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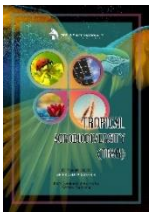

RESEARCH ARTICLE

PLANT AND FRUIT CHARACTERIZATION OF AVOCADO (*PERSEA AMERICANA* MILL.) GENETIC RESOURCES IN NEPAL

Binod Prasad Luitel*

National Horticulture Research Centre, Khumaltar, Lalitpur, Nepal Agricultural Research Council
Corresponding Author Email: binodsan@yahoo.com

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ABSTRACT

Avocado is a newly emerging important fruit crop in home gardens and farms of Nepal. A total of 16 avocado accessions (HRSDAV01, HRSDAV02, HRSDAV03, HRSDAV04, HRSDAV05, HRSDAV06, HRSDAV07, HRSDAV08, HRSDAV09, HRSDAV010, HRSDAV011, HRSDAV012, HRSDAV013, HRSDAV014, HRSDAV015 and HRSDAV016) were characterized for their tree, leaf, fruit and seed traits at Horticulture Research Station (HRS), Dailekh in 2020. Tree, fruit and seed qualitative traits were characterized using the avocado descriptors of International Plant Genetic Resources Institute (IPGRI). To study the fruit and seed quantitative traits, fifteen matured fruits were harvested from each accession and placed at laboratory in completely randomized design (CRD) with three replications. Results showed the wide variation in tree and leaf characters among 16 accessions. Accessions exhibited highly significant (P≤0.01) differences in fruit weight, fruit length and diameter, pulp weight and pulp/fruit ratio (%). Accessions HRSDAV07, HRSDAV06, HRSDAV09, HRSDAV03 and HRSDAV015 showed the highest pulp/fruit ratio of 83.3, 80.8, 78.8, 75.3 and 74.9%, respectively. Seed/fruit ratio was the lowest in accessions HRSDAV07 (10.9%), HRSDAV03 (12.1%), HRSDAV05 (13.4%) and HRSDAV06 (15.9%). Based on the characterization of fruit and seed traits, HRSDAV03, HRSDAV06 and HRSDAV07 are selected as the best accessions for the commercial production and breeding in avocado at mid-hills of Nepal.

Keywords

Avocado, breeding, characterization, quantitative traits, *Persea americana* Mill.

1. INTRODUCTION

Avocado is an important plant, belonging to Lauraceae family originated from high and lowland of Central America (Popenoe, 1920; Smith 1966; Storey et al., 1986). Due its nutritional value and highly appreciation of the fruits, avocado plant spread very fast from its origin to many countries of world. Avocado fruit is utilized for various medicinal purposes; such as hypotensive, hypoglycemic, anti-viral and treatment of ulcers, and cardiovascular diseases (Kosinska et al., 2012). Avocado is cultivated from tropical to warm temperate climate of the world. It is known as butter fruit or *Ghiu Phal* in Nepalese language and it is an emerging new fruit of Nepal (Atreya, 2020). The avocado plants have not yet been cultivated on commercial scale and it still grown farmers' home-yards.

Mexico is the largest producer of avocado in the world and its total production of Mexico was 1.78 million tons in 2022 (FAOSTAT, 2022). Besides Mexico, Dominician Republic, Peru, Indonesia, Columbia, Brazil, Kenya, United States, Venezuela and Israel are the major avocado producing countries in the world (FAOSTAT, 2020). In Nepal, five avocado varieties (Hass, Fuerte, Ettinger, Reed and Topatopa) had been introduced at National Fruit Development Center, Kirtipur, Horticulture Development Farm, Trishuli and Horticulture Development Farm, Sarlahi in 1978 (Atreya, 2020). After the establishment of Pakhribas Agriculture Research Centre (PARC), Dhankuta in 1972, avocado varieties had also been introduced by researchers and tourists of United Kingdom and since then, farmers have been growing the avocado trees in their backyard. However, the statistics of total cultivated area and the total production of avocado in Nepal has not estimated yet. Avocadoes are classified into three groups; Guatemalan (var. *guatemalensis*), Mexican (var. *drymifolia*) and West Indian types (var. *americana*) which are also referred as horticultural races (Popenoe, 1927; Bergh, 1992; Ashworth et al., 2011). West Indian race is also known as the 'lowland' race of avocado (Storey et al., 1986) and it can be grown from sea level to an altitude of about 1,000 m asl (Popenoe, 1952). Guatemalan and Mexican accessions show poor fruit set in the tropical climate (Juma et al., 2020). Mexican races survive only in colder regions but hybrids from crosses between different races can adapt to a wide range of environments (Bergh, 1992). In general, the accessions of Mexican race contain smooth, glossy skin and thin peel, big seed and loose in cavity, small fruit with high fat content and peanut taste. Guatemalan race is adaptable to highlands and cold resistance, thick and rough, stiff peel; small seed tight in cavity, large fruit, long ripening time and high savory nutty flavor. But West Indian race contains leather, green/yellowish/reddish color, big seed with rough cotyledon surface with medium fat content (Popenoe, 1974; Bergh and Ellstrand, 1986).

Different research stations and Horticulture Development Farms of Nepal have been propagating the avocado through seeds since its introduction. Seedlings produced at research stations and farms were introduced at HRS, Dailekh and established the avocado orchard in 2012. Previously, variation in fruit and seed quantitative characters in the collections of avocado in Dhankuta Municipality, Dhankuta was studied by (Poudel et al. 2018). Avocado has diverse trunk surface, tree shape, vigor, leaf shape, color, leaf margin and fruits may show numerous shapes including pyriform, narrowly obovate, ellipsoid or rhomboid (Morton, 1987;

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Abraham et al., 2018; Nkansah et al., 2013; Juma et al, 2020). Avocado flesh can be pale to rich-yellow, buttery or nutlike in taste (Morton, 1987). Furthermore, avocado contains diverse types of seed shape, cotyledon color and surface (Abraham et al., 2018).

Knowledge of genetic diversity is fundamental to develop the strategy for germplasm collection, management, and improvement of the genetic resources (Chiveu et al., 2009). Since avocado is a cross pollinated crop and seeds obtained from cross-pollination reveal genetic diversity (Juma et al., 2020). Avocado is characterized by a high level of heterozygous resulting in unpredictable hybrid (Lahav and Lavi, 2009). Agro-morphological traits and DNA markers are useful to analyse diversity in avocado varieties (Ramirez et al., 2005).It has a reported that restriction fragment length polymorphism (RFLP) and chloroplast DNA loci was the first DNA marker technique for evolutionary and phylogenetic analyses in avocado (Furnier et al., 1990). Extensive research on genealogical relationship between cultivated avocadoes were done by (Davis et al., 1998). In Dailekh, diverse avocado plants are grown and are well-adapted in similar agro-ecological region (Personal observation). Owing to its high-yield potential, nutritional properties and suitable agro-climatic condition for cultivation, avocado can be a high a potential fruit crop for nutritional security in Karnali Province and become a new export commodity. However, the plant and fruit characterization of fruit bearing avocado genetic resources at HRS, Dailekh has not been undertaken so far. Availability of adequate genetic pool is a necessary for the selection and variety development in avocado. Therefore, this research was conducted to characterize seed-propagated avocado accessions grown in HRS, Dailekh using phenotypic characters and to select potential accessions for commercial production and its future breeding program at mid-hills of Nepal.

2. Materials and Methods

2.1 Experimental Site and Climate

This study was conducted at HRS, Dailekh (28˚50'49.8" N longitude and 81˚43'19.4" E latitude with an elevation of 1, 255m above sea level). This station represents mid-hill region and falls under sub-tropical climate. The annual rainfall amount ranges between 140 and 160mm and the distribution is high around June-July. Temperature ranged from 6.1 to 28.7°C (HRS, 2020). But the average temperature in fruit bearing period (March-October) at Dailekh ranged from 8.6 to 24.1°C (HRS, 2020). Avocado seedlings (un-identified variety) were collected from Agriculture Research Station (ARS), Dhankuta (1,740m asl), Horticulture Development Farm (HDF), Trishuli (1,022m asl), and Horticulture Research Station (HRS), Kaski (845 m asl), and an orchard was established in 2012 at HRS, Dailekh. The orchard was managed with similar agronomic and cultural practices as recommended by (Atreya, 2020). Trees were started to flower and fruiting at the age of seven years. Fruit bearing trees (eight years old) in 2020 were nomenclatured as HRSDAV where 'HRSD' stands as Horticulture Research Station, Dailekh, and 'AV' stands as 'Avocado' and 01, 02 and successive accession numbers were given at each plant for the identification. Altogether, 16 different accessions beared the fruits.

2.2 Plant Morphological Characters

Trunk surface, tree shape and vigor, and leaf characters (shape, color, margin, and base shape) were recorded in 16 accessions using (IPGRI, 1995). Bare hands were used to touch the trunk surface to feel its smoothness or roughness. Tree shape and vigor were observed by visually. Tree shape was categorized into columnar, pyramidal, obovate, rectangular, circular, semi-circular, semi-elliptic, irregular and others. Likewise, tree vigor was classified into three groups; weak, intermediate and strong. The leaf shape, leaf color, margin and base shape were compared against their respective drawings in the field guide of (IPGRI, 1995).

2.3 Fruit and Seed Characters

Fruits were harvested on September 9, 2020 at their physiological maturity stage with pedicel and peduncle section from each accession and kept in laboratory condition (20.0 ± 3.5°C). A total of fifteen matured fruits were randomly selected from each accession and laid out in CRD with three replications where each replication consisted of five fruits. Pedicel length (cm) and peduncle length (cm), weight (g), fruit length (cm), diameter (cm), pulp weight (g), fruit volume (cc), days to fruit ripening, fruit shelf-life and fruit skin thickness (mm) were measured. Seed characters such as seed weight (g), length (mm), diameter (mm) and seed volume (cc) were measured. A stainless 60 cm ruler was employed to measure pedicel and peduncle length, fruit length, diameter, and fruit width. The fruit length (cm) was measured as the longest part of the fruit and fruit diameter (cm) was measured as the mid-section of each fruit. Pulp/fruit ratio was expressed in percentage as (pulp weight/fruit weight)*100. Fruit volume (cc) of each fruit was measured by volume of water displace by the fruit (water displacement method). Days taken to ripen the fruit from the day of harvesting to softening of the fruit were taken. Shelf-life of fruit was calculated based on days taken by ripe fruit until its flesh color change into black at room temperature (20°C±3.5°C). Fruit skin thickness (mm), seed length (mm) and diameter (mm) was measured using digital caliper (150mm, Model: DC-515). Fruit skin thickness more than 1.0 mm was considered as thick, 0.5-1.0mm as intermediate and less than 0.5mm as thin skin (Lestari *et al*, 2016). Fruit weight (g) and seed weight (g) were measured using electronic digital weight scale (H-Honda™, India). Fruit weight more than 500.0g was categorized into very large, 351.0-500.0g as large, 200.0-350.0g as medium and less than 200.0 g as small fruit. Similarly, seed weight more than 50.0 g categorized into large seed, 50.0-100.0g as intermediate and less than 50.0g as small seeds (Lestari et al., 2016). Seed length was measured at the longest part of the seed and the seed diameter was measured from the mid- section of the seed. Seed/fruit ratio was expressed in percentage as (seed weight/fruit weight)*100. Seed volume (cc) was measured by water displacement method. Fruit qualitative characters (pedicel position on fruit, fruit size uniformity, skin color, gloss of skin, fruit surface, fruit apex shape and base shape, fruit shape, flesh color and texture, flavor type) using IPGRI descriptors. Flesh taste was assessed by judge panel using 1-5 scales (1 = very poor, 2 = poor, 3 = fair, 4 = Good and 5 = Excellent). Seed characters (easy to peel, cotyledon color, cotyledon surface and seed shape) were recorded using IPGRI field guide (1995).

2.4 Statistical Analysis

Plant, fruit and seed qualitative traits of the avocado accessions were expressed in frequency and percentage. Fruit and seed quantitative traits were analyzed using GenStat Release 10.3 DE Software (VSN International Ltd., UK) using one-way analysis of variance (ANOVA) and significant differences between the means of different characteristics were separated by Duncan Multiple Range Test (DMRT). Graph was prepared using Sigma Plot (v.10.0.1.2, SPSS Inc, USA).

3. Results

3.1 Plant Qualitative Characters

Accessions HRSDAV01, HRSDAV02, HRSDAV03, HRSDAV04, HRSDAV06, HRSDAV014, HRSDAV015 and HRSDAV016 displayed smooth trunk surface (Table 1). Eight (50.0%) accessions showed rough trunk surface. Out of the 16 accessions, six (37.5%) exhibited circular tree shape, three (18.7%) had semi-circular type, two (12.5%) accessions had pyramid shape, three (18.7%) had rectangular type, and one accession had columnar shape. Similarly, seven (43.7%) accessions had strong tree vigor, five (31.2%) had intermediate vigor and three (18.7%) had weak vigor. Nine (56.2%) accessions displayed narrowly obovate leaf while four (25.0%) accessions had oval shaped leaf and one accession had ovate leaf. Except HRSDAV03 (undulated leaf margin), all the accessions showed entire leaf margin. Out of sixteen, ten (62.5%) accessions had dark green leaf and remaining accessions had green leaf. With regard to leaf base shape, 11 (68.7%) genotypes had acute type and remaining genotypes had obtuse leaf base.

Table 1: Plant Morphological Characters of Avocado Accessions at HRS, Dailekh, 2020

Accessions	Trunk surface	Tree shape	Tree vigor	Leaf shape[z]	Leaf Color[y]	Leaf margin	Leaf base shape
HRSDAV01	Smooth	Circular	Intermediate	N. obovate	D. green	Entire	Acute
HRSDAV02	Smooth	Semi-circular	Weak	Oval	Green	Entire	Obtuse
HRSDAV03	Smooth	Pyramid	Strong	N. obovate	D. green	Undulated	Acute
HRSDAV04	Smooth	Semi-circular	Weak	N. obovate	Green	Entire	Acute
HRSDAV05	Rough	Pyramid	Intermediate	N. obovate	Green	Entire	Acute
HRSDAV06	Smooth	Rectangular	Strong	Oval	D. green	Entire	Obtuse
HRSDAV07	Rough	Circular	Strong	N. obovate	D. green	Entire	Acute
HRSDAV08	Rough	Rectangular	Strong	Oval	D. green	Entire	Obtuse
HRSDAV09	Rough	Semi-circular	Intermediate	Ovate	Green	Entire	Obtuse
HRSDAV010	Rough	Rectangular	Intermediate	N. obovate	D. green	Entire	Acute
HRSDAV011	Rough	Columnar	Weak	Lanceolate	D. green	Entire	Acute
HRSDAV012	Rough	Circular	Strong	Oval	Green	Entire	Obtuse
HRSDAV013	Rough	Circular	Strong	N. obovate	D. green	Entire	Acute
HRSDAV014	Smooth	Circular	Strong	Oval	D. green	Entire	Acute
HRSDAV015	Smooth	Circular	Strong	N. obovate	D. green	Entire	Acute
HRSDAV016	Smooth	Rectangular	Intermediate	N. obovate	Green	Entire	Acute

[z]Leaf shape, N. obovate, Narrowly obovate; [y]Leaf color, D. green, Dark green.

3.2 Fruit Quantitative Characters

Accessions showed significant (P≤0.05) variation in pedicel and peduncle length but highly significant (P≤0.01) differences in fruit weight, length, diameter, pulp weight and pulp/fruit ratio (Table 2). HRSDAV03 had the highest pedicel length (2.8cm) but it was statistically similar to HRSDAV06 (2.4cm), HRSDAV04 (2.2cm), HRSDAV02 (1.9cm) and HRSDAV07 (1.8cm) but the lowest pedicel length (1.0cm) was measured in HRSDAV013 and HRSDAV015. The highest peduncle length (9.3cm) was measured in HRSDAV05 followed by HRSDAV01 (7.3cm), HRSDAV06 (7.3cm), HRSDAV08 (7.2cm) and HRSDAV016 (7.3cm) and HRSDAV015 (6.8cm) but the lowest peduncle length (4.0cm) was measured in HRSDAV011. HRSDAV01 showed the highest fruit weight (394.8g) followed by accessions HRSDAV06 (267.1g), HRSDAV03 (263.2g) and HRSDAV015 (254.7g) but it was not significantly different from the accessions HRSDAV05 (241.6g), HRSDAV010 (234.7g) and HRSDAV012 (217.1g). The longest fruit was measured in HRSDAV03 (14.0 cm) but it showed non-significant difference with HRSDAV08 (13.6cm). Fruit diameter was the highest in HRSDAV01 (7.5cm) which was statistically similar to accessions HRSDAV06 (7.2cm), HRSDAV05 (7.1cm), HRSDAV012 (7.1cm) and HRSDAV010 (7.0cm) but it was the lowest in HRSDAV011 (3.3cm). The maximum pulp weight (266.2g) was recorded in HRSDAV01 followed by HRSDAV06 (215.3g) and HRSDAV03 (196.0g) but these values were not significantly different from accessions HRSDAV015 (190.2g), HRSDAV05 (187.9g). HRSDAV011 had the least pulp weight (8.4g). The highest pulp/fruit ratio was measured in HRSDAV07 (83.3%) and HRSDAV06 (80.8%) but it was statistically similar to accessions HRSDAV09 (78.8%), HRSDAV05 (75.3%), HRSDAV015 (74.9%), HRSDAV016 (69.8%), HRSDAV01 (67.9%), HRSDAV010 (66.2%) and HRSDAV012 (64.7%) but the lowest pulp/fruit ratio (47.4%) was measured in HRSDAV011.

Table 2: Fruit Quantitative Characters of Avocado Accessions Evaluated at HRS, Dailekh, 2020

Accessions	Pedicel length (cm)	Peduncle length (cm)	Fruit wt. (g)	Fruit length (cm)	Fruit diameter (cm)	Pulp weight (g)	Pulp/fruit ratio (%)
HRSDAV01	1.3 cd	7.3 ab	394.8 a	12.9 b	7.5 a	266.2 a	67.9 abcd
HRSDAV02	1.9 abcd	4.5 cd	166.3 fgh	7.3 f	6.0 de	104.1 fg	62.7 bcde
HRSDAV03	2.8 a	5.3 bcd	263.2 b	14.0 a	6.6 bcd	196.0 b	75.3 abcd
HRSDAV04	2.2 abc	6.2 bcd	128.0 h	7.3 f	6.2 cde	81.8 g	63.9 abcde
HRSDAV05	1.6 bcd	9.3 a	241.6 bc	11.1 c	7.1 ab	187.9 bc	78.1 abc
HRSDAV06	2.4 ab	7.3 ab	267.1 b	11.4 c	7.2 ab	215.3 b	80.8 a
HRSDAV07	1.8 abcd	5.7 bcd	201.8 cdef	11.9 c	6.5 bcd	168.1 cd	83.3 a
HRSDAV08	1.5 bcd	7.2 abc	147.3 gh	13.6 ab	5.2 f	90.9 fg	62.0 bcde
HRSDAV09	1.3 cd	5.0 bcd	188.0 defg	9.2 de	6.8 abc	147.8 d	78.8 ab
HRSDAV010	1.2 cd	5.3 bcd	234.7 bcd	9.5 d	7.0 ab	155.1 d	66.2 abcd
HRSDAV011	1.2 cd	4.0 d	19.8 i	5.4 g	3.3 g	8.4 h	47.4 e
HRSDAV012	1.4 bcd	5.2 bcd	217.1 bcde	9.5 d	7.1 ab	137.3 de	64.7 abcd
HRSDAV013	1.0 d	5.4 bcd	158.0 fgh	11.2 c	6.0 de	92.3 fg	58.4 de
HRSDAV014	1.3 cd	5.8 bcd	170.7 efgh	8.4 e	6.5 bcd	103.8 fg	60.8 cde
HRSDAV015	1.0 d	6.8 abc	254.7 b	11.6 c	6.7 bcd	190.2 bc	74.9 abcd
HRSDAV016	1.3 cd	7.3 ab	165.1 fgh	9.8 d	5.7 ef	115.6 ef	69.8 abcd
Mean	1.57	6.11	201.1	10.27	6.34	141.0	68.3
F-Test	*	*	**	**	**	**	**
LSD (0.05)	0.87	2.23	44.98	0.885	0.62	29.49	14.92
CV (%)	33.1	22.3	13.4	5.2	5.9	12.5	13.1

*Significant at P≤0.05, **Highly significant at P≤0.01. The same letters in a column are not significantly different at P ≤ 0.05; DMRT.

3.3 Fruit and Seed Quantitative Characters

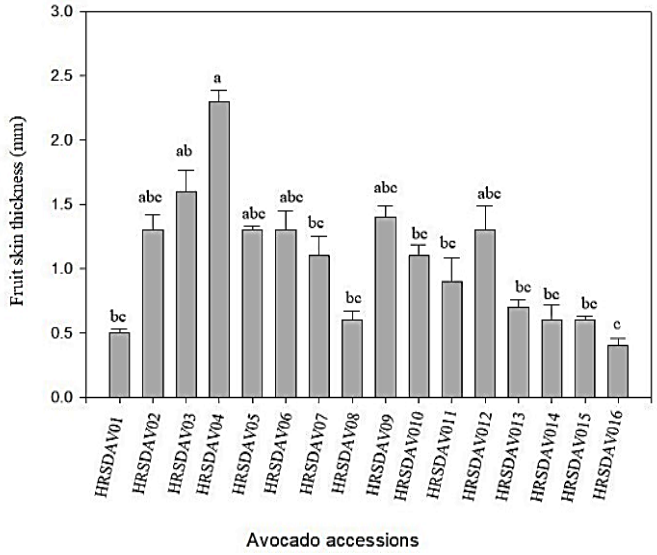

Figure 1: Fruit skin thickness (mm) of 16 avocado accessions. Values are the mean ± SE from three determinations. The same letters in the bars are not significantly different at P ≤ 0.05; DMRT.

Accessions showed highly significant (P≤0.01) variation in fruit skin thickness. The highest skin thickness (2.3mm) was measured in HRSDAV04 which was statistically similar to HRSDAV03 (1.6mm), HRSDAV09 (1.4mm), HRSDAV02 (1.3mm), HRSDAV0.5 (1.3mm), HRSDAV06 (1.3mm), and HRSDAV012 (1.3mm) and the lowest was measured in HRSDAV016 (0.4mm) (Figure 1).

Fruit volume, fruit ripening days and fruit shelf life, seed weight, seed length and diameter, seed per fruit ratio and seed volume were highly significant (P≤0.01) among accessions (Table 3). Fruit volume was the highest in HRSDAV01 (377.8cc) followed by HRSDAV03 (291.7cc), HRSDAV015 (290.6cc), HRSDAV015 (290.6cc) which were also statistically similar to accessions HRSDAV012 (261.7cc), HRSDAV05 (255.0cc) and HRSDAV010 (249.2cc). The lowest fruit volume (33.9cc) was measured in HRSDAV011. The earliest fruit ripening was recorded in HRSDAV013 (3.0 days) which was not statistically different from the accessions HRSDAV06 (5.0 days) and HRSDAV016 (5.0 days). In contrast, late ripening was recorded in HRSDAV010 (26.0 days) followed by HRSDAV04 (22.0 days) and HRSDAV03 (15.0 days). HRSDAV010 showed the longest fruit shelf life (14.0 days) followed by HRSDAV02 (8.0 days) and HRSDAV04 (8.0 days) but the lowest shelf life (3.0days) was observed in HRSDAV01, HRSDAV05, HRSDAV08, HRSDAV011, HRSDAV013, HRSDAV014, and HRSDAV016. The biggest seed weight (74.2g) was recorded in HRSDAV01 followed by HRSDAV014 (59.6g), HRSDAV015 (51.1g) and HRSDAV010 (50.0g) and the lowest weight (10.0g) was in HRSDAV011. The longest seed was measured in HRSDAV08 (65.1mm) and HRSDAV01 (61.5mm) and fruits of HRSDAV011 contained the shortest seed (25.9mm). HRSDAV01 measured the highest seed diameter (60.9mm) followed by HRSDAV014 (47.5mm) but it was statistically non-significant with accessions HRSDAV04 (44.1mm), HRSDAV013 (41.2mm), HRSDAV015 (40.2mm), HRSDAV09 (39.5mm) and HRSDAV012 (39.5mm). The lowest seed diameter (20.8mm) was measured in HRSDAV011. Seed/fruit ratio was the highest in HRSDAV011 (51.9%) followed by accessions HRSDAV014 (34.9%), HRSDAV04 (33.3%) and HRSDAV013 (30.4%) but the lowest seed/fruit ratio (10.9%) was in HRSDAV07. Similarly, HRSDAV01 showed the greatest seed volume (95.8cc) and the lowest (13.3cc) seed volume was in HRSDAV011.

Table 3: Fruit and Seed Quantitative Characters of Avocado Accessions Evaluated at HRS, Dailekh, 2020

Accessions	Fruit volume (cc)	Fruit ripening (days)	Fruit shelf life (days)	Seed weight (g)	Seed length (mm)	Seed diameter (mm)	Seed/fruit ratio (%)	Seed volume (cc)
HRSDAV01	377.8 a	7.0 fg	3.0 e	74.2 a	61.5 a	60.9 a	19.1 def	95.8 a
HRSDAV02	125.0 f	9.0 d	8.0 b	29.4 ef	41.5 cde	32.8 d	17.7 def	26.7 def
HRSDAV03	291.7 b	15.0 c	7.0 c	31.6 def	50.8 b	33.6 d	12.1 ef	35.8 cdef
HRSDAV04	125.8 f	22.0 b	8.0 b	42.7 cd	36.3 e	44.1 bc	33.3 b	51.7 bcd
HRSDAV05	255.0 bc	6.0 fg	3.0 e	32.6 def	42.4 cd	33.0 d	13.4 def	40.8 bcde
HRSDAV06	285.0 b	5.0 gh	4.0 d	43.0 cd	47.3 bc	38.2 cd	15.9 def	44.2 bcde
HRSDAV07	220.0 cd	6.0 fg	4.0 d	22.6 f	41.0 de	36.1 cd	10.9 f	32.5 def
HRSDAV08	176.7 def	7.0 fg	3.0 e	40.0 cde	65.1 a	34.4 d	27.1 bc	34.2 def
HRSDAV09	191.7 de	9.0 d	4.0 d	30.2 ef	43.3 cd	37.6 cd	16.1 def	21.7 ef
HRSDAV010	249.2 bc	26.0 a	14.0 a	50.0 bc	46.0 bcd	39.5 bcd	21.4 cd	53.3 bcd
HRSDAV011	33.9 g	6.0 fg	3.0 e	10.0 g	25.9 f	20.8 e	51.9 a	13.3 f
HRSDAV012	261.7 bc	9.0 d	4.0 d	40.0 cde	40.4 de	39.5 bcd	18.7 def	63.7 b
HRSDAV013	183.3 def	3.0 h	3.0 e	48.0 c	47.5 bc	41.2 bcd	30.4 b	40.0 bcde
HRSDAV014	174.2 def	6.0 fg	3.0 e	59.6 b	46.2 bcd	47.5 b	34.9	50.8 bcd
HRSDAV015	290.6 b	10.0 d	5.0 d	51.1 bc	47.5 bc	40.2 bcd	20.1 cde	61.7 bc
HRSDAV016	155.7 ef	5.0 gh	3.0 e	27.8 f	47.5 bc	34.5 d	16.8 def	43.3 bcde
Mean	212.3	9.3	4.7	39.55	45.64	38.38	22.50	44.3
F-Test	**	**	**	**	**	**	**	**
LSD (0.05)	53.63	1.83	1.26	10.56	5.40	8.17	7.29	23.16
CV (%)	15.1	11.81	16.09	16.0	7.1	12.8	19.4	31.3

** Highly significant at P≤0.01. The same letters in a column are not significantly different at P ≤ 0.05; DMRT.

3.4 Fruit Quality Characters

The pedicels were asymmetrically positioned on 10 accessions while three accessions had conically positioned and three accessions had centrally positioned (Table 4). Out of the 16 accessions, fruit size of nine accessions had highly uniform, six accessions had intermediate and one had low uniform. Fruit skin color varied from reddish purple, green, black, dark green, purple, yellowish, light green to green. Twelve (75.0%) accessions had glossy fruit surface, while four accessions (HRSDAV02, HRADAV09, HRADAV011 and HRSDAV012) contained dullness fruit surface. Out of the 16, ten (62.5%) accessions contained the smooth fruit surface and six genotypes had rough fruit surface. Thirteen accessions had rounded fruit apex while HRSDAV04 and HRSDAV012 had flattened fruit apex and HRSDAV011 had pointed fruit apex. Ten (62.5%) accessions had flattened fruit base while six accessions contained depressed fruit base (Table 4).

Fruit shape varied from pyriform, narrowly obovate, pear shape, spheroid, oval, ellipsoid to rhomboid types in the accessions (Figure 2). Six accessions; HRSDAV02 (Figure 2B), HRSDAV05 (Figure 2E), HRSDAV09 (Figure 2I), HRSDAV010 (Figure 2J), HRSDAV012 (Figure 2L), and

HRSDAV015 (Figure 2O) had narrowly obovate fruit shape. Four accessions namely; HRSDAV01 (Figure 2A), HRSDAV07 (Fig 2G), HRSDAV013 (Figure 2M) and HRSDAV016 (Figure 2P) had pyriform fruit shape. Two accessions; HRSDAV03 (Figure 2C) and HRSDAV08 (Figure 2H) had pear shape, one accession; HRSDAV04 (Figure 2D) had spheroid, one accession; HRSDAV06 (Figure 2F) had oval, one accession; HRSDAV011 (Figure 2K) had ellipsoid, and one accession; HRSDAV014 (Figure 2N) had rhomboid shape (Figure 2N).

Table 4: Fruit Quality Characters of Avocado Accessions Evaluated at HRS, Dailekh, 2020

Accessions	Pedicel position on fruit	Fruit size uniformity[y]	Fruit skin color[z]	Fruit skin	Fruit surface	Fruit apex shape	Fruit base shape
HRSDAV01	Asymmetrical	Interm.	R. purple	Glossy	Smooth	Rounded	Depressed
HRSDAV02	Asymmetrical	High	Green	Dull	Rough	Rounded	Flattened
HRSDAV03	Asymmetrical	High	D. green	Glossy	Rough	Rounded	Depressed
HRSDAV04	Conical	Interm.	Black	Glossy	Rough	Flattened	Depressed
HRSDAV05	Asymmetrical	High	Green	Glossy	Smooth	Rounded	Flattened
HRSDAV06	Asymmetrical	Interm.	D. green	Glossy	Smooth	Rounded	Depressed
HRSDAV07	Asymmetrical	High	Black	Glossy	Smooth	Rounded	Flattened
HRSDAV08	Central	High	Purple	Glossy	Smooth	Rounded	Flattened
HRSDAV09	Conical	High	Green	Dull	Smooth	Rounded	Flattened
HRSDAV010	Asymmetrical	Low	D. green	Glossy	Rough	Rounded	Depressed
HRSDAV011	Conical	Interm.	Yellowish	Dull	Rough	Pointed	Depressed
HRSDAV012	Asymmetrical	High	L. green	Dull	Rough	Flattened	Flattened
HRSDAV013	Central	High	Reddish	Glossy	Smooth	Rounded	Flattened
HRSDAV014	Conical	Interm.	Green	Glossy	Smooth	Rounded	Flattened
HRSDAV015	Asymmetrical	High	L. green	Glossy	Smooth	Rounded	Flattened
HRSDAV016	Asymmetrical	Interm.	Green	Glossy	Smooth	Rounded	Flattened

[y]Fruit size uniformity; Interm.; Intermediate, [z]Fruit size color; R. purple; Reddish purple, D. green; Dark green, L. green; Light green

Figure 2: Fruit shape of 16 avocado accessions, A, HRSDAV01 (pyriform); B, HRSDAV02 (narrowly obovate); C, HRSDAV03 (pear shape); D, HRSDAV04 (spheroid); E, HRSDAV05 (narrowly obovate); F, HRSDAV06 (oval); G, HRSDAV07 (pyriform); H, HRSDAV08 (pear shape at apex with long neck); I, HRSDAV09 (narrowly obovate); J, HRSDAV010 (narrowly obovate); K, HRSDAV011 (ellipsoid); L, HRSDAV012 (narrowly obovate); M, HRSDAV013 (pyriform); N, HRSDAV014 (rhomboid); O, HRSDAV015 (narrowly obovate); P, HRSDAV016 (pyriform).

3.5 Fruit Flesh and Seed Quality Characters

HRSDAV01 contained deep yellow flesh, and nine (56.2%) accessions showed green flesh. HRSDAV06 contained light yellow flesh and HRSDAV07 and HRSDAV08 showed yellow flesh. Fruits of HRSDAV010 had greenish yellow flesh and HRSDAV013 had light green type. Six accessions showed buttery flesh texture while eight accessions showed watery type and remaining two accessions (HRSDAV03 and HRSDAV07) had granular type. Nine (56.2%) accessions had nutty flavor, six had intermediate and one had flat or off-flavored type. Except accessions HRSDAV04 and HRSDAV011, all accessions had good taste. HRSDAV04, HRSDAV011 and HRSDAV016 found sticks to pulp and 11 (68.7%) accessions found easiness for fruit peeling, while two had intermediate types (Table 5). Seed cotyledon color also varied from cream, white, yellow, light yellow to green type. Eight accessions (50.0%) had yellow cotyledon, five accessions had cream color cotyledon, and three accessions, each had white, green and light yellow color cotyledon.

A total of six seed shapes were identified in the studied accessions and it varied from broadly ovate, oblate, base flattened with apex rounded, spheroid, ellipsoid to cordiform types (Figure 3). Eight accessions namely; HRSDAV01 (Figure 3A), HRSDAV03 (Figure 3C), HRSDAV05 (Figure 3E), HRSDAV06 (Figure 3F), HRSDAV07 (Figure 3G), HRSDAV08 (Figure 3H), HRSDAV015 (Figure 3O) and HRSDAV016 (Figure 3P) had broadly ovate seed shape. Two accessions; HRSDAV02 (Figure 3B) and HRSDAV012 had oblate seed shape. One accession; HRSDAV04 (Figure 3D) had base flattened with apex rounded, three accessions; HRSDAV09 (Figure 3I), HRSDAV010 (Figure 3J) and HRSDAV013 (Figure 3M) had spheroid, one accession; HRSDAV011 (Figure 3K) had ellipsoid and one accession; HRSDAV014 (Figure 3N) had cordiform seed shape.

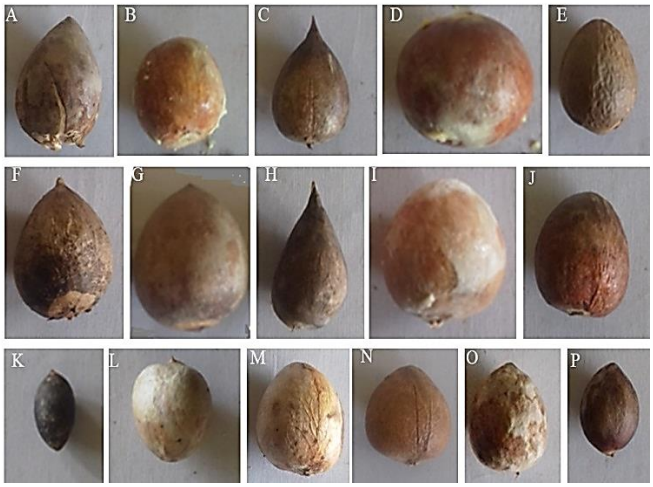

Figure 3: Seed shapes of 16 avocado accessions, A, HRSDAV01 (broadly ovate); B, HRSDAV02 (oblate); C, HRSDAV03 (broadly ovate); D, HRSDAV04 (base flattened apex rounded); E, HRSDAV05 (broadly ovate); F, HRSDAV06 (broadly ovate); G, HRSDAV07 (broadly ovate); H, HRSDAV08 (broadly ovate); I, HRSDAV09 (spheroid); J, HRSDAV010 (spheroid); K, HRSDAV011 (ellipsoid); L, HRSDAV012 (oblate); M, HRSDAV013 (spheroid); N, HRSDAV014 (cordiform); O, HRSDAV015 (broadly ovate); P, HRSDAV016 (broadly ovate).

Table 5: Fruit Flesh and Seed Quality Characters of Avocado Accessions Evaluated at HRS, Dailekh, 2020

Accessions	Flesh color	Flesh texture	Flavor type	Flesh taste [y]	Easiness to peel[z]	Cotyledon color	Cotyledon surface
HRSDAV01	Deep yellow	Watery	Nutty	Good	E. peels	Cream	Rough
HRSDAV02	Green	Buttery	Inter.	Good	E. peels	Cream	Rough
HRSDAV03	Green	Granular	Nutty	Excellent	E. peels	White	Smooth
HRSDAV04	Green	Watery	Inter.	Poor	Sticks to pulp	Yellow	Rough
HRSDAV05	Green	Buttery	Inter.	Fair	E. peels	Ivory	Intermediate
HRSDAV06	Light yellow	Buttery	Nutty	Excellent	E. peels	Yellow	Intermediate
HRSDAV07	Yellow	Granular	Inter.	Good	E. peels	Yellow	Smooth
HRSDAV08	Yellow	Watery	Nutty	Good	E. peels	Yellow	Intermediate
HRSDAV09	Green	Watery	Inter.	Good	E. peels	L. yellow	Rough
HRSDAV010	Greenish yellow	Buttery	Nutty	Good	Interm.	Yellow	Smooth
HRSDAV011	Green	Watery	Flat	V. poor	Sticks to pulp	Yellow	Smooth
HRSDAV012	Green	Buttery	Inter.	Good	E. peels	Cream	Smooth
HRSDAV013	Light green	Buttery	Nutty	Fair	Interm.	Yellow	Intermediate
HRSDAV014	Green	Watery	Nutty	Good	E. peels	Yellow	Intermediate
HRSDAV015	Green	Watery	Nutty	Good	E. peels	Cream	Smooth
HRSDAV016	Green	Watery	Nutty	Excellent	Sticks to pulp	Cream	Intermediate

[y]Flesh taste, V. poor; Very poor, [z]Easiness to peel, E. peels; Easily peels, Cotyledon color; L. yellow; Light yellow

Based on the result of pulp/fruit ratio and seed/fruit ratio, and other fruit quality characters, three accessions were identified the best accessions (Figure 4). Accessions HRSDAV03 (Figure 4A), HRSDAV06 (Figure 4B), and HRSDAV07 (Figure 4C) are selected for commercial production as well as parent materials for avocado breeding program.

Figure 4: The 3 selected superior avocado accessions from HRS Dailekh. A, HRSDAV03; B, HRSDAV06; C, HRSDAV07.

4. Discussion

Avocado accessions exhibited wide variation in plant traits including tree trunk surface, tree shape, tree vigor, leaf shape and color, leaf margin, and leaf base shape. These accessions have developed traits adaptable to the particular environment. This study showed that 50% of accessions had rough trunk surface. In contrast, reported only rough and very rough trunk surface among 15 avocado accessions in Indonesia (Ismadi and Hafifah, 2017). Guatemalan and Mexican avocado races are less rough while those of the West Indian race are rougher (Bergh, 1992). reported high percentage of the accessions had circular tree shape and present study also showed high percentage of accessions was circular to semi-circular type . Diversity in tree shape in avocado accessions was also reported by (Nkansah et al., 2013). The present study showed the extensive variation in leaf shape which varied from narrowly obovate, oval, ovate to lanceolate type. Leaf shape is an important character as it may express the extent of leaf area, hence seasonal integral of light interception which can directly affect plant yield (Nkansah et al., 2013). The reported only lanceolate (73.33%) and oblong lanceolate (26.67%) leaf shapes among 15 avocado accessions in Indonesia but in present study, 56.2% genotypes contained narrowly obovate leaves and rest of the genotypes exhibited oval, ovate and lanceolate leaf shape (Ismadi and Hafifah, 2017). Variation in leaf shape among the avocado plants were reported by previous researchers (Nkansah et al., 2013; Abraham et al., 2018). Variation in leaf color in genotypes may be significant in photosynthesis as dark green leaves tend to have high chlorophyll content which may be associated with high yields (Nkansah et al., 2013). Leaf color was used as morphological traits to characterize avocado variety (Ramirez et al., 2005). Had a reported two leaf margins (entire and undulate) and two leaf base shapes (acute and obtuse) in the avocado accessions and our study also showed similar results (Nkansah et al., 2013). Avocado leaves have diverse shapes like ovate, obovate, oval, roundish or lanceoloate (Abraham et al., 2018). The avocado genotypes established at Dailekh were seed-propagated which could have created the variation in plant morphological traits. reported that avocado plants originated from seed will be vary and are rarely equal the parent plant (Berg and Ellstrand, 1986).

In this study, pedicel length ranged from 1.0 to 2.8cm in avocado accessions but reported that pedicel length ranged from 0.6 to 1.5cm. Present study found wide variation in peduncle length in avocado accessions (Abraham et al., 2018). It is reported that 7.6% of the fruit had over 8cm peduncle length but accession HRSDAV05 had the longest (9.3cm) peduncle length (Abraham et al., 2018). Significant variation was observed in fruit weight and it ranged from 19.8 to 394.8g fresh weight in avocado accessions. Paz-Vega (1997) reported 200.0 to 300.0g fresh weight and reported 220.0 to 420.0g fresh weight in avocado genotypes. This study recorded the highest fruit weight (394.8g) in HRSDAV01 followed by HRSDAV06 (267.1g), HRSDAV03 (263.2g) and HRSDAV015 (254.7g) but reported the highest fruit weight (403.3g) in PAKAV009 (Poudel et al., 2018). Variation in the fruit weight among accessions agreed with the result of where they reported the variation in fruit weight ranging from 161.8 to 387.4g in R8T18 and R5T56 of avocado genotypes (Pisani and Ritenour, 2017). In contrast, reported that fruit weight ranged from 126.5 to 1265.8g fresh weight in avocado genotypes (Lestari et al., 2016). The variation in fruits characters in avocado accessions might be come from its dichogamic hermaphrodite characters since it has male and female flowers at the same tree which confirms the findings of (Gazit and Degani, 2002).

Present study observed the variation in fruit length ranging from 5.4 to 14.0cm with an average of 10.27cm and more than 50.0% accessions had more than 11.0cm fruit length. Reported the variation of fruit length ranging from 7.0 to 19.0cm with an average of 11.1cm (Abraham et al., 2018). This mentioned that average fruit length 15cm was reported in West Indian avocadoes (Crane, 2008). There a also reported that fruit length varied from 6.2 to 23.5cm. Fruit diameter showed significant variation and it ranged from 3.3 to 7.5cm with the average of 6.3cm (Lestari et al., 2016). In contrast, fruit diameter varied from 5.8 to 12.1cm in avocado genotypes (Lestari et al., 2016). Accessions showed the significant variation in pulp weight and similar result was reported by (Poudel et al., 2018). This study found maximum 80.8% and 83.3% pulp weight in HRSDAV07 and HRSDAV06, respectively but reported the maximum (61.4%) pulp weight in PAKAV002 (Poudel et al., 2018). As a reported that pulp contents based on fruit weight were in between 48.2% and 86.3% but present study showed the pulp/fruit ratio between 47.3% and 83.3% which is closed to the findings of (Lestari et al., 2016; Lestari et al., 2016). Edible flesh or pulp content around the seed is important criteria for avocado evaluation (Rouse and Knight, 1991). The reported up to 88% pulp/fruit in the avocado selection WA-2-3-27 (Alboyce Rouse and Knight, 1991).

In this study, seven (50.0%) accessions had thick (>1.0mm) fruit skin, six (37.5%) accessions had intermediate (0.5-1.0mm) and two accessions had

thin (<0.5mm) fruit skin. Popenoe (1974) reported that thin avocado peel (≤1.0mm) represents Mexican and West Indian avocado races. Likewise, reported thin avocado peel in the cultivars 'Susan, 'Sharwil' 'Rincon' and 'Fuerte' which are Guatemalan x Mexican hybrids (Morton, 1987). HRSDAV01 and HRSDAV016 showed thin (0.5mm) fruit skin which can be the West Indian races. But 50.0% accessions showed thick fruit skin which could be the presence of genetic material from the Guatemalan race. The described that most Guatemalan avocado cultivars have thick to very thick fruit peel (Popenoe,1974). This study showed the significant variation in seed weight and it varied from 10.0 to 74.2g with the average of 39.5g. Lestari et al. (2016) also described the variation in seed weight which ranged from 27.1 to 133.5g. Abraham et al. (2018) reported the seed weight between 25.0 and 125.0g. In this study, majority of the genotypes contained small seeds (< 50.0g) while only four accessions contained medium (50.0-100g) seeds. Large seeds are characteristics features of Mexican and West Indian races while small seeds are typical characteristics features of the Guatemalan race (Bergh and Lahav, 1996). This study found the significant variation in seed length and seed width and seed length varied from 25.9 to 65.1mm. Seed diameter varied from 20.8 to 60.9mm with the average of 38.3mm. This result is very close to Lestari et al. (2016) where they reported that seed length varied from 3.0 to 8.4cm and seed width varied from 3.0 to 6.8cm. Seeds of avocado fruits are large as compared to other fruits and seed size is an important trait for the selection of avocado genotypes (Poudel et al., 2018). In this study, accessions HRSDAV011 (51.9%), HRSDAV014 (34.9%), HRSDAV04 (33.3%), HRSDAV013 (30.4%), and HRSDAV08 (27.1%) had seed weight more than 25% of the fruit weight. In the study, they reported that seed weight more than 25% of the total fruit weight was unacceptable while selecting avocado genotypes of (Rouse and Knight, 1991). As a reported the highest (32.6%) seed weight in PAKAV008 (Poudel et al., 2018).

Avocado accessions showed wide variation in fruit characters (pedicel position on fruit, fruit size uniformity, skin color, skin type, fruit surface, fruit apex shape, base shape, fruit shape, flesh color, flesh texture, flavor type, taste and easiness to peel) and seed characters (cotyledon color, cotyledon surface and seed shapes,). Fruit shape is an important morphological character which appeals to consumers in the markets and great diversity in fruit shape provides a chance to interest diverse customers (Juma et al., 2020). Diversity in fruit shapes in avocado including rhomboid, ellipsoid, pyriform or obovate was reported by (Morton, 1987). In general, narrowly obovate, pyriform, rhomboid and ellipsoid shapes of fruits are typical of West Indian avocadoes. In this study, diverse fruit shape observed in the avocado accessions indicates the presence of genetic material from three avocado races. In this study, six accessions had rough skin and rough skin is the characteristics of Guatemalan avocado (Bergh and Ellstrand, 1986).

This study found three flesh texture; buttery, granular and watery. Buttery flesh texture is generally described as specific to Mexican avocadoes and some Guatemalan avocadoes (Popenoe, 1974). As a highlighted that Mexican and Guatemalan avocado cultivars have moderate to high oil content which might be associated to buttery and pastose flesh textures (Crane et al., 2016). Had also reported buttery flesh texture in 'Rincon' which is a Guatemalan x Mexican hybrid (Morton, 1987). The occurrence of buttery flesh texture in the present study also points to the presence of Mexican and Guatemalan avocadoes while the occurrence of watery flesh texture points to the existence of avocadoes of West Indian origin. But flesh texture might be also affected by environmental factors (Juma et al., 2020). Smooth, intermediate and rough cotyledon was observed in avocado accessions but only three accessions contained rough cotyledon. It is ascribed the rough cotyledon to the West Indian race and the smooth cotyledon to the Guatemalan and West Indian races leading to the assumption that all three avocado races are present in Dailekh (Bergh, 1992). Broadly ovate seeds were predominant among the accessions and the spheroid seeds were reported in avocado accessions in Tanzania (Juma et al., 2020).

5. Conclusion

Avocado accessions displayed great differences in morphological traits which suggest the genetic variation that could be used by fruit breeders for development of new varieties. These accessions were seed-propagated which could have contributed to the high variation in plant, fruit and seed characters. The seedlings were collected from different ranges (850 m asl - 1,740 m asl) where different races were adapted to different altitudes. These 16 avocado accessions grown in Dailekh assume to be represent all three botanical groups that are the Mexican, Guatemalan and West Indian races. Out of the 16 accessions, HRSDAV03, HRSDAV06 and HRSDAV07 can be selected as the best genotypes for fruit quality characters. These genotypes can be used to produce the graft saplings through clonal propagation for commercial production as well as for breeding materials for variety development. Application of molecular markers for proper identification of avocado accessions and assessment of their genetic diversity are further recommended to study at Dailekh.

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Conflict of Interest

The author declare no conflict of interest.

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