–0.08	–0.07	–0.8	–0.47	0	3.11	6.96	5.94	0.56	3.62	1.25	1.8
No. of secondary scaffold	2009									0.23	0.35	–1.87	–3.12	–1.62	–6.3	–27.54	–16.11	–17.18	–14.1	–7.29	–5.28 S
	2010									–0.31	–0.51	1.46	2.26	–2.78	–2.4	49.38	10.22	0.75	1.44	7.63	1.8
Tree spread (m^2)	2009											0.75	0.92	–0.69	–1.37	–3.34	–4.38	–1.97	–2.29	–0.93	–1.17
	2010											0.74	0.99	–0.2	0.16	–1.83	–2.31	–1.59	–1.86	–0.53	–0.73
Tree volume (m^3)	2009													–5.59	–11.06	–18.55	–33.16	–18.14	–17.3	–7.01	–8.98
	2010													–0.75	4.11	–8.8	–14.38	–15	–14.7	–3.74	–5.35
Annual extension growth (cm)	2009															–46.03	–8.97	–197	–18.27	–57	–203.8
	2010															–8.53	62.9	–43.93	18.32	–8.81	11.08
No. of fruits/plant	2009																	255.14	227.17	204.12	289.92
	2010																	219	228.86	110.95	162.55
Fruit weight (g)	2009																			87.57	107.6
	2010																			66.8	93.24
Yield/tree (kg)	2009																				
	2010																				

Table 3 Estimation of co-heritability for different paired characters in apple

Character	Tree height (m)		Trunk girth (mm)		No. of primary scaffolds		No. of secondary scaffold		Tree spread (m^2)		Tree volume (m^3)		Annual extension growth (cm)		No. of fruit/ plant		Fruit weight (g)		Yield/ tree (kg)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tree height (m)			1.21	1.14	0.42	–0.62	1.06	–24.5	1.03	1.01	0.84	0.92	1.09	0.41	4.13	0.54	–9.43	–36.61	–22.6	0.26
Trunk girth (mm)					3.61	0.28	0.5	–7.76	0.99	1.24	1.05	1.36	0.99	0.13	–0.72	0.55	0.77	1	1.27	1.15
No. of primary scaffolds							4.26	3.4	0.65	1.08	0.63	1.71	0.81	0.01	–29.9	1.17	1.25	0.15	2.3	0.69
No. of secondary scaffold									0.66	0.61	0.65	0.6	1.15	0.25	1.7	4.82	1.21	0.52	1.38	4.22
Tree spread (m^2)											0.82	0.74	0.5	–1.27	0.76	0.79	0.86	0.85	0.79	0.72
Tree volume (m^3)													0.51	–0.13	0.56	0.61	1.05	1.01	0.78	–0.7
Annual extension growth (cm)															2.52	–0.13	0.96	–2.39	1.05	–0.79
No. of fruits/ plant																	1.12	0.95	0.7	0.68
Fruit weight (g)																			0.81	0.72
Yield/tree (kg)																				

Table 4 Genotypic and phenotypic correlation coefficient matrix among different characters of apple during 2009–10

Character	Tree height (m)		Trunk girth (mm)		No. of primary scaffolds		No. of secondary scaffold		Tree spread (m^2)		Tree volume (m^3)		Annual extension growth (cm)		No. of fruit/ plant		Fruit weight (g)		Yield/ tree (kg)	
	G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P	G	P
Tree height (m)	1	1	0.72	0.43	0.22	0.31	–0.12	–0.06	0.75	0.48	0.83	0.68	0.19	0.11	0.11	0.01	–0.177	0.01	–0.051	0
	1	1	0.68*	0.37	–1	0.13	0.64**	0	0.57*	0.37	0.69**	0.51**	0.23	0.26	0.16	0.19	–0.18	0.03	0.06	0.15
Trunk girth (mm)			1	1	0.09	0.01	–0.03	–0.04	0.71	0.58	0.76	0.61	0.18	0.14	0.03	0.03	–0.18	–0.17	–0.13	–0.08
			1	1	–1	–0.28	–0.87**	0.01	0.48	0.26	0.52**	0.26	0.06	0.02	–0.08	–0.09	–0.15	–0.1	–0.12	–0.12
No. of primary scaffolds					1	1	–0.25	–0.03	0.35	0.34	0.36	0.38	0.44	0.34	0.15	0	0.27	0.13	0.26	0.07
					1	1	–1	0.05	–1	–0.21	–1	–0.33	–1	0.21	–1	0.17	–1	0.18	–1	0.25
No. of secondary scaffold							1	1	0.38	0.38	0.24	0.25	0.06	0.03	–0.38	–0.13	–0.52	–0.27	–0.47	–0.22
							1	1	–0.72	–0.21	–0.45	–0.14	0.13	0.06	1.34	6.04	0.03	0.01	0.97	0.038
Tree spread (m^2)									1	1	0.99	0.95	0.11	0.17	–0.37	–0.32	–0.47	–0.39	–0.48	–0.45
									1	1	0.98**	0.96**	0.09	0.03	–0.27	–0.22	–0.38	–0.31	–0.37	–0.34
Tree volume (m^3)											1	1	0.097	0.14	–0.2	–0.26	–0.44	–0.31	–0.37	–0.36
											1	1	0.03	0.1	–0.13	–0.15	–0.37	–0.26	–0.27	–0.26
Annual extension growth (cm)													1	1	–0.067	–0.01	–0.63	–0.45	–0.39	–0.26
													1	1	–0.04	0.15	–0.38	0.07	–0.22	0.12
No. of fruits/ plant															1	1	0.52	0.3	0.89	0.86
															1	1	0.61	0.42	0.91**	0.82**
Fruit weight (g)																	1	1	0.85	0.73
																	1	1	0.87**	0.79**
Yield/tree (kg)																			1	1
																			1	1

**Significant at 1% level of significance

SUMMARY

Correlation and co-heritability were studied among 13 applie cultivars. Genotypic and phenotypic variance were maximum for number of fruits/tree during both the years. High PCV and GCV were noted for tree volume and high heritability registered for tree spread and tree volume, whereas high genetic advance noted for number of fruits/plant. High heritability coupled with high genetic advance registered for tree volume, number of fruits/plant, fruit weight, and yield/ tree and trunk girth during both the years. High co-heritability was noted for number of fruits/tree and trunk girth and tree height with trunk girth and tree spread. Number of secondary scaffold and tree volume had high co-heritability with yield/ tree for both the years. Genotypic correlation coefficient for most of the association except tree height with number of primary scaffold and number of secondary scaffold with tree volume and tree spread and tree volume with annual extension growth were registered high.

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