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Research Journal of Agricultural Sciences
An International Journal

P- ISSN: 0976-1675
E- ISSN: 2249-4538

Volume: 13
Issue: 03

Res. Jr. of Agril. Sci. (2022) 13: 581–588

CARAS

Res. Jr. of Agril. Sci. (May-Jun 2022)
13(3): 581–588

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

www.rjas.org

Full Length Research Article

Pomological Evaluation of Apple (*Malus* × *domestica* Borkh.) Germplasm of North Kashmir through Cluster and Principal Component Analysis

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Received: 28 Feb 2022 | Revised accepted: 07 Apr 2022 | Published online: 11 May 2022

A B S T R A C T

In the present study, 28 apple genotypes from North Kashmir were assessed for twelve prominent fruit quality traits during the growing seasons of 2017-2020. Among the studied germplasm, fruit weight ranged from 17.10g in Kichhama Trel to 226.10g in Chemura. Flesh firmness, the most important trait that determines the shelf life of apple fruit was observed to be the highest in Kichhama Trel (2.09 lbf) and lowest in Titoo (0.37 lbf). The total soluble solids (TSS) were found to be the highest in Kichhama Trel (16.32 °Brix) and the lowest in an unnamed genotype UNG 3 (9.20°Brix), pH ranged from the lowest in Gole Delicious (2.96) to the highest in Razakwari (5.16), whereas titratable acidity (TA%) ranged from the lowest in Wagil Turush (0.28%) to the highest in Mudur Ambur (0.72%). Significant positive and negative correlations were recorded between all the evaluated fruit quality traits. The cluster analysis based on all the evaluated traits grouped the 28 apple genotypes into two main clusters with several sub-clusters. Principal component analysis (PCA) segregated the 12 evaluated traits into 5 main principal components that revealed 81.27% total variance. Moreover, the PCA scatter plot segregated the genotypes into two clusters with the right cluster of 11 genotypes having the highest values regarding the most important fruit quality traits such as fruit weight, fruit height, fruit width, and fruit firmness that can be regarded as potentially superior genotypes. The current findings will serve as an authentic basis for effective genetic resource management, cultivar improvement, and sustainable utilization of apple germplasm in future breeding programs in Jammu and Kashmir, India.

***Key words*:** Apple germplasm, Fruit quality, Cluster analysis, PCA, North Kashmir

Apple (*Malus* × *domestica* Borkh.) is an important fruit crop in Kashmir Valley and ranks first in production as well as export among all the fruits in the region (hortikashmir.gov.in). It is one of the four most important fruit crops after citrus, grapes, and banana, and one of the commercially most important horticultural crops in the temperate parts of the world [1]. Apple varieties are grown throughout the world including Central and West Asia, India, Western provinces of China, Europe, and parts of America and Africa [2].

Globally, more than 7500 named apple cultivars are present, but apple production is dominated by only 10-20 cultivars [3]. The dominance of a few cultivars leads to near monoculture, and thus increases the crop vulnerability to diseases, pathogens, and environmental threats [3]. In India, the Union Territory of Jammu and Kashmir is the major contributor to apple production producing nearly 70% of apple production in the country. There are more than 150 cultivars of apple in the Kashmir Valley [4] besides some unknown genotypes. The monoculture of a few delicious cultivars is associated with other constraints like apple scab, Alternaria, Powdery mildew diseases, lack of cold storage facility, diversion of orchard land to residential, commercial, and other infrastructure development purposes, and the substitution of traditional genotypes by newly introduced exotic genotypes coupled with changing climatic patterns have resulted in the loss of diversity and depletion of indigenous apple germplasm and several traditionally grown apple genotypes well adapted to the local agro-climatic conditions are at the brink of extinction [5]. It is, therefore, important to characterize all the existing genotypes so that these genotypes are preserved for the future development of market-driven and disease-resistant varieties. The newly identified genotypes with better characteristics could be characterized and promoted to the commercial level. The objective of this work was to analyze the diversity of apple genotypes in North Kashmir with emphasis on the important fruit quality traits. The information generated will help in distinguishing each genotype with specific passport data information besides identifying the commercial potential of

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otherwise lesser-known genotypes having market value traits similar to well-known and commercially successful genotypes.

MATERIALS AND METHODS

The Valley of Kashmir has very rich apple germplasm thriving in both privately owned and managed orchards and horticultural nurseries managed by the government. For assessing the available apple germplasm in the North Kashmir region, extensive field surveys and collection trips were undertaken throughout the apple orchards of the region during the growing seasons of 2017-2020. (Table 1) represents the collection sites and GPS coordinates of the sites of all investigated apple genotypes. In all pockets of the region, 28 different apple genotypes were identified and assessed for 12 fruit quality traits (Table 2). The information on the names of genotypes was gathered through local knowledge of orchardists, from experts of horticulture, and also from the available literature in the Department of Horticulture, Government of Jammu and Kashmir. Some of the apple trees growing in certain specific orchards had no name, and therefore, such trees were designated as unknown genotypes (e.g., UNG 1, UNG 2, and so on). A single tree of each genotype was tagged with an accession number. Fruits were handpicked at their commercial maturity stage to keep the consistency of maturity grade. A total of 10 fruits were randomly selected from each cultivar and hand-harvested at commercial maturity stage for recording various observations. The present data represent the mean values of the data taken during the three growing seasons. Various characteristics of fruits were recorded based on standard descriptors (Protection of Plant Varieties and Farmers Rights Authority (PPV & FRA), MOA, Government of India, New Delhi. The period of harvesting was recorded as early, mid, late and very late for the genotypes harvested in July, August, September and October respectively. Fruit shape was determined as per the ratio of fruit height/diameter, following the standard descriptors. The weight of 10 fruits of each genotype was determined by a digital electronic balance sensitive to 0.001g, recorded in grams and the average weight was calculated. Fruit size, i.e., height and width of fruits were measured by a cm scale. The skin and flesh colour of the fruits were visually noted while fruit flesh firmness was determined by Fruit Hardness Tester (FTH 803 Silverado) with an 11 mm plunger tip after removing the peel from the middle portion of the fruits and the data was expressed in Pound-force (lbf) following standard procedure. Two equally weighing flesh slices, one from the blush side and another from the non-blush side of each of the selected ten fruits from every genotype were cut off to extract juice for the analysis of the three prominent biochemical traits: Total Soluble Solids content (TSS), pH and Titrable Acidity (TA). TSS was measured at room temperature by a hand Refractometer Atago, PAL I (Atago Co. Ltd., Tokyo, Japan) following standard procedure, while pH was determined with the help of a digital pH meter (Hanna pH 213). Titrable acidity was determined by neutralization to pH 7.0 with 0.1N NaOH following the protocol devised by Ranganna [6] by the following formula:

$$\text{TA \%} = \frac{\text{Titre Volume} \times \text{Normality} \times \text{Volume to be made} \times \text{Eq. Wt. of acid} \times 100}{\text{Mg of solution taken} \times \text{aliquot taken} \times 1000}$$

Table 1 List of the evaluated apple genotypes and their collection sites from North Kashmir region

Name of the site	GPS coordinates	Name of the genotypes
Bagh- i Chetkak Wahipora- Langate	34° 23’ 8.21” N 74° 22’ 25 64” E	Jigergosh, Kichhama Trel
Khoribal Zaloora- Zaingair	34° 23’ 32.26” N 74° 22’ 25.64” E	Royal Misree, Titoo, UNG 5
Chek- i Harwan- Zaingair	34° 23’ 06.41” N 74° 22’ 28. 12” E	Razakwari, Safarkand
Haripora Wudar- Haripora Langate	34° 23’ 22 38” N 74° 21’ 53. 63” E	Chemura, UNG 4
Nathipora- Sopore	34° 22’ 08.18” N 74° 22’ 52.79” E	Pokhla, UNG 2
Chogal- Handwara	34° 4’ 13.73” N 34° 19’ 40.75” E	Condition, Lal Cider, Gole Delicious, Kala Maharaji
Baderher- Machipora- Zachaldara	34° 23’ 26.84” N 74° 14’ 41.36” E	Wagil Turush, Kesri, Cooper Four
Chakpuran- Kralgund	34° 20’ 03.17” N 24° 17’ 23.83” E	Krimson, Lal Misree
Mangwalpora- Kralgund	34° 20’ 41.54” N 74° 19’ 27.54” E	Kashmiri Ambri, Dilruba, UNG 3
Ludoora- Baramulla	34° 15’ 13.38” N 74° 23’ 04.91” E	Marchawangan Trel
Zangam- Pattan	34° 14’ 45.16” N 74° 56’ 82.97” E	Ginger Gold
Brath Kalan- Sopore	34° 22’ 55.60” N 74° 26’ 61.30” E	Turush Nawabi
Muqam- i Shareef Dar- Diwer- Lolab-Kupwara	34° 24’ 20 50” N 74° 26’ 55 65” E	UNG 1, Mudur Ambur

Data analysis

Descriptive statistics of 12 fruit quality traits (including minimum, maximum, average, standard deviation, and Coefficient of variation %) were determined using Excel 2013 (Microsoft Office package). Analysis of variance (ANOVA) was performed for all quantitative traits. Using the unweighed pair group method with arithmetic mean (UPGMA) based on the Euclidean distance

Coefficient, a dendrogram was constructed with PAST software [7]. Also, Simple correlation analysis and Principal

component analysis (PCA) based on all evaluated traits was performed using SPSS v20.0 (IBM SPSS Statistics, 2011). Based on the first two principal components (PC1 and PC2) a scatter plot was created using PAST software.

Table 2 List of the 12 morphological traits used for the diversity analysis of the 28 apple genotypes

Trait	Abbreviation	Unit / code
Harvesting period	HPE	1: Early, 2: Medium, 3: Late, 4: Very Late
Fruit shape	FSH	1. Conic, 2. Cylindrical, 3. Cylindical waisted, 4. Globose, 5. Obloid, 6. Ellipsoid and 7. Ovoid
Fruit ground colour	GCO	1: Green yellow, 2: Green
Fruit over colour	OCO	1: Medium red, 2: Dark red, 3: Light yellow, 4: Light pink, 5: Dark pink
Fruit type of over colour	OCT	1: Streaked, 2: Striped, 3: Mottled, 4: Complete
Fruit weight	FWE	gm
Fruit height	FHE	Cm
Fruit diameter	FDI	cm
Fruit flesh firmness	FFF	Lbf
pH	pH	-
TSS	TSS	°Brix
TA	TA	%

RESULTS AND DISCUSSION

For the first time the fruit quality variability of apple genotypes from North Kashmir was evaluated in the study. The results revealed a wide-ranging variability of high magnitude present in the evaluated traits among the analyzed genotypes. The mean scores for various qualitative and quantitative characters of the twenty-eight apple genotypes under study are shown in (Table 3). Clearly all the genotypes showed distinguishing characteristics and significantly differed from each other in most of the evaluated characters. One way analysis of variance showed significant differences ($P<0.0001$) among all the quantitative traits.

Table 3 Descriptive statistics of the morphological traits recorded in the studied apple genotypes

Genotype	HPE	FWE (g)	FSH	FHE (cm)	FWI (cm)	GCO	IOC	TOC	FFI (lbf)	TSS° Brix	pH	TA
UNG 5	1	116.00	7	5.10	6.93	2	2	1	0.53	11.70	3.50	0.3
Chemura	4	226.10	7	6.81	8.41	1	3	4	1.85	11.35	3.50	0.4
Condition	1	57.10	6	4.46	4.99	1	2	1	0.51	13.60	4.45	0.39
Cooper Four	2	91.15	1	5.90	7.2	2	2	1	0.43	13.36	4.23	0.3
Dilruba	2	89.56	6	4.94	6	1	2	3	0.94	14.30	3.38	0.44
Ginger Gold	2	90.42	6	4.81	5.89	2	3	4	1.13	14.50	3.84	0.36
Gole Delicious	4	168.60	6	5.95	7.54	1	2	3	1.13	11.46	2.96	0.67
UNG 3	2	142.03	7	6.33	7.11	1	2	1	0.93	9.20	3.87	0.36
Jigergosh	2	203.64	4	7.29	7.51	1	1	1	0.50	12.50	4.65	0.68
Kala Maharaji	4	225.02	7	6.47	8.12	1	2	2	1.29	12.30	3.22	0.38
Kichhama Trail	3	17.10	6	2.73	3.32	1	1	3	2.09	16.32	3.10	0.48
Kashmiri Ambri	3	92.60	3	5.45	6.27	2	4	1	1.55	15.15	4.08	0.56
Kesri	2	102.78	7	5.13	6.3	1	1	1	0.45	12.52	3.71	0.42
UNG 2	1	79.84	7	4.79	5.91	1	2	1	1.60	11.60	3.65	0.33
Krimson	2	93.60	7	5.16	6.26	1	1	1	0.54	12.30	3.19	0.32
Lal Cidar	2	67.49	6	4.54	5.96	2	4	1	0.45	13.70	4.44	0.4
Lal Mishree	1	81.98	5	5.52	5.43	1	1	1	1.15	13.10	3.49	0.38
Marchawangun Trail	2	95.70	4	5.42	5.91	2	2	1	0.86	10.60	4.01	0.4
Mudur Ambur	1	60.45	6	4.92	5.18	1	1	1	0.51	10.40	4.62	0.72
Pokhla	2	163.35	2	6.53	7.27	2	1	1	0.43	14.20	4.32	0.46
Razakwari	1	132.00	4	7.07	6.74	1	1	1	0.46	11.41	5.16	0.5
UNG 4	1	162.91	3	6.48	6.85	1	1	3	1.15	14.60	4.18	0.52
Royal Misree	4	210.60	3	7.73	7.55	1	2	1	1.26	13.40	3.28	0.42
Safarkand	3	67.48	6	4.87	5.44	1	5	3	1.22	11.24	4.10	0.7
Tithoo	2	62.50	6	4.37	4.95	1	2	1	0.27	12.98	3.56	0.33
Tursh Nawabi	1	80.40	3	5.02	5.21	1	2	4	0.00	12.31	3.72	0.7
UNG 1	1	81.92	6	5.11	5.71	2	4	2	0.79	11.60	3.41	0.71
Wagil Turush	1	116.90	6	5.84	6.2	2	1	4	0.00	10.90	3.56	0.28
Min	1	17.1	1	2.73	3.32	1	1	1	0.0	9.2	2.96	0.28
Max	4	226.1	7	7.73	8.41	2	5	4	2.09	16.32	5.16	0.72
SD	1.04	54.78	1.65	1.06	1.11	0.48	1.1	1.2	0.53	1.61	0.54	0.14
Average	2.04	113.54	5.29	5.53	6.29	1.32	2	1.9	0.86	12.59	3.83	0.46
CV%	50.88	48.24	31.26	19.16	17.58	36	54	63	61.88	12.76	14.05	30.74

Fruit weight is a valuable character in consumer preferences and in the present study it showed a broad range between 57.10 g (Condition) to 226.10 g (Chemura) except Kichhama Trel which showed an exceptionally lower fruit weight of 17.38 g. Out of the 28 assessed genotypes, 16 genotypes had a mean fruit weight below 100 g, 8 had between 100 g to 200 g and 4 had a mean fruit weight higher than 200 g. Fruit weight is known to be determined by a complex interplay of genetics, environment and cultural practices. Since all the 28 genotypes under study grew in similar environmental conditions with little agro-climatic interventions, it appears logical to infer that the genotypes like Chemura, Kala Maharaji, Jigergosh, Royal Misree, Pokhla and UNG 4 have inherent ability to utilize their resources efficiently to produce perfect fruit weight which is by and large acceptable to the consumers as consumers generally like large sized apples. In other words, these genotypes have a good genetic potential for this character. In the current study, fruit height ranged from 2.73 cm to 7.73 cm with a mean value of 5.53 cm. Similarly, fruit width ranged from 3.32 cm to 8.41 cm with an average value of 6.29 cm. Our results are similar to those reported by Reig *et al*. [8] in a study of apples in Spain (77.6 g to 265.8 g) and those reported by Mir *et al*. [9] for apples in India (91.68 g to 274.37 g). However, a comparatively narrower range of fruit weight (71 g to 165 g) was reported by Damyar *et al*. [10] for Iranian apples and 86.71 g to 247.26 g for Indian apples, as reported by Dar *et al*. [11].

Fruit shape was calculated on the basis of fruit height/ width ratio. It is controlled by both climatic and non-climatic factors, and shows great variation. The observed fruit shape showed wide variability from ellipsoid (39.28%), globose (10.71%), conic (3.57%), ovoid (25.00%), cylindrical-waisted (14.28%), obloid (3.57%) and cylindrical (3.57%) (Table 4). Our results differ from those of Dar *et al*. [11], who reported predominance of ovoid and oblong fruit shapes in apple cultivars of Kashmir Valley. Mratinic and Aksic [12] evaluated South Serbian apples and reported a great variation in their fruit shape. From commercial point of view, fruit shape is an important pomological trait. In general, conic and cylindrical-waisted apple shapes are generally preferred by consumers over other apple shapes in India.

Table 4 Frequency distribution for the evaluated fruit qualitative traits in the studied apple genotypes

Trait	Frequency Unit	Code and frequency No.						
		1	2	3	4	5	6	7
HPE	No.	10 (Early)	11(Mid)	3(Late)	4(Very late)			
	%	35.7	39.3	10.7	14.3			
FSH	No.	1 (Conic)	1 (Cylindrical)	4 (Cylindrical waisted)	3 (Globose)	1 (Obloid)	11 (Ellipsoid)	7 (Ovoid)
	%	3.57	3.57	14.28	10.71	3.57	39.28	25
GCO	No.	19 (Green yellow)	9 (Green)					
	%	67.9	32.1					
IOC	No.	10 (Medium red)	12 (Dark red)	2 (Light yellow)	3 (Light pink)	1 (Dark pink)		
	%	35.7	42.9	7.1	10.7	3.6		
TOC	No.	17 (Streaked)	2 (Stripped)	5 (Mottled)	4 (Complete over colour)			
	%	60.7	7.1	17.9	14.3			

Fruit skin colour in apple has two components-background colour and over colour. The background colour in the studied genotypes was found to be mostly green yellow, although some genotypes had green background colour. As the fruits approach maturity, they develop attractive over colour due to accumulation of anthocyanin pigments. The analyzed genotypes depicted over colour ranging from dark red (42.90%), medium red (35.70%), light pink (10.70%), light yellow (7.10%) to dark pink (3.60%) (Table 4). The intensity of over colour varied among the analyzed genotypes and slightly even from one fruit to another within the same genotype. The external skin colour of apples is determined primarily by the ground colour and secondarily by the superimposed anthocyanin pigmentation [13]. However, fruit colour is affected by the stage of fruit maturity, light intensity, temperature, amount of rainfall, nutritional and other environmental factors, and by the microenvironment within the area of the apple tree [14].

Fruit firmness is an important character that determines the quality and shelf life of apple fruit [15] and loss of fruit firmness is a serious problem resulting in the loss of fruit quality [16]. Fruit firmness is controlled both by genetic and agro-climatic factors including cultural factors like crop density and water management. Fruit firmness is strongly influenced by maturity with fruit firmness decreasing as the fruit ripens [17]. In the present investigation, the fruit flesh firmness ranged from 0.37 lbf (Titoo) to 2.09 lbf (Kichhama Trel) (Table 3). Apple fruits with higher firmness value are crispy and hence liked by the majority of the customers. Fruit flesh firmness is also strongly influenced by fruit size [18] with smaller fruits like Kichhama Trel, Ginger Gold etc. being generally firmer than larger fruits like Razakwari, Jigergosh etc. due to a higher cellular density in the former. Nevertheless, flesh firmness was poorly correlated with fruit weight, fruit height and fruit diameter in this study. The firmness of the apple fruit significantly decreased with increasing storage duration [19]. The post-harvest softening of apple fruit is believed to be related to cell wall breakdown [20] due to enzymatic activities [21] and pectin solublization [22] reducing the mechanical strength of cell walls which decrease the firmness in apple fruits [16].

Biochemical characters like total soluble solids (TSS), pH and titratable acidity (TA) which determine the fruit quality varied among studied apple genotypes. TSS is a very important quality attribute which influences fruit taste. Among the studied genotypes the obtained TSS values ranged from 9.20 °Brix in UNG 3 to 16.32 °Brix in Kichhama Trel. Only 1 genotype namely UNG 3 showed TSS below 10.00 °Brix, while as all other genotypes yielded a TSS values above 10.0 °Brix (Table 3). This range of TSS values is in agreement with the results reported by Kanchan *et al*. [23] the local apple cultivars grown in India with average TSS values of 11.50 °Brix. Bostan [24] reported TSS value from 10.50 to 15.00 °Brix, whereas Mratinic and Aksic [12] reported TSS value from 12.55 to 19.24 °Brix among the accessions studied by them. Bozovic *et al*. [25] also reported almost similar results with TSS value ranging

from 11.3 to 16.0 °Brix in some old apple varieties in central Montenegro. Similarly, Dar *et al*. [11] reported TSS values from 11.44 to 15.10°Brix for six apple cultivars grown in Kashmir.

The pH of the fruit depends mainly on organic acids in the fruit, which are consumed in respiration, resulting in lower acidity and high pH with increasing storage duration [26]. The currently studied genotypes revealed acidic pH ranging from 2.96 (Gole Delicious) to 5.16 (Razakwari), with an average of 3.83. The genotypes with maximum pH value include Razakwari followed by Jigergosh, Condition, Lal Cider and Pokhla. On the other hand the lowest value for pH was recorded in Gole Delicious, Kichhama Trel and Krimson (Table 3). Similar findings were reported by Vieira *et al*. [27] who reported pH values between 3.90 and 4.27 in six apple genotypes grown in Southern Brazil. On the other hand, pH values between 3.59 and 4.16 were reported by Wu *et al*. [28] for apple genotypes grown in China.

Titratable acidity (TA) is used to perceive quality of fruit in apple [29]. A balanced sugar acid ratio is highly liked by consumers. In the present study, TA showed a range of 0.28% (Wagil Turush) to 0.72% (Mudur Ambur) with an average of 0.46 (Table 3). Similarly, Dar *et al*. [11] reported acidity range of 0.35% to 0.80% among Kashmir apples evaluated by them. Rasool *et al*. [30], claimed acidity range of 0.12% to 0.33% in a managed set of apple accessions of Kashmir, whereas Mratinic and Aksic [12] recorded acidity range of 0.10 % to 0.82% in South Serbian apples. Acidity in apples is mainly due to presence of malic acid and during storage, a decrease is registered in acidity as a result of consumption of organic acids by respiration [26].

Multivariate analysis

Correlation analysis

The correlation coefficient was carried out to elucidate the linear relationship between the 12 traits in the current study. In the present study, a significant positive correlation was recorded between various fruit traits which could be the result of genetic linkage (Table 5).

Harvesting period showed positive correlation with fruit width (r = 0.493). Similarly, fruit weight showed positive correlations with fruit height (r = 0.884). In a similar way, fruit width showed highly significant positive correlation with harvesting days (r =0.415), fruit weight (r =0.912), and fruit height (r = 0.860). Apart from the positive correlations, significant negative correlations were also recorded between various traits including fruit shape and fruit height, fruit width, ground colour, and TSS. Significant positive and negative correlations between various fruit quality traits have been also recorded in the previous studies of apple [8], apricot [31-32], mulberry [33], pomegranate [34].

Table 5 Simple correlations among the fruit qualitative and quantitative traits of the studied apple genotypes

	HPE	FEW	FSH	FHE	FWI	GCO	IOC	TOC	FFF	TSS	pH	TA
HPE	1											
FEW	.493**	1										
FSH	0.059	-0.142	1									
FHE	0.241	.884**	-.392*	1								
FWI	.415*	.912**	-0.13	.860**	1							
GCO	-0.175	-0.151	-0.263	-0.076	0.05	1						
IOC	0.29	-0.15	0.116	-0.183	-0.026	0.33	1					
TOC	0.187	0.077	0.117	-0.109	-0.049	-0.047	0.175	1				
FFI	.564**	0.141	0.179	-0.07	0.031	-0.228	0.258	0.207	1			
TSS	0.132	-0.2	-0.361	-0.291	-0.28	0.115	-0.008	0.092	0.275	1		
pH	-.424*	-0.074	-.413*	0.214	0.006	0.136	-0.019	-0.347	-.378*	-0.066	1	
TA	0.048	-0.01	-0.229	0.039	-0.127	-0.209	0.231	0.192	0.021	-0.081	0.215	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

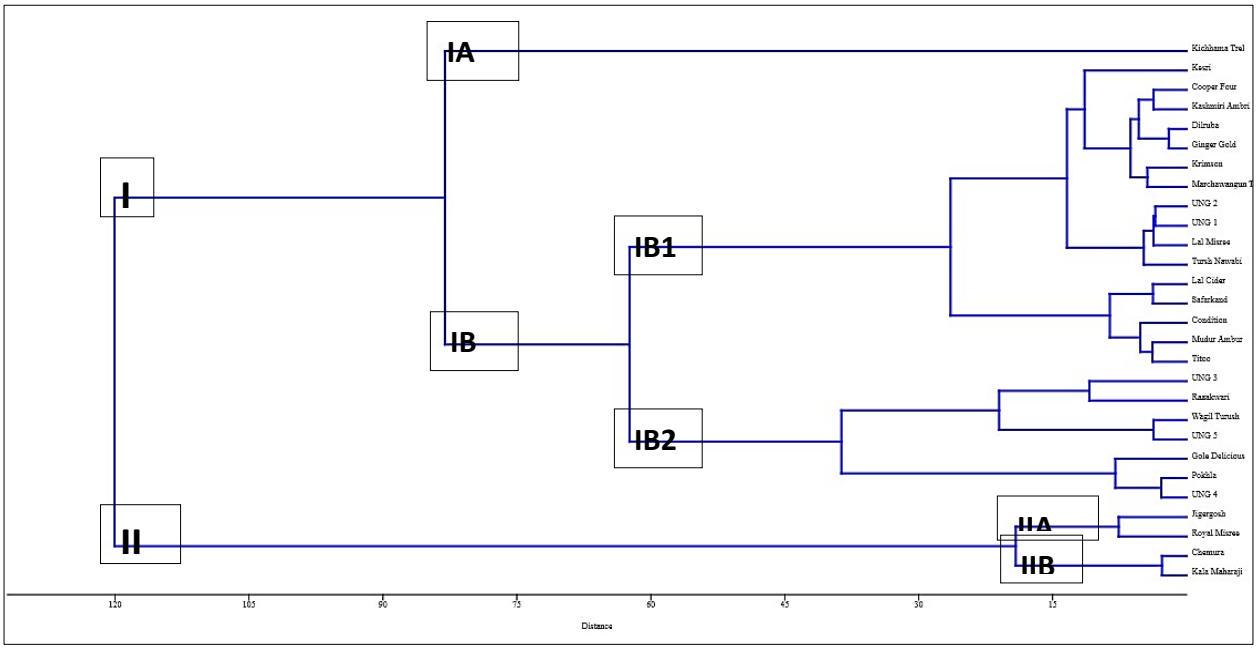

Fig 1 UPGMA dendrogram of the studied apple genotypes based on the 12 evaluated traits using Euclidean distances

Cluster analysis

In order to assess the variability for the fruit quality parameters of the apple genotypes under the current study, an unweighed Pair Group Method Analysis (UPGMA) dendrogram was constructed on the basis of the data of mean values of fruit quality traits recorded during the growing seasons of 2017-2020 by using Euclidean Distance method. All the 28 apple genotypes were grouped into two main clusters: cluster I and Cluster II (Fig 1). The main cluster I further divided into two sub-clusters IA which included only one genotype Kichham Trail having the smallest fruit size and fruit weight, while the sub-cluster IB which formed the largest sub-cluster further separated into two sub groups IB1 and IB2. The sub-group IB1 included 16 genotypes having smaller to medium fruit weights ranging from 57.10 g to 102.78 g, whereas the sub-group IB2 included 7 genotypes having the medium fruit weight varying from 116.00 g to 168.60 g. However, the main cluster II grouped 4 genotypes into two sub-clusters IIA and IIB having the highest fruit weight in the range of 203.64 g to 226.10 g. Our results showed close proximity to those of Mir *et al*. [9] who grouped apple cultivars on the basis of fruit quality and observed that weight and flesh firmness of the fruits were important traits for grouping apple cultivars and reported that cluster analysis proved efficient for discriminating the cultivars. Similarly, a study made by Dar *et al*. [11] also differentiated apple accessions into three clusters mainly based on fruit weight and TSS.

Table 6 Eigen values of the principal components from the PCA of the evaluated traits

Traits	Component				
	1	2	3	4	5
HPE	0.54*	0.66*	0.23	-0.06	-0.01
FWE	0.97*	0.03	-0.03	-0.02	-0.04
FSH	-0.20	0.50*	-0.68	0.09	0.33
FHE	0.92*	-0.32	0.04	0.04	-0.03
FWI	0.94*	-0.09	-0.02	-0.13	0.20
GCO	-0.15	-0.27	0.45	-0.46	0.61*
IOC	-0.10	0.36	0.49	0.20	0.67*
TOC	0.01	0.51*	0.17	0.25	0.03
FFI	0.15	0.76*	0.20	-0.06	-0.18
TSS	-0.26	0.20	0.58*	-0.45	-0.50
pH	-0.03	-0.75	0.27	0.25	0.00
TA	0.00	-0.01	0.40	0.85*	-0.12
Total	3.13	2.43	1.60	1.32	1.26
Percent of variance	26.09	20.29	13.34	11.01	10.54
Cumulative %	26.09	46.38	59.73	70.74	81.28

*Eigen values are significant ≥0.50

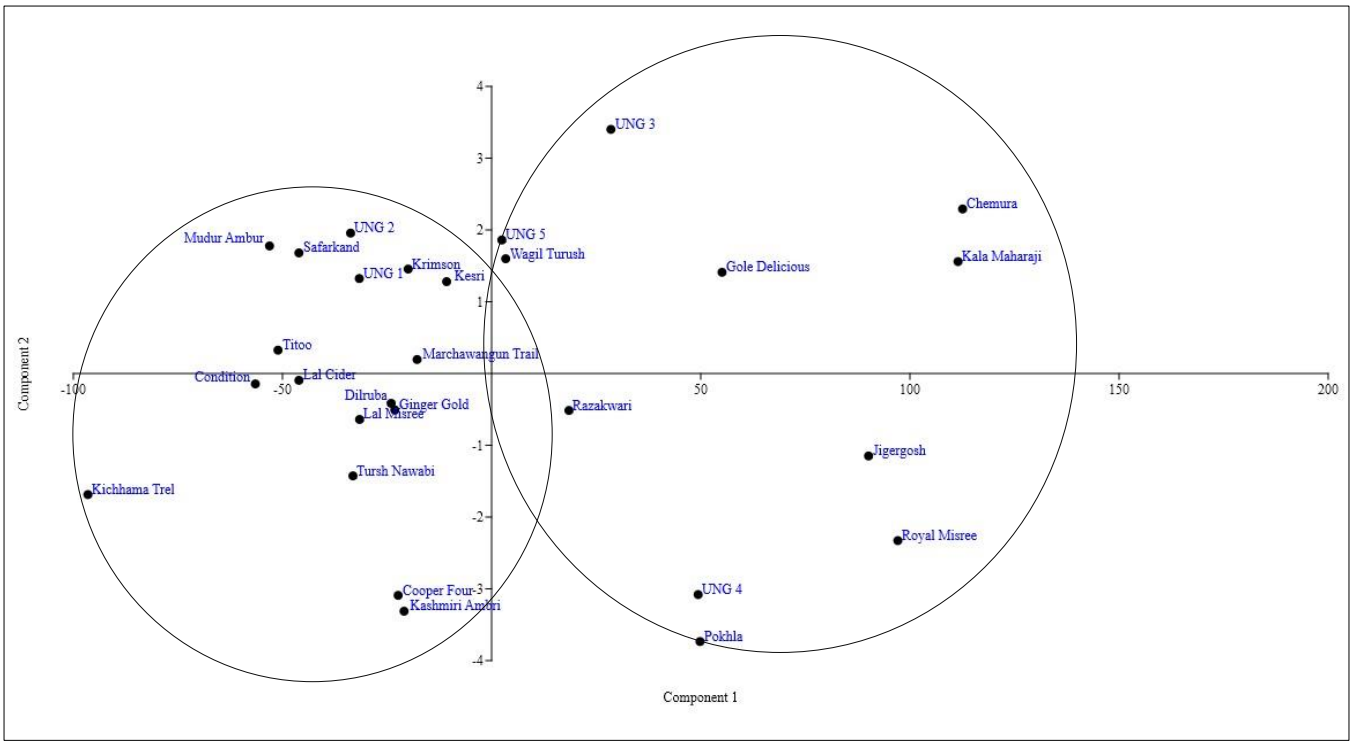

Fig 2 Scatter plot for the studied apple genotypes based on PC1 and PC2

Principal component analysis

Principal Component Analysis (PCA**)**, one of the multivariate statistical procedures was used to find out the main factors to reduce the number of traits for differentiating the studied apple genotypes. The PCA performed in the present study revealed that more than 80% of the recorded variability was defined by the first 5 components (Table 6). The first two components explained 46.38 % of the total variation, wherein

26.09% variation was on PC1 and 20.29% on PC2. The rest of the components (PC3 – PC5) altogether explained 34.89% of the total variance. For each factor, the traits with principal component loading ≥0.50 were considered as significant. The first component (PC1) was found positively correlated with harvesting period, fruit weight, fruit height, and fruit width. Similarly, the second component (PC2) was found to be significantly correlated with three characters including fruit shape, type of over colour, and fruit flesh firmness. These results showed consonance with those obtained by Rasool *et al*. [30], Hassan *et al*. [35] and Dar *et al*. [11] who reported that principal components accounted for 88.76%, 88.16% and 78% of the total trait variation respectively.

The scatter plot based on the principal component analysis was formed from the first two components PC1 and PC2. In the scatter plot, the formation of two clusters can be seen (Fig 2). A total of 11 genotypes with medium to high fruit weight, fruit height, fruit width, and fruit firmness were positioned more dispersedly on the right plane of the plot while the remaining 17 genotypes with smaller fruit weights and fruit dimensions, were positioned on the left plane of the PCA plot. Apart from the fruit quality traits, biochemical traits like TSS, pH and TA chiefly led to the formation of the two clusters. Results from both PCA and cluster analysis grouped 11 superior apple genotypes (UNG 3, Razakwari, Wagil Turush, UNG 5, Gole Delicious, Pokhla, UNG 4, Jigergosh, Royal Misree, Chemura and Kala Maharaji) on the basis of important fruit quality traits such as fruit harvesting period, fruit weight, fruit height, fruit width, fruit shape, type of over colour and fruit flesh firmness, that can be used in future national and international apple breeding programmes.

CONCLUSION

The assessed apple genotypes differ widely in all the evaluated fruit quality traits. The results are certainly representative and valuable, and will provide great opportunities for genetic gain through selection or hybridization of breeding resources for improving fruit quality traits and serve as a base for economically valuable phenotypes. The results of PCA and cluster analysis segregated 11 superior apple genotypes on the basis of fruit harvesting period, fruit weight, fruit height, fruit width, fruit shape, type of over colour and fruit flesh firmness. Fruit shape, weight, firmness, over colour, pH, TSS and TA seem to be crucial factors in determining the commercial success of any apple genotype. The present study confirmed the necessity of preserving these unique genetic resources for future breeding and improvement programmes and continuing their study as the present germplasm is suffering from the practice of monoculturing of some commercially elite apple genotypes with high market value. The information generated could be used to prepare genotype specific passport data information which in turn shall be helpful in the identification of these genotypes by the stakeholders.

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