

Research Article

Morphological Diversity among Accessions of Apple Tree (*Malus × Domestica* Borkh)

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Worldwide, apple ranks fourth in terms of economic importance after citrus, grapes, and bananas with a world production of above 71 million tonnes per year. Apple accessions that are in cultivation throughout the world appear to have come from a genetically similar source. Their diversity has further been decreased through the use of preferred few accessions in breeding programmes. Determination of morphological diversity among the accessions maintained at Nyanga Experimental Station is key for identification and informed use of the accessions in adaptive research. The purpose of this study was to determine the extent of morphological diversity among apple accessions conserved at Nyanga Experimental Station, Zimbabwe, and identify promising accessions for use as cultivars in warmer environments. Sixty-eight *Malus domestica* accessions of worldwide provenance all maintained at Nyanga Experimental Station were evaluated in a complete randomized design with three replications. The experiment was managed following the standard cultural practices for apples. Characterization using morphological markers was done following the format of the International Board for Plant and Genetic Resources (IBPGR). Data were subjected to cluster analysis based on the unweighted paired group method using arithmetic averages (UPGMA) method. A narrow genetic diversity was observed as reflected by the pairwise genetic similarity matrix that ranged from 80 to 100%. Promising accessions such as Anna, Mayaan, Michal, Elah, Tydeman's Early Worcester, Discovery, and Mollies Delicious were identified for use as cultivars in warmer areas.

1. Introduction

The cultivated apple (*Malus x domestica* Borkh) is a native of central Asia, in particular, the Tian Shan Mountains where western China borders with the former Soviet Union states up to the Caspian Sea [1]. Worldwide, apple ranks fourth in terms of economic importance after citrus, grapes, and bananas [2–4]. It occurs on all continents in a diverse environment that is reflective of its adaptive potential [5, 6]. It is one of the most important commercially grown horticultural crops in temperate zones of the world [7, 8]. Apples are rich in antioxidants such as α -tocopherol that have antiageing and anticancer properties [8–10]. Furthermore, apples have a unique flavour that makes them acceptable by

many consumers worldwide [11]. With a world production estimated at 68.7 million tonnes in 2018, apples rank third worldwide among the fresh fruits traded [12]. Apples also contribute immensely to the raw materials for the food and brewing industry, especially in the production of ciders [13, 14]. China is the largest world producer of apples accounting for 48% of the total world production [7]. In Zimbabwe, most of the apples are introductions with a few exceptions being chance seedlings and bud spots. Apple production is confined to the Eastern Highlands, Nyanga, in particular, where temperatures are sufficiently low in winter to support production. A significant source of apple germplasm exists within the collections conserved at Nyanga Experimental Station, which has not been adequately

characterized. Germplasm characterization will provide information on the traits of the accessions. Lack of such information limits the use that can be made of the collections, hence restricting the value and usefulness of the accessions to the institute and other users [15].

The food needs for the increasing population, climatic changes, urbanization, and industrialization, along with the destruction of forests, are the main challenges of modern life. Therefore, it is very important to evaluate plant genetic resources in order to cope with these problems [16]. Until recently, morphological and biochemical traits were used for distinguishing among populations and for their taxonomical classification. In addition, more recently, molecular markers have been used for the classification of different plant species [17]. Determining morphological diversity in cultivated apple accessions allows for the quantification of the variation that still exists in the currently cultivated apple germplasm. It, therefore, becomes imperative to identify gaps in which new initiatives will be required and promote necessary resources mobilization. Since it is highly probable that the apple accessions that have been introduced to Zimbabwe may have some desirable allelic diversity useful for the improvement of fruit quality, adaptive potential, and other agronomic traits, it becomes a necessity to characterize and conserve a wide array of the genetic pool of the domestic apple. It is apparent that apple genetic diversity has been narrowing as revealed by the fact that only an estimated 20–22% of apple genetic resources have survived the gene pool decrease. This necessitates characterization and conservation of the apple germplasm to prevent further loss [18]. Diverse apple genetic resources avail opportunities to breeders to develop new and improved apple cultivars with desirable characteristics that encompass traits preferred by farmers such as yield potential and large fruits and those preferred by breeders such as pest and disease resistance and photosensitivity [19]. The knowledge that genetic diversity is the central pillar of biodiversity, diversity within species, between species, and of ecosystems, necessitates characterization of accessions to facilitate the making of proper choices of parental materials by breeders [19–21].

Characterization is done through the use of two main markers individually or in tandem. The markers could be morphological or molecular in nature. In this study, characterization was done through the use of morphological descriptors that are highly heritable and are easy to score. The use of morphological descriptors to characterize trees and fruits is the first and key procedure in the description, classification, and characterization of collections of germplasm [22]. Apple genetic diversity studies cast some light on information that could be used to answer questions related to crop breeding, evolution, domestication, and conservation of apple accessions. Morphological characterization enables easy and quick discrimination among phenotypes and permits grouping of the accessions. Genetic diversity analysis in germplasm collections generates information that can be assembled to enhance the reliable classification of

accessions and identification of subsets of core accessions that may have utility for specific breeding purposes [22].

There is a significant source of apple germplasm within the collections conserved at Nyanga Experimental Station where accession number is above 60. Most of these accessions are inadequately characterized introductions, chance seedlings, and bud spots. This then implies the existence of a huge set of accessions that require characterization to facilitate utilization and conservation. To utilize the collections effectively, the materials have to be characterized and analyzed. Through characterization, duplications could be exposed and eliminated, thereby saving the resources needed for conservation. Characterization could enable the identification of varieties that have desirable agronomic and quality traits and with the potential to be grown beyond the major apple production zones. Current commercially grown varieties are those adaptable to Eastern Highlands conditions, Nyanga, in particular, where temperatures are sufficiently low to support production (to provide adequate chilling). Identification of early flowering (low chill) accessions could allow apple production to be expanded to less cold conditions where such relatively high temperatures can effectively induce flowering. The objective of this study was to characterize 68 apple accessions conserved at Nyanga Experimental Station based on morphological markers.

2. Materials and Methods

2.1. Study Site. The research was carried out at Nyanga Experimental Station (18°S, 33°E), which is located within the Nyanga National Park, 15 km away from Nyanga town. The experimental station is at an altitude of 1800 m above sea level and falls within the agroecological zone classified as Natural Region One, which lies within the 1200 mm mean annual rainfall belt. Summer mean maximum temperatures of 17°C and mean minimum temperature of 15°C are experienced per annum. Frost is prevalent at the station. The soils are deep clay loams having a pH range of 5.5–6.0 (CaCl₂).

2.2. Apple Materials. Among the 68 apple accessions, chance seedlings (Granny Smith and Marjorie Pye), bud spots, and improved varieties of worldwide provenance were evaluated in the 2015/2016 and 2016/2017 cropping seasons (Table 1). Some of the accessions are commercial varieties such as Golden Delicious, Starking, Braeburn, Gala, Mollie's Delicious, Top Red, Granny Smith, Pink Lady, Fuji, Starking, and Mutsu while others such as Sweet Connelly, Macoun, Braeburn, Cox's Orange Pippin, Golden Delicious, Jonagold, Spartan, Northern Spy, Lodi, Red Astrachan, and Egremont Russet are heirloom varieties whereas some varieties such as Tydeman's Early Worcester, Anna, Michal, Mayaan, and Rushinga, a seedling of Mayaan, have less chilling requirement. Some cultivars have both good culinary and eating attributes, for example, Granny Smith, yet others have

TABLE 1: Names and codes of the apple germplasm evaluated.

Entry number	Entry code	Entry name	Origin
1	AN	Anna	Israel
2	CC	Cheddar Cross	England
3	EH	Elah	Israel
4	MN	Mayaan	Israel
5	ML	Michal	Israel
6	TEW	Tydeman's EW	United Kingdom
7	VB	Vista Bella	USA
8	SK	Starking	USA
9	DY	Discovery	England
10	DK	Drakenstein	South Africa
11	EA	Emperor Alexander	Ukraine
12	GA	Gala	New Zealand
13	MD	Mollie's Delicious	USA
14	MW	Merton Worcester	England
15	MR	Michaelmas Red	England
16	OD	Odin	New Zealand
17	PR	Paula Red	USA
18	SC	Sweet Connelly	England
19	SKR	Starkrimson	USA
20	SR	Summer Red	Canada
21	BS	Bowless Seedling	Zimbabwe
22	BC	Buncombe	USA
23	CA	Cornish Aromatic	England
24	ER	Egremont Russet	England
25	GD	Golden Delicious	USA
26	LS	Laxton Superb	England
27	LL	Lord Lambourne	England
28	LSU	Lord Suffield	England
29	MCN	Macoun	USA
30	MT	Mutsu	Japan
31	JG	Jonagold	USA
32	OH	Ohinemuri	Australia
33	RA	Red Astrachan	Russia
34	SFFTRI	Spartan FFTRI	Canada
35	SEXIRE	Spartan EXIRE	Canada
36	SR	Splendour	New Zealand
37	SP	Sturmer Pippin	England
38	SS	Sunset	England
39	TR	Top Red	USA
40	WP	Waveny AC Pye	Zimbabwe
41	WD	Wellspur Delicious	USA
42	WQ	Winter Quarrenden	England
43	BB	Braeburn	New Zealand
44	DT	Democrat	Australia
45	HY	Hartley	Zimbabwe
46	LW	Lady Williams	Australia
47	MP	Marjorie Pye	Zimbabwe
48	PA	Primicia	Brazil
49	RUS	Rushinga	Zimbabwe
50	SM	Schwim	Zimbabwe
51	WN	Winston	England
52	GS	Granny smith	Australia
53	IP	Irish Peach	Ireland
54	LI	Lodi	USA
55	CE	Chap's Early	USA
56	HC	Holstein Cox	Germany
57	CN	Champion	USA
58	CO	Commerce	USA
59	COP	Cox's Orange Pippin	England
60	MR	Mother	USA

TABLE 1: Continued.

Entry number	Entry code	Entry name	Origin
61	TO	Twenty Ounce	USA
62	EKP	Early King of Pippins	France
63	NS	Northern Spy	USA
64	COE	Cox's Orange ex-Kortgard	Denmark
65	CON	Cox's Orange Noble	England
66	RDC	Reinette du Canada	France
67	ANP	American Non-Pareil	USA
68	RP	Ribston Pippin	England

good cider-making qualities, for instance, Schwim, Cox's Orange Pippin, and Northern Spy.

2.3. Experimental Design and Management. One-year-old apple seedlings grafted on MM106 clonal rootstock were planted in holes 60 cm wide \times 60 cm long \times 60 cm deep, spaced at 2 m within the row and 4 m between the rows. The 68 apple accessions were planted in a complete randomized design with 3 replicates. A plot consisted of a single tree. Compound J (15N: 5P: 20K) fertilizer and agricultural lime were applied at planting at the rate of 1000 g each per planting station. Weeds were controlled using mechanical methods (tractor-drawn gladiator mower). Pest control for the following pests was exercised: woolly aphids, pernicious scale, and powdery mildew. Woolly aphids were controlled using Dimethoate 400 EC at the rate of 120 ml per 100 litres of water per hectare. The pernicious scale was controlled using orchard oil applied at the rate of 1.5 litres per 100 litres of water per hectare, and powdery mildew and scab were controlled using Copper Oxychloride WP 850 g per kg applied at the rate of 250 g per 100 litres of water per hectare. The perfo-rain overhead irrigation system was used at the rate of 34 mm per fortnight.

2.4. Data Collection. Apple accessions data were collected and recorded using the International Board for Plant and Genetic Resources (IBPGR) descriptor list for apples [23] focussing on the following parameters: origin, tree vigour, tree habit, bitter pit susceptibility, bruising susceptibility, season of flowering, secondary flowering, regularity of flowering, self-compatibility of flowers, fruit size, fruit shape (Figure 1), texture, firmness without skin, eating quality dessert, ground colour, overcolour, type of overcolour, fruit attractiveness, russet type, russet amount, harvest maturity, maximum storage life, eating maturity, and chill hours (Table 2). Chill units were calculated using the Utah model that assigns one full chill unit per hour for temperatures between 3 and 9°C starting from mid-May to mid-September.

2.5. Data Analysis. Multivariate analysis of variance (MANOVA) for phenotypic traits was carried out using Genstat 14 [24]. The resultant means were used for hierarchical cluster analysis using Euclidean distance and the unweighted paired group method using arithmetic averages (UPGMA) method.

3. Results

Results from the hierarchical cluster analysis showed that the apple accessions had a similarity range of 80–100% (Figure 2). When the dendrogram was cut at an 87.5% similarity level, 12 groups were formed, and these groups had several clusters under them.

3.1. Group One. This group had eight accessions namely, Anna, Elah, Michal, Tydeman's Early Worcester, Mollies Delicious, Paula Red, Cheddar Cross, and Vista Bella. The group formed six clusters.

3.1.1. Cluster I. The accessions Anna and Michal fell under cluster I. They were 90.5% similar. They all originated from Israel and had a globose fruit shape, green-yellow ground colour, good fruit attractiveness, very fine russet type, very early harvest maturity, good eating quality dessert, intermediate bitter pit susceptibility, intermediate bruising susceptibility, very fine fruit texture, very poor maximum storage life at room temperature, high susceptibility to woolly aphid, an upright tree habit, vigorous tree growth habit, extremely early flowering season, and an intermediate secondary flowering. The dissimilarities on the two accessions were based on the traits, fruit size, fruit overcolour, and type of fruit overcolour. Anna had a medium-large fruit size, whereas Elah had a medium fruit size. Anna had a red fruit overcolour compared to Elah's brown. Anna had a mottled type of fruit overcolour, while Elah had a slightly blushed overcolour.

3.1.2. Cluster II. The accessions Michal and Tydeman's Early Worcester fell under cluster II. The similarity between them was 99.1%. These two accessions had a green-yellow ground colour, good eating quality dessert, intermediate bitter pit susceptibility, intermediate-to-high bruising susceptibility, soft fruit firmness without skin, very poor maximum storage life, high susceptibility to woolly aphid, fine flesh texture, high susceptibility to powdery mildew, spreading tree habit, an early season of flowering, regular flowering habit, an intermediate secondary flowering, and a good self-compatibility of flowers. Dissimilarities were observed on the place of origin, fruit shape, fruit overcolour, fruit attractiveness, type of fruit overcolour, russet amount, and harvest maturity. Michal originated from Israel, while Tydeman's Early Worcester originated from England. Michal had a red

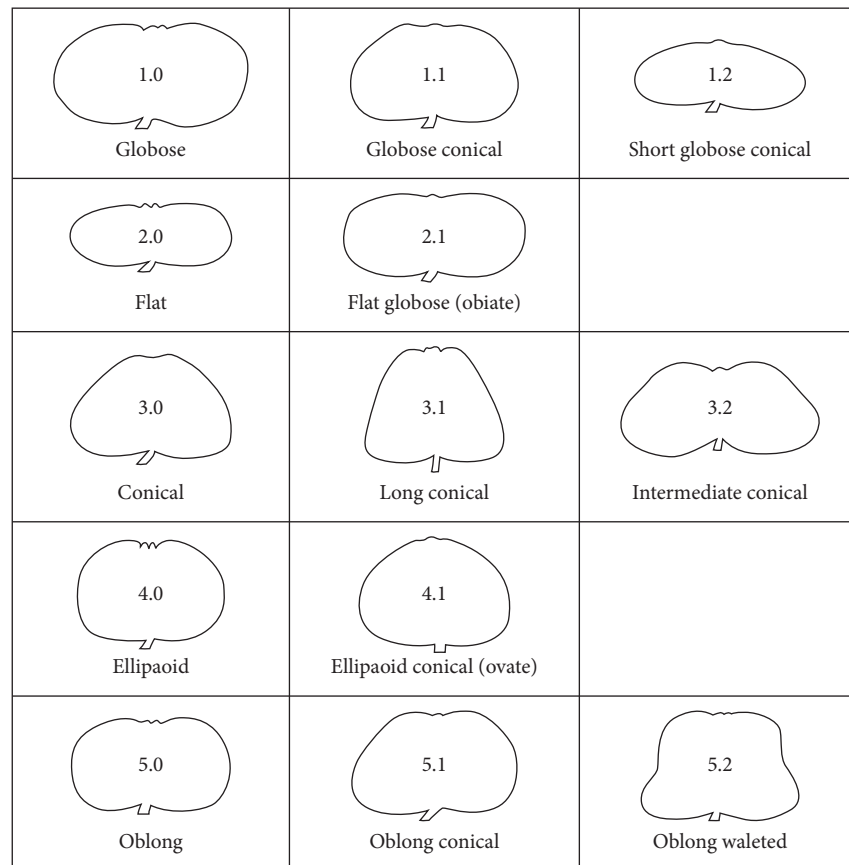


FIGURE 1: Apple fruit shapes [23].

TABLE 2: Description of traits measured.

Trait	Measurement
Origin	Countries were given codes ranging from 1 to 13. Australia had code 1, Canada 2, England 3, Israel 4, Denmark 5, France 6, South Africa 7, Russia 8, USA 9, Zimbabwe 10, Ireland 11, and Germany 12.
Fruit shape	Measured on a score of 1.0–5.2 (Figure 1).
Fruit size	Measured in comparison to reference cultivars and on a score of 1–9 (Figure 1): a score of 1 showing an extremely small fruit and 9 showing an extremely large fruit.
Ground colour	The ground colour was determined on the ground colour of the skin of a fully mature fruit. It was measured on the score of 1–6: a score of 1 represented red colour, 2 orange, 3 cream-white, 4 yellow, 5 green-yellow, and 6 green.
Overcolour	Overcolour of the skin of a fully mature fruit was determined on score of 1–6, where 1 represented orange, 2 pink, 3 red, 4 dark red, 5 purple, and 6 brown
Fruit attractiveness	Fruit attractiveness was determined subjectively as it varies between regions and experts and was scored on a scale of 1–9 with a score of 1 indicating extremely poor and reference cultivar being Egremont Russet and 9 showing extremely good and the reference cultivar being the Discovery.
Type of overcolour	Type of overcolour was determined on the score of 1–8. The score of 1 represented striped, 2 streaked, 3 mottled, 4 splashed, 5 slightly blushed, 6 washed out (faded), 7 complete overcolour, and 8 others.
Russet type	Measured on a scale of 1–9: a score of 1 represented extremely fine, 2 very fine, 4 intermediate, 6 coarse, 8 scaly, and 9 cracked.
Russet amount	Measured as a percentage of fruit surface russetted. Russet amount was scored on a scale of 1–9: a score of 1 represented 0%, 2 represented 12%, 3 stood for 25%, 4 for 37%, 5 for 50%, 6 for 62%, 7 for 75%, 8 for 87%, and 9 for 100% russet.
Eating quality dessert	This was measured through a qualitative combined assessment of flavour, acidity, sweetness, aroma, and astringency at the optimum time of eating. This was scored on a scale of 1–9 where a score of 1 reflected the extremely poor eating quality and 9 showed extremely good eating quality.
Bitter pit susceptibility	This was determined by randomly sampling 10 fruits per cultivar in the field and observing if they had bitter pit. A score of 0–9 was used, where a score of 0 depicted absence of bitter pit whereas 9 indicated extreme severity.

TABLE 2: Continued.

Trait	Measurement
Bruising susceptibility	Bruising susceptibility was determined by observing the condition of a fully mature fruit in a storage tray. It was measured on a scale of 1–9, where a score of 1 indicated extremely slight bruising while 9 showed extremely high susceptibility to bruising.
Firmness without skin	Fruit firmness without skin was recorded in kilograms on fruit that was just ripe on a part of the fruit from which the outer skin had been removed using a penetrometer that had an 8 mm probe. The pressure required to penetrate was scored on a 1–5 scale where 1 indicated extreme softness and 5 showed extreme firmness with reference cultivar being Granny Smith.
Texture	This was measured on the basis of the texture of the flesh of a ripe fruit. It was scored on a score of 1–9 with a score of 1 representing extremely coarse flesh and 9 showing extremely fine texture.
Maximum storage life	Maximum storage life was determined through keeping 5 of each fruit type at room temperature and observing which one deteriorated first, and a score of 1–9 was assigned: a score of 1 indicating extremely poor maximum storage life while 9 indicated extremely good maximum storage life at room temperature.
Pest susceptibility	Pest susceptibility was determined through the presence of key apple pests on the plants such as apple woolly aphid, codling moth, and the rosy apple aphid. The presence of the apple woolly aphid was given a score of 8, codling moth a score of 9, and rosy apple aphid a score of 10
Fungi susceptibility	Fungi susceptibility was determined on the presence of certain types of fungi on a score of 1–3. A score of 1 indicated presence of <i>Podosphaera laucotricha</i> (mildew), 2 presence of <i>Venturia inaequalis</i> (scab), and 3 <i>Nectria galligena</i> (canker), <i>Phytophthora cactorum</i> (collar rot and root rot)
Tree habit	Measured on the basis of the natural habit of branches of the untrained tree and a score of 1–9 with a score of 1 indicating extremely upright, 5 indicating spreading habit, 7 showing drooping habit, and 9 reflecting a weeping habit.
Tree vigour	Measured on a score of 1–9 with a score of 1 reflecting extreme weakness and 9 showing extreme vigour based on reference cultivars.
Flowering period	Measured on a score of 1–9 with a score of 1 indicating extremely early and 9 showing extremely late.
Regularity of flowering	Measured on a score of 1–9 with a score of 1 indicating extremely irregular, 5 showing biennialism, and 9 reflecting extremely regular flowering habit.
Secondary flowering	Measured on a score of 1–9 with a score of 1 indicating extremely rare, 7 showing frequent, and 9 reflecting extremely frequent secondary flowering.
Self-compatibility	Assessed by artificially self-pollinating flowers on a tree. The outcome was grouped as self-compatible when fruits set or self-incompatible when fruits do not set.

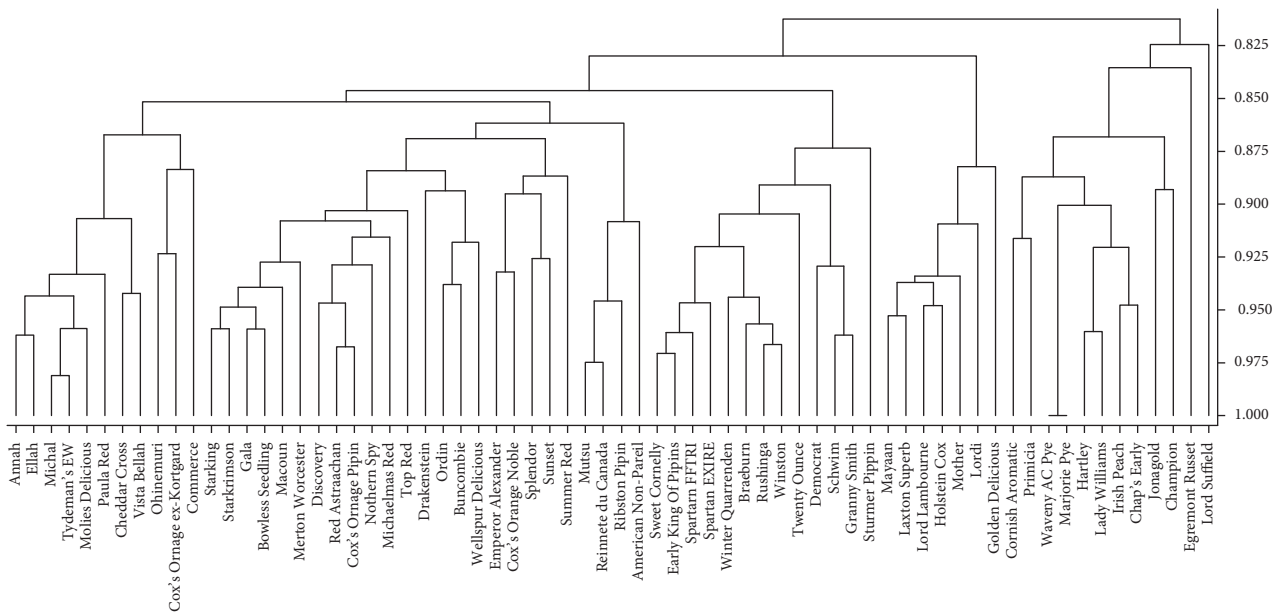


FIGURE 2: Dendrogram of apple accessions relatedness.

fruit overcolour, whereas Tydeman's Early Worcester had a dark-red overcolour. Michal had intermediate fruit attractiveness, while Tydeman's EW had a good one. Michal had a

striped type of overcolour compared to Tydeman's Early Worcester's mottled one. Russet amount for Michal was 37%, while that for Tydeman's Early Worcester was 12%.

Michal had a very early harvest maturity, whereas Tyde-man's Early Worcester had an intermediate harvest maturity.

3.1.3. Cluster III. This cluster had only one accession, Mollies Delicious (Figure 2). It had a medium fruit size, green-yellow ground colour, an intermediate russet type, good eating quality dessert, intermediate bitter pit susceptibility, soft fruit firmness without skin, very poor maximum storage life, high woolly aphid susceptibility, an early flowering season, regular flowering, an intermediate secondary flowering, and good self-compatibility of flowers.

3.1.4. Cluster IV. In this cluster, there was only one accession, namely, Paula Red (Figure 2). It had a green-yellow ground colour, good eating quality dessert, high susceptibility to woolly aphids, an intermediate secondary flowering, good self-compatibility of flowers, and an intermediate bitter pit susceptibility.

3.1.5. Cluster V. The accessions Cheddar Cross and Vista Bella fell under this cluster. These two accessions were 85.5% similar. These two accessions had a medium fruit size, green ground colour, red overcolour, very fine russet type, poor eating quality dessert, poor maximum storage life, high susceptibility to woolly aphid, fine fruit texture, soft to intermediate fruit firmness without skin, an upright tree habit, intermediate tree vigour, an extremely early flowering season, exhibited biennial flowering, an intermediate secondary flowering, and a good self-compatibility of flowers.

3.2. Group Two. This group had only three accessions, namely, Ohinemuri, Cox's Orange ex-Kortgard, and Commerce. They were approximately 88.75% similar.

3.2.1. Cluster I. Cluster I consisted of the accessions Ohinemuri and Cox's Orange ex-Kortgard. The accessions were merged at a 97% similarity level. These had dissimilarities in the following attributes: Ohinemuri had a pink fruit overcolour, while Cox's Orange ex-Kortgard had a dark-red fruit overcolour. Ohinemuri had an extremely good fruit attractiveness, while Cox's Orange ex-Kortgard had intermediate fruit attractiveness. Ohinemuri had a complete type of overcolour, whereas Cox's Orange ex-Kortgard had a striped type of overcolour. Ohinemuri had an intermediate russet type, while Cox's Orange ex-Kortgard had a very fine russet type. In terms of russet amount, Ohinemuri had 12% russet, and Cox's Orange ex-Kortgard had 62%. Ohinemuri had a very early harvest maturity, while Cox's Orange ex-Kortgard had a late harvest maturity. Ohinemuri had an intermediate eating quality dessert compared to Cox's Orange ex-Kortgard's good eating quality dessert. Ohinemuri had a severe susceptibility to bitter pit, while Cox's Orange ex-Kortgard had a slight susceptibility to bitter pit. Ohinemuri had slight susceptibility to bruising, while Cox's Orange ex-Kortgard slight-to-intermediate bruising

susceptibility. Ohinemuri had intermediate fruit firmness without skin, and Cox's Orange ex-Kortgard had very soft fruit firmness without skin. Ohinemuri had an intermediate flesh texture, while Cox's Orange ex-Kortgard had fine flesh texture. Ohinemuri had a good maximum storage life compared to Cox's Orange ex-Kortgard's with a very poor maximum storage life. Ohinemuri had a severe susceptibility to the woolly aphid, while Cox's Orange ex-Kortgard had an intermediate susceptibility to woolly aphids. Ohinemuri had intermediate tree vigour, whereas Cox's Orange ex-Kortgard had vigorous tree vigour.

3.2.2. Cluster II. The accession Commerce fell under cluster II (Figure 2). Commerce had yellow ground colour, high susceptibility to powdery mildew, an upright tree habit, a flat globose fruit shape, medium-to-large fruit size, irregular flowering, rare secondary flowering, striped type of overcolour, and very fine russet type.

3.3. Group Three. This group had the accessions Starking, Starkrimson, Gala, Bowless Seedling, Macoun, Merton Worcester, Discovery, Red Astrachan, Cox's Orange Pippin, Northern Spy, Michaelmas Red, Top Red, Drakenstein, Odin, Buncombe, and Wellspur Delicious. These accessions were clustered together at the 88.75% similarity level (Figure 2).

3.3.1. Cluster I. This cluster had two accessions that were Starking and Starkrimson. The similarity between them was 96.8% (Figure 2). These two had a medium fruit size, yellow ground colour, dark-red overcolour, good fruit attractiveness, very fine russet type, 12% russet amount, fine fruit texture, high susceptibility to woolly aphid, high susceptibility to powdery mildew, an upright tree habit, vigorous tree vigour, regular flowering, incompatible flowers, and a United States of America origin. In terms of dissimilarities, Starking had an ellipsoid fruit shape, striped type of overcolour, medium-to-late harvest maturity, an intermediate-to-good eating quality dessert, slight bitter pit susceptibility, an intermediate-to-severe bruising susceptibility, extremely firm fruit firmness without skin, poor maximum storage life, an intermediate-to-late flowering season, and an intermediate secondary flowering, while Starkrimson had an intermediate conical fruit shape, mottled type of fruit overcolour, early-to-medium harvest maturity, good eating quality dessert, an intermediate bitter pit susceptibility, slight-to-intermediate bruising susceptibility, intermediate-to-firm fruit firmness without skin, good maximum storage life, an intermediate season of flowering, and rare secondary flowering.

3.3.2. Cluster II. The accessions Gala and Bowless Seedling fell under this cluster, and they were merged at 93.5%. These accessions both had a medium fruit size, slight-to-intermediate bitter pit susceptibility, fine fruit texture, high susceptibility to woolly aphid, an upright tree habit,

intermediate tree vigour, regular flowering, and an intermediate secondary flowering.

3.3.3. Cluster III. This cluster had only a single accession, Macoun (Figure 2). Macoun had an intermediate fruit size, good fruit attractiveness, striped type of fruit overcolour, very fine russet type, fine flesh texture, high susceptibility to woolly aphid, high susceptibility to powdery mildew, an upright tree habit, an intermediate season of flowering, regular flowering, and an intermediate secondary flowering.

3.3.4. Cluster IV. This cluster also had a single accession, Merton Worcester (Figure 2) Merton Worcester had an intermediate fruit size, fine fruit texture, high susceptibility to woolly aphid, an upright tree habit, and a regular flowering.

3.3.5. Cluster V. Cluster V had only the accession, Discovery (Figure 2). Discovery had medium fruit size, striped type of overcolour, an early harvest maturity, good eating quality dessert, soft-to-intermediate fruit firmness without skin, high susceptibility to woolly aphid, an upright tree habit, intermediate tree vigour, good fruit attractiveness, a fine flesh texture, an intermediate maximum storage life, and an intermediate self-compatibility of flowers.

3.3.6. Cluster VI. Cluster VI comprised the accessions Red Astrachan and Cox's Orange Pippin. These accessions were 89.6% similar. The characteristics that joined them together were a medium fruit size, good fruit attractiveness, striped type of overcolour, an early harvest maturity, good eating quality dessert, soft fruit firmness without skin, fine flesh texture, an intermediate maximum storage life, high susceptibility to woolly aphid, high susceptibility to powdery mildew, an upright tree habit, intermediate tree vigour, an intermediate secondary flowering, and an intermediate self-compatibility of flowers.

3.3.7. Cluster VII. The accession Northern Spy (Figure 2) fell under this cluster. Northern Spy had striped fruit overcolour, good eating quality dessert, fine flesh texture, high susceptibility to woolly aphid, high susceptibility to powdery mildew, an upright tree habit, intermediate tree vigour, an intermediate secondary flowering, a medium fruit size, an early harvest maturity, and a soft-to-intermediate fruit firmness without skin.

3.3.8. Cluster VIII. Michaelmas Red was the only accession in this cluster (Figure 2). Michaelmas Red had a good eating quality dessert, intermediate susceptibility to powdery mildew, an upright tree habit, intermediate tree vigour, and an intermediate self-compatibility of flowers.

3.3.9. Cluster IX. The Top Red accession was also clustered singly (Figure 2). Top Red had a striped type of fruit overcolour, 12% russet amount, high susceptibility to woolly aphid, and an intermediate secondary flowering.

3.3.10. Cluster X. Drakenstein was also a lone accession under this cluster (Figure 2). Drakenstein had a high susceptibility to woolly aphid, an upright tree habit, a small-to-medium fruit size, and an intermediate regularity of flowering.

3.3.11. Cluster XI. The accessions Odin and Buncombe fell under this cluster. Odin and Buncombe were 93.1% similar. They both had a medium fruit size, dark-red fruit overcolour, poor eating quality dessert, slight bitter pit susceptibility, upright tree habit, regular flowering habit, and an intermediate secondary flowering.

3.3.12. Cluster XII. Cluster XII had only the accession, Wellspur Delicious (Figure 2). Wellspur Delicious had a medium fruit size, high susceptibility to woolly aphid and an upright tree habit, a red fruit overcolour, good eating quality dessert, intermediate-to-severe bitter pit susceptibility, and exhibited rare secondary flowering.

3.4. Group Four. Group four had five accessions, and they were Emperor Alexander, Cox's Orange Noble, Splendour, Sunset, and Summer Red. The group was merged at about a 88.75% similarity level. Three clusters were formed under this group (Figure 2).

3.4.1. Cluster I. Cluster I comprised the accessions Emperor Alexander and Cox's Orange Noble. The two accessions had a 93.5% similarity. Both accessions had a large fruit size, red fruit overcolour, good fruit attractiveness, 87% russet amount, poor eating quality dessert, slight bitter pit susceptibility, coarse flesh texture, poor maximum storage life, high susceptibility to woolly aphid, an upright tree habit, vigorous tree vigour, regular flowering habit, and an intermediate secondary flowering.

3.4.2. Cluster II. The accessions Splendour and Sunset fell under this cluster. The similarity between the two accessions was 92.5%. The two had an orange type of overcolour, a very fine russet type, good eating quality dessert, firm fruit firmness without skin, high susceptibility to apple woolly aphid, an upright tree habit, intermediate tree vigour, intermediate season of flowering, intermediate secondary flowering, and self-compatibility of flowering.

3.4.3. Cluster III. This cluster had a single accession, Summer Red (Figure 2). They both had an orange fruit overcolour, very fine russet type, good eating quality dessert, and soft-to-intermediate fruit firmness without skin, high susceptibility to woolly aphid, an upright tree habit, intermediate tree vigour, intermediate season of flowering, an intermediate secondary flowering, and an intermediate self-compatibility of flowers.

3.5. *Group Five*. In this group, four accessions were clustered together, and they were Mutsu, Reinette du Canada, Ribston Pippin, and American Non-Pareil. These were merged at approximately 91.25% similarity level (Figure 2). Three clusters were formed under this group (Figure 2).

3.5.1. *Cluster I*. The accessions that fell under this cluster were Mutsu and Reinette du Canada. The two had a 99.2% similarity. They both had an orange fruit overcolour, very fine russet type, good eating quality dessert, soft-to-intermediate fruit firmness without skin, high susceptibility to woolly aphid, an upright tree habit, intermediate tree vigour, an intermediate season of flowering, an intermediate secondary flowering, and an intermediate self-compatibility of flowers.

3.5.2. *Cluster II*. In cluster II, there was only one accession, and this was Ribston Pippin (Figure 2). Ribston Pippin had a brown fruit overcolour, good eating quality dessert, soft-to-intermediate fruit firmness without skin, high susceptibility to woolly aphid and powdery mildew, spreading tree habit, regular flowering habit, an intermediate secondary flowering, an intermediate self-compatibility of flowering, a coarse flesh texture, medium-to-late harvest maturity, splashed type of fruit overcolour, good fruit attractiveness, and an intermediate fruit shape.

3.5.3. *Cluster III*. Likewise, cluster three had only the accession American Non-Pareil (Figure 2). American Non-Pareil had a good eating quality dessert, high susceptibility to woolly aphid and powdery mildew, regular flowering habit, an intermediate secondary flowering and self-compatibility of flowers, a drooping tree habit, soft fruit firmness without skin, and a purple fruit overcolour.

3.6. *Group Six*. The accessions Sweet Cornelle, Early King of Pippins, Spartan FFTRI, Spartan EXIRE, Winter Quarrenden, Braeburn, Rushinga, Winston, Twenty Ounce, Democrat, Schwim, Granny Smith, and Sturmer Pippin fell under this group (Figure 2). They were approximately 88.75% similar. Nine clusters were formed under this group (Figure 2).

3.6.1. *Cluster I*. The accession Sweet Connelly and Early King of Pippins were the members of cluster I. They were 97.2% similar. The accessions had a similar fruit shape, a medium fruit size, similar ground colour, an early harvest maturity, low susceptibility to bitter pit, and an early flowering period.

3.6.2. *Cluster II*. In this cluster, there was only the accession Spartan FFTRI (Figure 2). It had an intermediate fruit size, good fruit attractiveness, very early harvest maturity, good eating quality dessert, high susceptibility to woolly aphid and powdery mildew, an upright tree habit, an early flowering period, and a regular flowering habit.

3.6.3. *Cluster III*. Cluster III had also a single accession Spartan EXIRE (Figure 2). It had a large-to-very-large fruit size, intermediate fruit attractiveness and harvest maturity, high susceptibility to woolly aphid and powdery mildew, an upright tree habit, intermediate tree vigour, an intermediate flowering period, and regular flowering habit.

3.6.4. *Cluster IV*. The accession Winter Quarrenden was the lone member of this cluster (Figure 2). It originated from England and had an intermediate fruit size, good fruit attractiveness, good eating quality dessert, an intermediate-to-late harvest maturity, highly susceptible to woolly aphid and powdery mildew, an upright tree habit, a medium flowering period, and a regular flowering habit.

3.6.5. *Cluster V*. Braeburn was the only accession in this cluster (Figure 2). It had a medium fruit size, intermediate fruit attractiveness, a late harvest maturity, good eating quality dessert, high susceptibility to woolly aphid and powdery mildew, a late flowering period, and a regular flowering period.

3.6.6. *Cluster VI*. Two accessions, Rushinga and Winston, were the members of this cluster (Figure 2). Rushinga and Winston had an 88.7% similarity. They had a similar fruit shape, ground colour of the fruit, fruit overcolour, a striped type of fruit overcolour, medium fruit size, late harvest maturity, good eating quality dessert, fine flesh texture, high susceptibility to woolly aphid and powdery mildew, an upright tree habit, an intermediate flowering period, and a regular flowering habit.

3.6.7. *Cluster VII*. This cluster had only the accession Twenty Ounce (Figure 2). It had a large fruit size, good fruit attractiveness, an intermediate harvest maturity, an intermediate-to-good eating quality dessert, high susceptibility to woolly aphid and powdery mildew, an upright tree habit, an early-to-intermediate flowering period, and a regular flowering habit.

3.6.8. *Cluster VIII*. Democrat was the only accession in this cluster (Figure 2). It had an intermediate-to-large fruit size, a striped type of fruit overcolour, late harvest maturity, poor eating quality dessert, high susceptibility to woolly aphid and scab, an upright tree habit, a late flowering period, and a regular flowering period.

3.6.9. *Cluster IX*. This cluster comprised the accessions Schwim and Granny Smith, and they were merged at the 95.1% similarity level. They had a late flowering period, very late harvest maturity, green ground colour, good fruit attractiveness, poor eating quality dessert, an upright tree habit, an intermediate secondary flowering, and good self-compatibility of flowers.

3.7. *Group Seven.* This group was a single accession group (Figure 2). It had the accession Sturmer Pippin that amalgamated with group six at the 87.5% similarity level. It originated from England and had good fruit attractiveness, 12% russet amount, very late harvest maturity, good eating quality dessert, low susceptibility to bruising, late flowering period, regular flowering habit, and high susceptibility to woolly aphids.

3.8. *Group Eight.* There were seven accessions in this group that included Mayaan, Laxton Superb, Lord Lambourne, Holstein Cox, Mother, Lodi, and Golden Delicious. They were approximately 88% similar. Five clusters were formed in this group (Figure 2).

3.8.1. *Cluster I.* This cluster consisted of the accessions Mayaan and Laxton Superb. The similarity between them was 91.6%. They had good fruit attractiveness, a medium fruit size, 12% russet amount, very fine russet type, fine flesh texture, high susceptibility to woolly aphids, and vigorous growth.

3.8.2. *Cluster II.* The accessions Lord Lambourne and Holstein Cox constituted cluster II and were 94.6% similar. The two accessions had a medium fruit size, similar ground colour of the fruit, fruit firmness without skin, a high susceptibility to woolly aphid, regular flowering habit, and good self-compatibility of flowers.

3.8.3. *Cluster III.* This cluster had only the accession, Mother (Figure 2). The accession had a medium fruit size, good fruit attractiveness, an early-to-intermediate harvest maturity, a good eating quality dessert, high susceptibility to woolly aphid and powdery mildew, an intermediate flowering period, a regular flowering habit, and an intermediate secondary flowering.

3.8.4. *Cluster IV.* Lodi was the only accession under this cluster (Figure 2). It had a medium-to-large fruit size, intermediate fruit attractiveness, an early harvest maturity, a poor eating quality dessert, and high susceptibility to woolly aphid and powdery mildew.

3.8.5. *Cluster V.* Only Golden Delicious fell under this cluster (Figure 2). The accession had a medium fruit size, good fruit attractiveness, intermediate-to-late harvest maturity, a good eating quality dessert, intermediate bitter pit susceptibility, a fine flesh texture, high susceptibility to woolly aphids and powdery mildew, spreading tree habit, medium-to-late season flowering period, displayed biennial flowering habit, and an intermediate secondary flowering.

3.9. *Group Nine.* The group had seven accessions under it. The accessions were Cornish Aromatic, Primicia, Marjorie Pye, Waveny AC Pye, Hartley, Lady Williams, Irish, and

Chap's Early. They were about 88.75% similar (Figure 2). Four clusters were formed in this group.

3.9.1. *Cluster I.* The accessions Cornish Aromatic and Primicia fell under this cluster (Figure 2). The accessions had same ground colour of the fruit, fruit overcolour, type of overcolour, a late harvest maturity, good fruit attractiveness, fine flesh texture, high susceptibility to powdery mildew, regular flowering habit, and an intermediate secondary flowering.

3.9.2. *Cluster II.* This cluster had the two accessions Waveny AC Pye and Marjorie Pye that were clustered as one accession and had a 100% similarity (Figure 2). These two were similar in all respects.

3.9.3. *Cluster III.* Hartley and Lady Williams constituted this cluster, and they were merged at the 80% similarity level (Figure 2). They had the same origin, fruit shape, a small-to-medium fruit size, same ground colour of the fruit, overcolour, type of overcolour, russet type, russet amount, fruit flesh texture, a spreading tree habit, and an intermediate secondary flowering.

3.9.4. *Cluster IV.* Irish Peach and Chap's Early were the members of this cluster (Figure 2). They were 95.4% similar. The two had similar fruit ground colour, overcolour, good fruit attractiveness, high susceptibility to powdery mildew, a regular flowering habit, and an intermediate secondary flowering.

3.10. *Group Ten.* The accessions Jonagold and Champion were the constituents of group ten and were 86.3% similar. The accessions had similar fruit overcolour, good fruit attractiveness, 12% russet amount, good eating quality dessert, low susceptibility to bruising, regular flowering habit, and an intermediate secondary flowering.

3.11. *Group Eleven.* In this group, there was only one accession, Egremont Russet (Figure 2). This accession originated from England and had a medium fruit size, very poor fruit attractiveness, cracked russet type, an intermediate harvest maturity, very good eating quality dessert, intermediate bitter pit susceptibility, high susceptibility to woolly aphids and scab, an intermediate flowering period, a regular flowering habit, and an intermediate secondary flowering.

3.12. *Group Twelve.* Only the accession Lord Suffield was the member of this group (Figure 2). It originated from England and had a large fruit size, poor fruit attractiveness, an early harvest maturity, poor eating quality dessert, high susceptibility to powdery mildew and scale insects, and an early flowering period.

Finally, all the clusters were progressively joined together to form groups at reduced levels of similarity, and all the

groups were, in turn, joined together to form one major cluster at about 80% level of similarity.

4. The Dendrogram for Flowering, Place of Origin, and Harvest Maturity Relatedness of Apple Accessions

When the dendrogram was cut at a 0.90 similarity level, six groups were formed (Figure 3). The diversity range with respect to the season of flowering, place of origin, and harvest maturity was from 0.70 to 1.00.

4.1. Group One. Group 1 had 13 accessions, and they were Annah, Elah, Mayaan, Michal, Tydeman's Early Worcester, Discovery, Lord Suffield, Summer Red, Drakenstein, Gala, Odin, Early King of Pippins, and Cheddar Cross. This group was merged at a 92.5% similarity level.

4.1.1. Cluster I. The accessions Anna and Elah were clustered in this cluster. They were 100% similar. They had Israel as their place of origin, very early harvest maturity, and an extremely early season of flowering.

4.1.2. Cluster II. The accessions Mayaan and Michal fell under this cluster (Figure 3). They both originated from Israel and had a very early harvest maturity and an early season of flowering. They were 100% similar.

4.1.3. Cluster III. This cluster comprised the accessions Tydeman's Early Worcester, Discovery, and Lord Suffield (Figure 3). The three accessions originated from England and had an early harvest maturity and an early season of flowering. They were 100% similar.

4.1.4. Cluster IV. This cluster had one accession, Summer Red (Figure 3). It originated from Canada and had an early flowering period and early harvest maturity.

4.1.5. Cluster V. The accession Drakenstein fell under this group (Figure 3). Drakenstein originated from South Africa and had an early harvest maturity and an early season of flowering.

4.1.6. Cluster VI. Gala and Odin were the accessions that were clustered together in this group. They were 100% similar. Both of these accessions originated from New Zealand and had an early harvest maturity and an early season of flowering.

4.1.7. Cluster VII. This cluster had one accession, Early King of Pippins (Figure 3). Early King of Pippins originated from New Zealand and had an early flowering period, an early flowering period, and a very early harvest maturity.

4.1.8. Cluster VIII. The accession Cheddar Cross was singly clustered (Figure 3). It originated from England and had an extremely early flowering period and an intermediate harvest maturity.

4.2. Group Two. This group had 20 accessions. The accessions were Merton Worcester, Holstein Cox, Champion, Ohinemuri, Mutsu, Splendour, Reinette du Canada, Cox's Orange ex-Kortgard, Cox's Orange Noble, Michaelmas Red, Egremont Russet, Laxton's Superb, Spartan FFTRI, Spartan EXIRE, Lord Lambourne, Cornish Aromatic, Sunset, Winter Quarrenden, Cox's Orange Pippin, and Ribston Pippin (Figure 3). The accessions were 92.5% similar.

4.2.1. Cluster I. Two accessions were joined together in this cluster, and they were Merton Worcester and Holstein Cox and were 100% similar. They both originated from England. They had an early flowering period and an intermediate-to-late harvest maturity.

4.2.2. Cluster II. The accession Champion was the only member of this cluster (Figure 3). This accession originated from England and had an early flowering season and an intermediate harvest maturity.

4.2.3. Cluster III. Ohinemuri was the only accession in this cluster (Figure 3). Ohinemuri originated from New Zealand and had an early season of flowering and very early harvest maturity.

4.2.4. Cluster IV. Mutsu fell under this cluster by itself (Figure 3). It originated from Japan and had early-to-intermediate season of flowering and an intermediate-to-late harvest maturity.

4.2.5. Cluster V. Splendour and Reinette du Canada were clustered under this cluster (Figure 3). The two accessions were 99.3% similar. Splendour originated from New Zealand, while Reinette du Canada originated from France. Both had an intermediate season of flowering and harvest maturity.

4.2.6. Cluster VI. The accessions Cox's Orange ex-Kortgard and Cox's Orange Noble constituted cluster VI (Figure 3). They were 99.8% similar. Both accessions originated from England and had an early flowering period.

4.2.7. Cluster VII. The accessions Michaelmas Red, Egremont Russet, and Laxton's Superb were clustered in this cluster. The similarity for the three accessions was 100%. These accessions originated from England and had an intermediate season of flowering and intermediate harvest maturity.

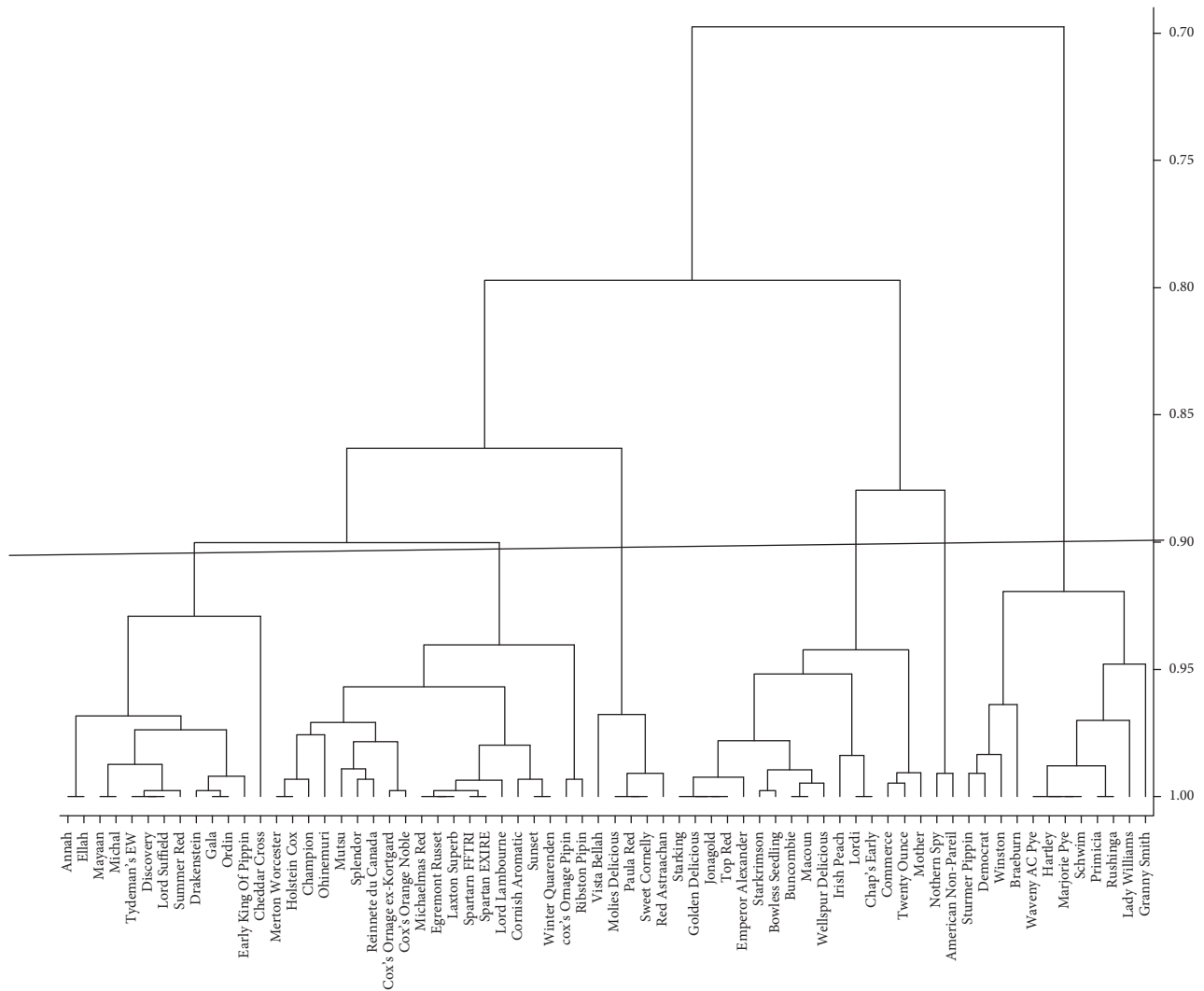


FIGURE 3: The dendrogram for flowering, place of origin, and harvest maturity relatedness of apple accessions.

4.2.8. Cluster VIII. Two accessions Spartan FFTRI and Spartan EXIRE were the members of this cluster (Figure 3). The similarity between them was 100%. They originated from Canada and had an intermediate season of flowering and intermediate harvest maturity.

4.2.9. Cluster IX. Lord Lambourne was the lone accession in this cluster (Figure 3). This accession originated from England and had an intermediate-to-late season of flowering and an intermediate-to-late harvest maturity.

4.2.10. Cluster X. Cornish Aromatic singly fell under cluster X (Figure 3). The accession originated from England and had an intermediate season of flowering and late harvest maturity.

4.2.11. Cluster XI. Cluster XI comprised the accessions Sunset and Winter Quarrenden (Figure 3). These two accessions were 100% similar. They originated from England

and had an intermediate season of flowering and medium harvest maturity.

4.2.12. Cluster XII. Cox's Orange Pippin and Ribston Pippin were the accessions of this cluster (Figure 3). The similarity between them was 99.3%. They originated from Denmark. Cox's Orange Pippin had an early flowering period, while Ribston Pippin had an early-to-intermediate flowering period. Both had an early-to-intermediate harvest maturity.

4.3. Group Three. This group comprised five accessions that were amalgamated at the 96.75% similarity level. The accessions were Vista Bella, Mollies Delicious, Paula Red, Sweet Connelly, and Red Astrachan (Figure 3).

4.3.1. Cluster I. Vista Bella was singly clustered under this cluster (Figure 3). This accession originated from the United States of America and had an extremely early season of flowering and very early harvest maturity.

4.3.2. *Cluster II.* Cluster II had the accessions Mollies Delicious, Paula Red, and Sweet Connelly (Figure 3). These accessions were merged at the 100% similarity level. They all originated from the United States of America and had an early season of flowering and early harvest maturity.

4.3.3. *Cluster III.* This cluster had a single accession, Red Astrachan (Figure 3). It originated from Russia and had an early season of flowering and early harvest maturity.

4.4. *Group Four.* This group had 16 accessions that included Starking, Golden Delicious, Jonagold, Top Red, Emperor Alexander, Starkrimson, Bowless Seedling, Buncombe, Macoun, Wellspur Delicious, Irish Peach, Lodi, Chap's Early, Commerce, Twenty Ounce, and Mother (Figure 3).

4.4.1. *Cluster I.* This cluster had four accessions, namely, Starking, Golden Delicious, Jonagold, and Top Red (Figure 3). These accessions were 100% similar. All the accessions originated from the United States of America and had an intermediate-to-late season of flowering and harvest maturity.

4.4.2. *Cluster II.* Cluster II had only one accession, Emperor Alexander (Figure 3). It originated from Ukraine and had an intermediate season of flowering and intermediate-to-late harvest maturity.

4.4.3. *Cluster III.* Starkrimson and Bowless Seedling fell under this cluster (Figure 3). They were 99.1% similar. Starkrimson originated from the United States of America and Bowless Seedling from Zimbabwe; they had an intermediate season of flowering and early-to-intermediate harvest maturity.

4.4.4. *Cluster IV.* The accessions Buncombe and Macoun constituted cluster III (Figure 3). They were 100% similar. They originated from the United States of America and had an intermediate season of flowering and harvest maturity.

4.4.5. *Cluster V.* Wellspur Delicious was the only accession in this cluster (Figure 3). It originated from the United States of America and had an intermediate-to-late season of flowering and intermediate harvest maturity.

4.4.6. *Cluster VI.* Irish Peach was the only accession in this cluster (Figure 3). It originated from Ireland and had a late season of flowering and intermediate harvest maturity.

4.4.7. *Cluster VII.* Lodi and Chap's Early fell under cluster VII (Figure 3). Similarity between them was 100%. They originated from the United States and had a late season of flowering and intermediate harvest maturity.

4.4.8. *Cluster VIII.* Commerce and Twenty Ounce were the members of this cluster (Figure 3). They had a 99.5% similarity. They originated from Germany. Commerce had an intermediate flowering period and harvest maturity, while Twenty Ounce had an early-to-intermediate flowering period and intermediate harvest maturity.

4.4.9. *Cluster IX.* Mother was the only accession in this cluster (Figure 3). It originated from Scotland and had a late season of flowering and intermediate harvest maturity.

4.5. *Group Five.* The accessions Northern Spy and American Non-Pareil constituted this group (Figure 3). Both accessions originated from Germany. Both accessions had an early flowering period and a late-to-very-late harvest maturity.

4.6. *Group Six.* Twelve accessions were clustered under this group. The accessions were Sturmer Pippin, Democrat, Winston, Braeburn, Waveny AC Pye, Hartley, Marjorie Pye, Schwim, Primicia, Rushinga, Lady Williams, and Granny Smith (Figure 3).

4.6.1. *Cluster I.* Two accessions, Sturmer Pippin and Democrat, were the constituents of this cluster (Figure 3). The two accessions were 99% similar. Democrat originated from Ireland, while Sturmer Pippin originated from England. They had a very late flowering and harvest maturity.

4.6.2. *Cluster II.* Winston was the only accession in this cluster (Figure 3). It originated from England and had an intermediate season of flowering and late harvest maturity.

4.6.3. *Cluster III.* Braeburn was singly clustered under cluster III (Figure 3). It originated from France and had an intermediate flowering period and late harvest maturity.

4.6.4. *Cluster IV.* This cluster had four accessions that were Waveny AC Pye, Hartley, Marjorie Pye, and Schwim (Figure 3). The similarity among them was 100%. All originated from Zimbabwe and had late flowering period and harvest maturity.

4.6.5. *Cluster V.* The accessions Primicia and Rushinga were joined under cluster VI (Figure 3). Primicia originated from Brazil, while Rushinga originated from Zimbabwe. They had an early season of flowering and early harvest maturity.

4.6.6. *Cluster VI.* The accession Lady Williams was the only accession in this cluster (Figure 3). It had a very late flowering period and harvest maturity.

4.6.7. *Cluster VII.* Granny Smith was the only accession in cluster VIII (Figure 3). It is thought to have originated from the French crab and had a late flowering period and very late harvest maturity.

5. Discussion

Narrow genetic diversity was detected in the apple germplasm conserved at Nyanga Experimental Station as shown by the 80–100% similarity matrix range among the accessions. The observed low level of diversity is in agreement with the observation that most current commercial apple orchards are dominated by a few selected varieties bred from crosses involving only a few known parents [25, 26]. The apple accessions were grouped into 12 groups with several clusters under them. The clusters in each and every group amalgamated with each other until they were all joined together to form one large group at a much lower level of similarity in the dendrogram. The so-formed groups were then merged with the other groups at an even much-reduced level of similarity to form one major cluster. In other words, dissimilarity increased as the individual clusters merge to form amalgams. Tree habit predominantly ranged from upright to spreading. The moderate phenotypic trait differences exhibited by the apple accessions imply that all parameters may be useful for genetic diversity studies. This agrees with similar studies carried out by Mandic et al. [27] where they have reported the existence of genetic variation in the phenology, fruit weight, and yield of apples. The intensity of overcolour varied from red to dark red in many accessions. This is confirmed by similar studies [28].

The apple accessions Anna, Elah, Michal, Mayaan, Tydeman's Early Worcester, Vista Bella, Mollies Delicious, and Cheddar Cross could be useful in breeding programmes for the improvement of chilling requirement as reflected by their low chill requirement as shown by their extremely early to early flowering periods.

The accessions were grouped into six flowering period groups (Figure 3). This agrees with findings in a similar study on 60 apple varieties [29]. The first grouping was that of the extremely early to very early flowering accessions. Included in this group were accessions such as Anna, Elah, Michal, Mayaan, Tydeman's Early Worcester, Discovery, Lord Suffield, Summer Red, Drakenstein, Gala, Odin, Early King of Pippins, and Cheddar Cross. The second group was for the early flowering with accessions such as Merton Worcester, Ohinemuri, Michaelmas Red, and others. The third group was for the early-to-intermediate flowering and accessions such as Jonagold, Starkrimson, Macoun, and others. The fourth group was for the late to very late and had accession such as Waveny AC Pye, a seedling of Granny Smith; Northern Spy; Lady Williams; and others. Most of the accessions fell within the intermediate-to-late flowering range just as was observed by Ildiko [29]. Parent–progeny relationship was observed in some accessions as in the case of Waveny AC Pye being clustered in the same group with its parent, Granny Smith (Figure 3).

It was observed that most of the accessions originated from England and the United States of America. Usually,

accessions from the same locality tend to share some common traits. This could be to the influence of the local people preferring certain traits such as soft-fleshed apples for old people resulting in the trait being incorporated in most varieties and hence the close similarity. Most of the accessions showed that they have a high susceptibility to the apple woolly aphid and powdery mildew. It could be due to the lack of genes for resistance as most of the cultivars were bred from a few selected parents that could have been lacking in such traits. It was also observed that the bulk of the accessions had an intermediate fruit size with few accessions in either extreme. This could be due to artificial selection favouring intermediate types.

Fruit colour and attractiveness, russet amount, and type reflected some level of variation with different shades, amounts, and types being noticed. These are quality attributes with mostly the fruits with colours with some shades of red and fine russet being preferred by the market.

The apparent phenotypic dissimilarities among the apple accessions could be ascribed to minor differences in the relevant genes and variation in gene expression due to differences in the plasticity of the phenotype in transcription factor sequences. They could be due to several genes and their response to the environment [30, 31].

Based on multivariate cluster analysis, the apple accessions have shown narrow genetic diversity having a similarity matrix ranging from 80 to 100%. The observed narrow phenotypic diversity among the apple accessions could be due to the fact that most of the accessions came from a common parent. This seems to agree with Noiton and Shelbourne [25] who reported that the current commercial orchard production is mainly dependent on a few cultivars that have been bred from crosses that made use of a few preferred cultivars. The narrow diversity implies that most of the genes within the apple accessions are similar to a high degree. The existence of a narrow genetic diversity among apple accessions was reported by Way et al. [26]. The narrowing of the genetic diversity could have come about as a result of a change in the genetic base of the domestic apple brought about by the domination of nowadays' markets by a narrow range of cultivars with attributes that suit the consumer, grower, and retail preferences [5]. Noiton and Alspach [32] pointed out inbreeding and coancestry in modern apple cultivars as some of the causes of the narrowing of the apple genetic base.

It has been observed that the genetic base of the apple has been slowly narrowing as reflected by the fact that from a situation whereby more than 7000 cultivars were described to the present situation where most of the world's production is dependent on two cultivars, namely, Delicious and its red spots and Golden Delicious. Furthermore, present expansion is hinged on their seedlings: Gala, Mutsu, and Jonagold that came from Golden Delicious together with Empire and Fuji, which came from Delicious [5]. So the close similarity exhibited by the apple accessions could be explained by this.

Two accessions, Waveny AC Pye and Marjorie Pye, were clustered as one accession as shown in Figure 2. This could be explained by the fact that they were duplicate accessions;

they were just one accession known by two names. The story was that the accession is a seedling of Granny Smith, which was selected at Murambi in Mutare. The man who selected it gave it his name, but when his wife died, he changed the name to Marjorie Pye in memory of his wife.

The possible explanation why the Israeli cultivars Anna, Elah, Mayaan, and Michal clustered together with accessions such as Mollies Delicious, Tydeman's Early Worcester, Cheddar Cross, and Vista Bella could be that they could have shared one of their grandparents, particularly, the low chill imparting parent. For the Israeli accessions, it is known that they shared the accession Delicious as one of the parents in the crosses and some other accessions such as Red Hadassiya possessing the low chill characteristic [33]. In some instances, progeny–parent relationships were observed where the accession Starkrimson was a whole tree variation of the accession Starking being clustered close to it (Figure 2). The two dendrograms (Figures 2 and 3) did not show direct correspondence between geographic origin and placement of accession. This agrees to the traditional exchange of planting material as found in similar studies [34]. It could be suggested that due to the need to meet the strict requirements of world markets, breeders are persuaded to use materials from different countries to breed towards common characteristics dictated by the markets (Gepts) [35].

It is important, however, to point out that some tendency by some accessions with the same geographic origin to concentrate within particular groups and clusters was observed. It may be reasoned that accessions from the same country could have arisen from a common ancestor. The tendency to cluster together could be explained by similarities brought about by intentional artificial selection or unintentional genotypic bottlenecks [36]. Furthermore, different breeding efforts for certain biotic and abiotic stresses in one country could lead to some materials from the same country being concentrated in the same cluster.

Despite the evident narrow genetic diversity exhibited by the cultivated apple accessions, there is merit in acquiring materials from outside for the purpose of improving certain traits such as disease resistance and low chill requirement. There are several wild relatives of the domesticated apple from which certain key agronomic traits could be tapped. For instance, the low chill character can be found within species such as *Malus baccata*, *Malus brevipes*, *Malus floribunda*, *Malus sylvestris*, and others [37].

The narrow diversity range reflected by the close to 100% similarity shown by some accessions could be as a result of experimental factors. The morphological characterization does not afford the finer degree of resolution as provided by molecular characterization. Errors could have occurred during the scoring process and also human bias by the data recorders could have come into play.

The less fine degree of resolution ascribed to morphological clustering has been reported to be due to the effect of the environment on the performance and phenotypes of quantitative traits. It may therefore be put forward that only the use of molecular markers for diversity analysis in the future could give good results that are not influenced by the environment and at a minimal cost. The use of

morphological markers, however, could retain its usefulness in the detection of the presence of some genes where specific molecular markers have not been developed.

6. Conclusions

There is a narrow genetic diversity among the apple accessions at Nyanga Experimental Station. Promising accessions for use as cultivars in warmer areas were identified. They included Anna, Elah, Mayaan, Michal, Mollies Delicious, Cheddar Cross, Vista Bella, Rushinga, Primicia, Tydeman's Early Worcester, Discovery, and Drakenstein. These accessions possess the low chill character and an extremely early to early harvest maturity among other critical traits in apple tree selection in Zimbabwe. The study identified useful genetic materials for conservation and/or use in future breeding programmes for apples.

Data Availability

Data are available upon request to the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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