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Varietal Assessment, Correlation Studies and Path Coefficient Analysis in Apple in High Hill Conditions of Himachal Pradesh, India

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ABSTRACT

The present investigation was conducted during March, 2023-October, 2024 at Regional Horticultural Research and Training Station Mashobra, Shimla, Himachal Pradesh, India to assess varietal diversity and inter-relationships between the various traits in 30 apple cultivars. Data was collected for physical and biochemical characters of fruits. Maximum fruit weight (184.62 g), length (7.00 cm) and breadth (7.47 cm) was recorded in variety Red Delicious, while highest fruit firmness was found in Carrol (9.15 kg cm^{-2}). Regarding biochemical analysis highest TSS (14.77°Brix) and juice content (87.52%) was recorded in variety Honey Gold and maximum acidity (0.75%) was present in Granny Smith. Maximum ascorbic acid was found in Scarlet Spur II (6.55 mg 100 g^{-1}) and anthocyanin content was recorded in variety King Roat (16.89 mg 100 g^{-1}). Estimating correlations and path analysis between variables is widely used to determine how to enhance important attributes for crop quality. Fruit weight was found to be positively and significantly associated with fruit length (0.609), breadth (0.742), titratable acidity (0.255) and juice content (0.458). Path coefficient analysis revealed that various traits such as fruit length (0.504), breadth (0.304), firmness (0.013), acidity (0.199) and juice content (0.197) had positive direct effects on fruit weight, however direct negative effect on fruit weight was recorded with TSS (-0.316), ascorbic acid (-0.202) and anthocyanin content (-0.076). It was thus concluded that these physico-chemical traits used as selection indicators for increased production with high-quality apple cultivars.

KEYWORDS: Apple, variability, correlation, path analysis

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1. INTRODUCTION

Apple (*Malus×domestica* Borkh) is one of the most important and widely distributed fruit crops in the cold and mild climates of temperate regions in the world (Harris et al., 2002), belongs to family Rosaceae (Westwood, 1993). It is originated in South Western Asia, Caucasus region of Turkistan (Vavilov, 1951). Its occurrence across all continents in a different environment reflects its adaptive potential (Janick et al., 1996). In India, apple is the most cultivated and economically important fruit crop of the temperate region and its cultivation is commercially confined to the north-western Himalayan region, comprising the states of Jammu and Kashmir, Himachal Pradesh, and Uttarakhand which accounts for 92% of the total apple production. Although, apple is temperate zone fruit crop but now days being cultivated in subtropical and tropical zones (Wani et al., 2022). Its cultivation has also been extended to the states of north-eastern region Arunachal Pradesh, Sikkim, Nagaland and Meghalaya and Nilgiri hills in Tamil Nadu (Kumar et al., 2023). In Himachal Pradesh, apple is leading cash crop than other fruits, it is cultivated in area of 1,15,680 ha area and annual production is 6,72,343 mt having a productivity of 5.81 mt ha^{-1} (Anonymous, 2023). Apple is a widely consumed fruit, known for its distinctive flavour and numerous health benefits. It is rich in vitamins, fiber, organic acids, and soluble sugars. Apples contain antioxidants like α-tocopherol, which exhibit anti-aging and anticancer effects. It is reported that apple helps to reduce risk of asthma, lung cancer, diabetes, thrombotic stroke, ischemic heart disease and proliferation activities (Boyer and Liu, 2004). Several new apple colour strains and varieties have been introduced in the country, and some have shown good adaptation to different agro-climatic conditions. These varieties hold significant potential for use in breeding programs, particularly in the mid-hill regions of the North-Western Himalayas in India (Verma et al., 2024). The assessment of apple varieties is fundamental for identifying superior genotypes, understanding genetic diversity, and aiding in the effective utilization of germplasm in breeding programs (Migicovsky and Myles, 2017). Although only a small number of apple varieties are cultivated commercially, apple germplasm is incredibly diverse, and there are still variations with unexplored potential for increased production and quality (Mir et al., 2020). Improvement in apple requires knowledge of extent of variation in available varieties, interaction of quantitative characters (Kumar and Mir, 2012). To gain a deeper understanding of the inter-relationships among these traits, multivariate statistical approaches such as correlation analysis and path coefficient analysis are commonly employed (Rasool et al., 2019). Correlation analysis quantifies the degree of association between pairs of traits, helping to identify traits that move together and can be selected simultaneously (Hayes et al., 1995). The significant and positive correlation between different pairs would be helpful for genetic improvement of different traits in single step. However, it does not indicate the direct and indirect effects of one trait on another. Path coefficient analysis, on the other hand, partitions the correlation coefficients into direct and indirect effects (Patil et al., 2024), offering a clearer picture of the causal relationships among traits. Therefore, correlation in combination with path analysis would give a better insight into cause and effect of relationship between different traits The present investigation aimed to estimate the variability in respect of various quantitative traits and to understand inherent relationship for fruit quality in apple genotypes so as to bring improvement through future breeding programmes.

2. MATERIALS AND METHODS

2.1. Experimental site

An experiment was conducted during from March, 2023 to October, 2024 in the Field Gene Bank of Regional Horticultural Research and Training Station Mashobra, Shimla, Himachal Pradesh, India. The experimental farm was situated at the elevation of 2286 m above msl with latitude of 31.1°N and longitude of 77.2°E and area falls under wet-temperate, high hills agro-climatic zone. The average summer temperature was about 29.4°C and minimum temperature does not go below -4°C. The average annual temperature of the experimental area was 18°C and average annual rainfall was about 135 to 150 cm. The present study was conducted on 12 years old apple tree grafted on M7 rootstock spaced at 2.5×2.5 m^2. The experiment was laid out in a Randomised Complete Block Design on thirty varieties of apple varieties (Silver Spur, Well Spur, Starking Delicious, Jonagold, Early Red One, Starkrimson, Red Delicious, Scarlet Spur II, Oregon Spur II, Honey Gold, Ace Spur, Gold Rush, Bright-N-Early, Red Cap Valtod, Valley Spur, King Roat, Schlect Spur, Redlum Gala, Gale Gala, Fulford Gala, Buckeye Gala, Dark Baron Gala, Aztec Fuji, Fuji Kiku, Auvil Early Fuji, Fuji Raku Raku, Sun Fuji, Spartan, Carrol and Granny Smith) with three replications.

2.2. Method of data collection

The data on fruit weight was calculated by selecting ten fully developed fruit from each replication and weighed on Electronic balance, average fruit weight was recorded and expressed in g. Length and breadth were measured with the help of digital Vernier Calipers as average of ten mature fruits and expressed in cm. The fruit firmness was determined by digital penetrometer model Acucal Digital

Fruit Pressure Tester (Model ACSY4), expressed in kg cm^{-2}. Biochemical analysis, viz., TSS content in the fruit samples was determined by using a Milwaukee Digital Refractometer (0–32°Brix), acidity was recorded by standard method given by Ranganna, 1995. The quantitative estimation of ascorbic acid was done according to the method given in (Anonymous, 1980). Anthocyanin pigment in apple peel was determined by the method proposed by Harborne (1973). Juice content was calculated by extracting juice from fruit sample then weighed and percentage was calculated on the basis of total fruit weight. The statistical analysis was carried out for each observed character by using OPSTAT and SPSS software. The mean values of data were subjected to analysis of variance as described by Gomez and Gomez (1984). Data on genotypic and phenotypic correlations were calculated by using analysis of variance and covariance matrix suggested by Al-Jibouri et al. (1958). Path coefficient analysis of different traits with fruit weight was estimated by the method given by Dewey and Lu (1959).

3. RESULTS AND DISCUSSION

3.1. Physical parameters

The data on fruit characteristics of different apple varieties is depicted in Table 1. Among selected varieties considerable variations were reported for morphological traits of apple. The results revealed that highest fruit weight (184.62 g) was recorded in Red Delicious which was followed by Granny Smith (165.25 g) and significantly higher than all other varieties. However, lowest fruit weight (98.02 g) was recorded in variety Schlect Spur, that was statistically at par with Carrol (99.47 g). The maximum fruit length (7.00 cm) was reported in Red Delicious, statistically at par with Starking Delicious (6.76 cm) and Early Red One (6.58 cm). Data for minimum fruit length was observed in Redlum Gala (5.19 cm) which was statistically similar to Valley Spur (5.35 cm), Carrol (5.41 cm), Sun Fuji (5.45 cm) and Bright-N-Early (5.59 cm). Variety Red Delicious exhibited maximum (7.47 cm) fruit breadth when compared with other varieties which was followed by Fuji Raku Raku (7.06 cm) and Granny Smith (7.04 cm) but was statistically higher than all varieties under study. Whereas, minimum (5.55 cm) fruit breadth was noticed in Schlect Spur and statistically not different from Bright-N-Early (5.70 cm) and Valley Spur (5.77 cm). Similar results were documented in previous findings by Kishor et al. (2018) who also found maximum fruit weight (217.33 g) length (6.98 cm) and diameter (8.22 cm) in Red Delicious. The differences in fruit weight, size (length and breadth) with respect to different apple cultivars has been reported by number of researchers (Sharma et al., 2017; Kaushal et al., 2024), who observed comparable differences in their investigations. The variation in fruit weight and size (length and breadth) in different apple varieties are mostly ascribed to the inter-varietal differences linked with genetic make-up of the cultivars and governed by both number and size of cell and intercellular spaces of the fruit tissues (Kotiyal et al., 2017). The number as well as size of leaves also determine the fruit size and quality, as plants with greater leaf area exhibited enhanced photosynthetic efficiency which in turn supply the photosynthates to the fruits (Rasool et al., 2022). The data on fruit firmness revealed that highest fruit firmness was reported in Carrol (9.15 kg cm^{-2}) which was statistically at par with Auvil Early Fuji (9.08 kg cm^{-2}), but significantly higher than all other varieties. Whereas, minimum fruit firmness was observed in Well Spur (6.45 kg cm^{-2}) which was statically at par with Honey Gold (6.50 kg cm^{-2}). Fruit firmness is the important trait to account the shelf life and quality parameters of fruit.). The current results are in corroboration with those of Demirsoy et al. (2016), Sharma et al. (2017), Ali et al. (2023), Girish (2024) who found fruit firmness ranged from 5.3–9.9 kg cm^{-2}, 5.53–8.58 kg cm^{-2}, 7.11 to 8.71 kg cm^{-2}, 5.91–7.55 kg cm^{-2} in their respective studies. There is a number of factors that fruit firmness varies, including the variety itself (Magness et al., 1926), geographic location, maturity stage and environmental factors (Musacchi and Serra, 2018).

3.2. Biochemical parameters

The varieties under study exhibited substantial differences for the biochemical traits in apple as given in Table 1. Among selected varieties, highest (14.77°B) TSS was present in Honey Gold that was statistically similar with Gale Gala (14.63°B), whereas lowest TSS content (11.15°B) was reported in Starking Delicious which was statistically same with Bright -N- Early (11.16°B), Valley Spur (11.20°B) and Red Cap Valtod (11.26°B) varieties. The data for titratable acidity revealed that highest acidity (0.74%) was recorded in Granny Smith variety that was significantly higher than all varieties, however minimum (0.16%) was recorded in Bright-N-Early which was statistically at par with Silver Spur (0.18%) and Red Cap Valtod (0.19%). Many researchers has noted wide range of variation in TSS as reported by Sharma et al. (2017) and Kishor et al. (2018) ranging from 9.60–15.95°B and 11.06–14.73°B in their respective research which are in agreement with present investigation. The highest acidity was reported in Granny Smith (0.74%), which was in agreement with earlier research of Girish (2024), who also found maximum acidity in Granny Smith. Different researcher Hassan et al. (2017) and Kotiyal et al. (2017) also noted variation in acidity content of apple. The amounts of sugar and acid in the fruit tissue, as well as the balance between them, determine taste of fruit. In addition to genetic factors, climatic conditions and cultural

Table 1: Physical and biochemical properties of different apple varieties

Varieties	Fruit weight (g)	Fruit length (cm)	Fruit breadth (cm)	Fruit firmness (kg cm^{-2})	TSS (°B)	Titratable acidity (%)	Ascorbic acid (mg 100 g^{-1})	Anthocyanin content (mg 100 g^{-1})	Juice content (%)
Silver spur	131.04	6.44	6.51	7.73	12.52	0.18	5.39	12.72	71.81
Redlum gala	110.94	5.19	6.11	7.93	13.46	0.39	4.82	11.50	67.40
Spartan	149.05	6.10	6.87	6.92	12.41	0.45	3.72	10.03	78.18
Well spur	104.02	6.24	6.24	6.45	11.51	0.23	5.45	12.61	63.46
Starking delicious	154.52	6.76	6.98	8.42	11.15	0.28	4.24	11.25	72.63
Granny smith	165.25	6.41	7.04	7.48	12.51	0.74	5.60	3.63	78.00
Jonagold	146.83	6.39	6.53	7.08	12.93	0.47	5.83	7.95	69.93
Early red one	145.99	6.58	6.77	8.08	11.94	0.25	6.10	12.61	65.28
Starkrimson	138.67	6.25	6.53	7.71	12.30	0.27	4.68	12.92	69.12
Red delicious	184.62	7.00	7.47	8.19	12.06	0.28	4.92	12.59	72.37
Carrol	99.47	5.41	6.29	9.15	12.87	0.34	3.49	9.63	53.71
Gale gala	119.48	6.26	6.72	8.65	14.63	0.46	4.72	11.95	72.78
Scarlet spur II	132.96	6.42	6.77	7.70	12.19	0.25	6.55	14.22	65.65
Oregon spur II	124.45	6.37	6.49	8.31	11.95	0.25	5.82	12.07	58.34
Aztec fuji	136.04	5.86	6.38	8.02	12.76	0.35	3.32	10.42	66.11
Fuji kiku	134.79	5.72	6.69	7.62	12.57	0.47	3.80	8.74	71.75
Auvil early fuji	109.29	5.73	6.33	9.08	12.61	0.48	4.50	10.76	70.33
Fuji raku raku	161.86	5.96	7.06	7.41	11.81	0.49	4.49	9.34	72.25
Sun fuji	121.40	5.45	6.54	8.42	12.94	0.55	3.85	11.34	73.78
Honey gold	139.15	6.46	7.01	6.50	14.77	0.58	6.42	4.05	87.52
Ace spur	114.42	6.07	6.41	7.15	11.69	0.21	5.46	9.79	69.77
Gold rush	118.79	5.70	6.61	7.67	12.48	0.45	6.14	4.84	71.19
Bright-N-Early	121.12	5.59	5.70	6.77	11.16	0.16	4.78	8.87	73.26
Red cap valtod	113.60	6.01	6.10	7.84	11.26	0.19	4.05	14.81	73.45
Valley spur	116.37	5.35	5.77	8.34	11.20	0.23	4.53	10.37	71.40
Fulford gala	112.87	5.67	7.03	6.85	13.84	0.53	4.46	7.91	70.45
King roat	144.05	6.39	6.57	8.07	12.69	0.32	3.60	16.89	73.34
Buckeye gala	125.20	5.95	6.60	6.75	12.91	0.25	5.02	13.44	68.80
Dark baron gala	133.19	5.95	6.57	7.13	12.73	0.39	3.61	13.93	70.94
Schlect spur	98.02	6.05	5.55	7.49	12.67	0.24	5.13	12.87	60.77
CD (p=0.05)	5.01	0.42	0.32	0.22	1.48	5.27	3.22	2.35	1.78

techniques used in orchards affect the quantity of sugars and acids in fruits (Wu et al., 2007; Hudina and Stampar, 2006). In present study maximum ascorbic content (6.55 mg 100 g^{-1}) was observed in Scarlet Spur II, significantly at par with (6.42 mg 100 g^{-1}) Honey Gold, while minimum content was recorded (3.32 mg 100 g^{-1}) in Aztec Fuji which was statistically at par with Carrol (3.49 mg 100 g^{-1}). Similarly, Kishor et al. (2018), reported that ascorbic acid varied among different apple cultivars. The maximum anthocyanin content was noticed in King Roat (16.89 mg 100 g^{-1}) and minimum anthocyanin content was found in variety Granny Smith (3.63 mg 100 g^{-1}) which was statistically at par with Honey Gold (4.05 mg 100 g^{-1}). The variety Honey Gold (87.52%) resulted in highest juice content when compared with selected varieties and minimum juice content was recorded in Carrol (53.71%). The amount of anthocyanin content also showed comparable variation in different apple varieties as reported by Girish (2024) and Jalai et al. (2024) in their work which were aligned with the present investigation. As anthocyanin were responsible for the skin colour formation which was mainly affected by intensity of light, and low temperature was crucial for anthocyanin accumulation (Devi et al., 2021). Juice content among selected varieties also had considerable variation. Gong et al. (2013), and Jan and Davide (2018), who observed juice content varied variety to variety (73.18–78.3%), (54.25–74.38%) and (67.41–70.52%) respectively, were in support with present results. These fruit bio-chemical parameters might vary across regions and years due to diverse climatic conditions, soil variables, cultural practices and also due to differences in fruit maturity at harvest and genetic diversity among genotypes.

3.3. Correlation studies

From the correlation analysis among all the traits, it was observed that genotypic correlation coefficient was higher than phenotypic correlation coefficients as given in Table 2. In present investigation, fruit weight was considered the dependent variable. Fruit weight showed significant and positive correlation with fruit length (0.609) and fruit breadth (0.742), titratable acidity (0.255) and juice content (0.458). Fruit length exhibited significant and positive correlation with fruit breadth (0.508) and ascorbic acid (0.390). Fruit breadth was significantly and positively associated with TSS (0.245), while significantly and negatively correlated with anthocyanin content (-0.211). Juice content positively and significantly correlated with fruit breadth (0.372), TSS (0.232) and titratable acidity (0.459), whereas, significant negative association with fruit firmness (-0.382) and anthocyanin content (-0.377). The findings of current study were in accordance with the results observed by Verma et al. (2024) who reported that fruit weight was significantly and positively correlated with fruit length (0.59) and fruit breadth (0.59). According to Sharma et al. (2016) fruit weight had significant and positive correlation with both fruit length and breadth in apple. Kumar and Mir (2012) also recorded fruit weight was significantly and positively associated with fruit length and breadth. The significant positive correlations between trait pairs could aid in simultaneously improving multiple traits when high or low values were desired. However, negatively correlated traits, requiring simultaneous increases or decreases, couldnot be improved in a single step. The traits showing no significant correlation were likely independent of each other.

Table 2: Correlation of genotypic and phenotypic level among various traits in apple varieties

		2	3	4	5	6	7	8	9
1.	G	0.609**	-0.098	-0.087	-0.123	0.410**	0.176	0.197	0.672**
	P	0.508**	-0.094	-0.078	-0.121	0.390**	0.158	0.177	0.609**
2.	G		-0.093	0.255*	0.482**	0.140	-0.225*	0.393**	0.741**
	P		-0.084	0.245*	0.459**	0.128	-0.211*	0.372**	0.705**
3.	G			-0.064	-0.049	-0.299**	0.265*	-0.382**	-0.093
	P			-0.064	-0.047	-0.297**	0.262*	-0.377**	-0.093
4.	G				0.590**	0.047	-0.261*	0.233*	-0.106
	P				0.582**	0.048	-0.259*	0.232*	-0.104
5.	G					-0.048	-0.653**	0.466**	0.256*
	P					-0.050	-0.649**	0.459**	0.255*
6.	G						-0.288**	0.038	0.057
	P						-0.286**	0.038	0.057
7.	G							-0.379**	-0.116
	P							-0.377**	-0.116
8.	G								0.465**
	P								0.458**

*Significant at p=0.05; **Significant at p=0.01; 1: Fruit length; 2: Fruit breadth; 3: Fruit firmness; 4: TSS; 5: Titratable acidity; 6: Ascorbic acid; 7: Anthocyanin; 8: Juice content; 9: Fruit weight

3.4. Path analysis

The path coefficient analysis (Table 3) revealed that direct positive effect towards fruit was observed by the following characters viz; fruit length (0.504), fruit breadth (0.364), fruit firmness (0.013), titratable acidity (0.179) and juice content (0.197), whereas direct negative effect on fruit weight was exhibited by TSS (-0.316), ascorbic acid (-0.202)

Table 3: Estimates of direct and indirect effects of different traits on fruit weight of apple among different varieties

	1	2	3	4	5	6	7	8	9
1.	0.504	0.222	-0.001	0.028	-0.022	-0.083	-0.013	0.039	0.672**
2.	0.307	0.364	-0.001	-0.081	0.086	-0.028	0.017	0.077	0.741**
3.	-0.049	-0.034	0.013	0.020	-0.009	0.061	-0.020	-0.075	-0.093
4.	-0.044	0.093	-0.001	-0.316	0.106	-0.009	0.020	0.046	-0.106
5.	-0.062	0.176	-0.001	-0.187	0.179	0.010	0.049	0.092	0.256*
6.	0.206	0.051	-0.004	-0.015	-0.009	-0.202	0.022	0.007	0.057
7.	0.088	-0.082	0.003	0.083	-0.117	0.058	-0.076	-0.075	-0.116
8.	0.099	0.143	-0.005	-0.074	0.083	-0.008	0.029	0.197	0.465**

*Significant at p=0.05; **Significant at p=0.01; Residual effect is 0.22; 1: Fruit length; 2: Fruit breadth; 3: Fruit firmness; 4: TSS; 5: Titratable acidity; 6: Ascorbic acid; 7: Anthocyanin; 8: Juice content; 9: Fruit weight

and anthocyanin (-0.076). Fruit breadth had indirect positive effect with fruit length (0.222), TSS (0.093), titratable acidity (0.176), ascorbic acid (0.051) and juice content (0.143), while negative indirect effect with fruit firmness (-0.034) and anthocyanin (-0.082). The results of present study were in accordance with findings of Barua and Sharma (2004) and Verma et al. (2024). The characters exhibiting a negative direct effect on fruit quality should be given less priority during genotype selection compared to those with a positive direct effect. Unexplained effects in path coefficient analysis were treated as residual effects and low level of them at genotypic level indicated that the traits included in present study accounted for most of the variation present in the dependent variable that was fruit weight.

4. CONCLUSION

Fruit weight exerted significantly positive phenotypic and genotypic correlation with different traits which revealed the inherent relationship among them. The path analysis studies allowed the portioning of the correlations between fruit weight and its components into direct and indirect effects confirmed the positive direct effect of these physiological and development traits on fruit weight; therefore, they could function as selection indices for the advancement of apple cultivars.

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