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Variation of qualitative traits in natural accessions of Libyan strawberry tree (*Arbutus pavarii* Pamp) in Al-Jabal Al-Akhdar, Libya.

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Abstract:

The present study characterized twenty-four accessions of Libyan strawberry tree (*Arbutus pavarii* Pamp.), an endemic species restricted to Al Jabal Al Akhdar, using twenty morphological categories derived from seven descriptive traits. These traits comprised four leaf traits (blade length, blade width, leaf shape, and leaf size) and three fruit traits (fruit size, fruit mass, and fruit shape). All accessions of *A. pavarii* exhibited variation in the frequencies and proportions of categories for the descriptive leaf and fruit traits. All observed differences among the studied traits were statistically significant, with the exception of the leaf shape (LSH) and the fruit shape (FSH), for which no significant differences were detected. The current findings suggest that the unequal variation in the distribution and frequencies of descriptive traits among Libyan strawberry tree accessions is subject to the control of genetic factors in addition to variation in environmental conditions. This unequal distribution leads to the dominance of specific categories as a result of environmental filtering Such variation in the distribution and frequencies of descriptive traits has been recorded in numerous wild species and is considered an established ecological phenomenon, as trait categories are not distributed equally but generally follow an unequal distribution governed by both genetic and environmental factors.

Keywords: *Arbutus pavarii* Pamp., Al Jabal Al Akhdar, Endemic species, Qualitative traits.

1.Introduction:

Biodiversity is most clearly reflected in morphological diversity. Morphological differences between and within species represent the most evident forms of biological variation. In nearly all natural populations, diverse morphological traits are consistently, and predominantly observed across individuals. The desire to explain how this diversity arises and is maintained at all levels (from individuals to species) has been the driving force behind scientific research throughout the various stages of evolutionary biology (Young, 2007). Morphometric traits have served as a robust data source in plant taxonomy since its inception, owing to their widespread availability and extensive phenotypic variation. These morphometric divergencies are governed by the genetic regulation of morphogenesis, the degree of heterozygosity, and plastic responses induced by contrasting environmental conditions (Aravanopoulos, 2010). Morphological characters usually exhibit a greater degree of inter-population differentiation than genetic markers (Hamrick, 1983) and it has been suggested that different evolutionary forces may be acting upon these different sets of characters (Mitton, 1978). Furthermore, phenotypic characteristics have been, and continue to be, used as fundamental distinguishing descriptors in the classification of living organisms. Morphological characteristics are considered the main and effective descriptive tool in characterizing the germplasm of plant species (Tous *et al*., 1996; Furat and Uzun, 2010). For example, the morphological characteristics of pods and seeds have been widely used as morphometric markers to determine the variation among wild populations of carob (Elfazazi *et al*., 2017; Ali *et al*., 2019). The widespread use of morphological traits in the assessment of genetic diversity is due to the fact that they provide a simple, easy, and inexpensive method for measuring genetic differences between and within populations of the same species. In addition, these techniques contribute important information to breeding programs as well as to strategies for the conservation and maintenance of species (Sarıkamıs, *et al*., 2010; Van Beuingen and Bush, 1997). Despite its small area (1% of the country's territory), Al-Jabal Al-Akhdar holds exceptional

importance, as it is considered the ecological habitat for many endemic plant species in Libya (Radford *et al*., 2011; Flora of Libya, 2024; Ali *et al*, 2025). Libyan strawberry tree (*Arbutus pavarii* Pamp), locally known as "Shamari", represents one of the most important endemic plant species in this region. Shamari (Libyan strawberry, *A. pavarii* Pamp) is a rare, endemic shrub belong to Ericaceae family (GBIF, 2024; Kabiel *et al*., 2016; IUCN, 2022; Elabidi and Elshatshat 2017). It is currently threatened by anthropogenic activities, holding the status of Near Threatened A2c ver. 3.1 on the IUCN Red List (Harvey-Brown, 2022).

Moreover, the Libyan strawberry tree (*A. pavarii* Pamp) locally has nutritional and therapeutic properties, and it is considered one of the most important forage plants for bees in Al-Jabal Al-Akhdar. The honey produced from using this plant as a forage source is regarded as one of the best and most expensive types in Libya, due to its widespread use for therapeutic purposes in local folk medicine. Furthermore, *A. pavarii* has been used in traditional Libyan medicine to treat many human diseases, including gastritis and kidney disorders (El shatshat 2009; El Hawary *et al*., 2016).

Due to the scarcity of data regarding the diversity of Libyan strawberry, particularly the phenotypic variation among its populations within their natural habitats in Al-Jabal Al-Akhdar, establishing a comprehensive database is of urgent scientific importance.

Consequently, the present study was conducted to evaluate the inter- and intra-population phenotypic variation among natural populations of Libyan strawberry (*Arbutus pavarii* Pamp) in Al-Jabal Al-Akhdar, thereby providing critical baseline information for future genetic and conservation research.

2. Material and Methods

2.1. Study location:

Al-Jabal Al-Akhdar (32°35′52″ N 21°28′22″ E) is located in the northeast of Libya. It consists of highlands that represent the highest elevation of the plateau geologically known as the Cyrenaica Platform.

The climate of Al-Jabal Al-Akhdar follows the Mediterranean climate, which is characterized by hot, dry summers and mild, wet winters. According to the aridity index, Al-Jabal Al-Akhdar records values ranging from 0.2 to 0.3, placing it within the semi-arid region. It is considered the most humid region in Libya, with rainfall rates ranging from 250 mm to 650 mm(Ali *et al*.,2025; Zatout,2013).

2.2. Plant material:

The study was conducted on wild Libyan strawberry tree or shrubs (*Arbutus pavarii* Pamp.) collected from 24 sites (24 wild accessions) growing naturally in Al-Jabal Al-Akhdar region. The Accessions of this endemic species were distributed across different natural habitats in the region (Table 1). Their distribution sites within the study region ranged from Wadi Sutta site at an elevation of 65 m to the Telgaza site at an elevation of 792 m.

2.3. Measurements and data collection:

Leaf and fruit samples were collected during the growing season of 2025, ensuring the samples were free from mechanical injuries and disease symptoms. Ten leaf and 10 fruit samples were collected from each tree, with each accession represented by 10 trees. Leaf dimensions were measured, along with fruit measurements (dimensions, volume, and mass). The measured leaves and fruits were then categorized within each trait (Fig 1 and 2). The distribution of categories within the descriptive character was carried out by following the standard methods used in such studies in similar species, with the necessary modifications introduced as required by the nature of the plant under study (Table 2). There were 7 descriptive traits: 4 traits for the leaf (blade length, blade width, leaf shape, leaf size); and 3 traits for the fruit (fruit size, fruit weight, fruit shape).

Table 1. Accession code, names of sites, coordinates and elevation of Libyan strawberry tree (*Arbutus pavarii* Pamp.) populations in Al-Jabal Al-Akhdar used in the study.

Accessions		Longitude (E)	Latitude (N)	Altitude (m)
Code	Site			
Accsh-1	Al-Dabousiya الدبوسية	22° 16' 49.07"E	32° 50' 12.65"N	294
Accsh-2	Haboon حبون حبون	21° 49' 07.20"E	32° 12' 55.14"N	641
Accsh-3	Telgaza تلغزا	21° 48' 20.58"E	32° 41' 03.80"N	792
Accsh-4	Al-Zarda الزردة	22° 05' 47.51"E	32° 47' 30.77"N	701
Accsh-5	Mibra ميبرة	21° 38' 48.62"E	32° 51' 20.15"N	255
Accsh-6	Yara يارا	22° 05' 15.35"E	32° 50' 16.81"N	560
Accsh-7	Settia سطية	21° 56' 46.68"E	32° 50' 24.43"N	415
Accsh-8	Chenizira شنيظيرة	21° 29' 09.87"E	32° 44' 10.56"N	416
Accsh-9	Zawiya Anblo زاوية انيلو	21° 04' 04.32"E	32° 42' 48.53"N	351
Accsh-10	Bands باندس	21° 40' 36.80"E	32° 41' 33.61"N	620
Accsh-11	Al-Wardiyah الوردية	21° 29' 11.00"E	32° 39' 13.25"N	355
Accsh-12	Wadi Suta وادي السوتة	21° 40' 14.48"E	32° 55' 28.60"N	65
Accsh-13	Ibrahim Bouras إبراهيم بوراس	20° 39' 47.52"E	32° 20' 11.05"N	373
Accsh-14	Qandulah قندولة	21° 38' 16.26"E	32° 34' 17.29"N	739
Accsh-15	Bashmaru بشمارو	21° 81' 90.34"E	32° 72' 61.27"N	679
Accsh-16	Tolmeitha طلميثة	20° 56' 20.47"E	32° 39' 42.30"N	263
Accsh-17	Wadi Seif وادي سيف	21° 32' 52.51"E	32° 50' 28.38"N	74
Accsh-18	Sidi Khalid سيدي خالد	22° 28' 23.90"E	32° 44' 60.30"N	400
Accsh-19	Taknis تاكنس	21° 07' 09.41"E	32° 30' 52.13"N	465
Accsh-20	Khawabi خوابي	20° 48' 48.92"E	32° 35' 31.97"N	317
Accsh-21	Shawnia شونيا	21° 46' 13.94"E	32° 51' 28.05"N	370
Accsh-22	Ras al-Helal راس الهلال	22° 10' 28.83"E	32° 52' 27.28"N	231
Accsh-23	Asqfa اسقفا	20° 35' 32.05"E	32° 16' 39.90"N	448
Accsh-24	Qasr al-Raqeeq قصر الرقيق	22° 09' 46.62"E	32° 49' 10.06"N	590

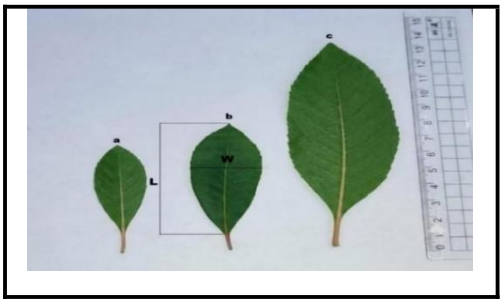


Fig1. Variation in qualitative leaf traits of Libyan strawberry tree in relation to dimensions (length, L and width, W). Short and small-sized leaf (a), intermediate and medium-sized leaf (b), long and large-sized leaf (c).

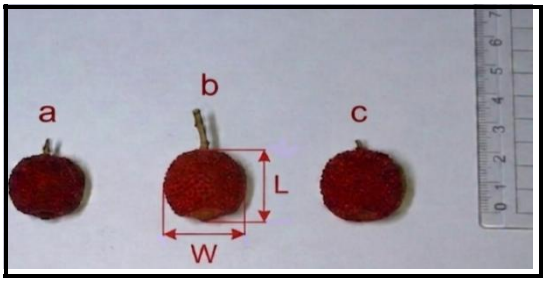


Fig2. Diversity in qualitative fruit traits of Libyan strawberry tree in relation to dimensions (length, L and width, W) and weight. Light mass and small-sized fruit (a), medium mass and medium-sized fruit (b), heavy mass and large-sized fruit (c).

2.4. *Data analysis*

For data analysis, phenotypic frequency distributions of qualitative traits were calculated in all accessions. The Chi-square test for independence was conducted to determine whether the traits and accessions are associated, while the Chi-square test for homogeneity was applied to test the homogeneity of accessions (Bolboaca *et al*., 2011). The calculated Chi-square values were compared with the tabulated value to test their statistical significance at *df* = (number of rows – 1) (number of columns – 1) for the independence test, and at *df* = number of rows – 1. The number of rows represents the number of populations, while the number of columns represents the number of categories for each trait. The statistical analysis was performed using Minitab ver.18 software.

Table 2. Description of categories for qualitative traits of fruits and leaves in the Libyan strawberry tree (*Arbutus pavarii* Pamp.) in Al Jabal Al Akhdar.

Plant organ	Trait	Trait categories	Code	Description
Leaf	Blade Length (BL)	Short	1	BL < 5 cm
		Intermediate	2	BL = 5 – 6.5 cm
		Long	3	BL > 6.5 cm
	Blade Width (WL)	Narrow	5	BW < 2 cm
		Moderate	7	BW = 2 – 2.5 cm
		Wide	9	BW > 2.5 cm
	Leaf Shape (LSH)	Elliptic-oblong	5	LSI ≥ 2
		Elliptic-ovate	7	LSI < 2
	Leaf Size (LS)	Small	3	LS < 10 cm^2
		Medium	5	LA = 10 – 15 cm^2
		Large	7	LA > 15 cm^2
Fruit	Fruit Size (FS)	Small	1	FS < 1.5 cm^3
		Medium	2	FS = 1.5 – 2.5 cm^3
		Large	3	FS > 2.5 cm^3
	Fruit Mass (FM)	Light	5	FM < 1.75 g
		Medium	7	FM = 1.75 – 2.75 g
		Heavy	9	FM > 2.75 g
	Fruit Shape (FSH)	Oblate	3	FSI < 0.90
		Spherical	5	FSI = 0.90 – 1.10
		Elongate	7	FSI > 1.10

3. Results and discussion:

3.1. Characterization of Libyan strawberry tree in Al-Jabal Al-Akhdar

The entire Libyan strawberry tree (*Arbutus pavarii* Pamp.) accessions that are naturally growing in Al-Jabal Al-Akhdar was characterized using 20 phenotypic categories resulting from 7 descriptive traits, which were as follows: 4 leaf traits (blade length, blade width, leaf shape, and leaf size) and 3 fruit traits (fruit size, fruit mass, and fruit shape).

Table (3**)** summarizes the frequencies and percentages of qualitative trait categories for leaves and fruits in Libyan strawberry tree (*A. pavarii* Pamp.) samples in Al-Jabal Al-Akhdar. Regarding blade length (BL), intermediate leaves were the most frequent in Libyan. strawberry samples (64.58%, *n*=155), followed by short leaves (19.17%, *n* = 46), while long leaves were the least frequent (16.25%, *n* = 39). As to blade width (BW), narrow leaves were the least frequent (20.42%, *n* =49), followed by wide leaves, which were more frequent (33.75%, *n*=81), while moderate leaves recorded the highest frequency (45.83%, *n* = 110). Two categories were observed for leaf shape (LSH): elliptic-ovate shape, which was predominant at 86.25% (*n* = 207), and elliptic-oblong shape, which was less frequent at 13.75% (*n* = 33). Leaf size (LS) appeared in all Libyan strawberry samples in three categories: small, medium, and large. Small leaves recorded the highest percentage at 47.92% (*n* = 115), followed by medium leaves at 41.25% (*n* = 99), and finally large leaves, which were the least frequent at 10.83% (*n* = 26).

All Libyan strawberry tree (*A. pavarii* Pamp) samples showed variation in the frequencies and proportions of categories for descriptive fruit traits (Table 3). In respect of fruit size (FS), medium size was predominant at 52.08% (*n* =126), followed by small fruits at 31.67% (*n* =75), while large size recorded the lowest proportion at 16.25% (*n* = 39). Fruit mass (FM) was classified into three weight categories: light, medium, and heavy. Medium category was the most prevalent, recording 49.17% (*n* = 118), followed by light category at 37.08% (*n* =89), while heavy category was the least, recording 13.75% (*n*=33). Regarding fruit shape (FSH), oblate shape was the most common at 54.16% (*n* = 130), followed by spherical shape at 40.84% (*n* = 98), while elongate shape was the least common at 5% (*n* = 12). The current results are consistent with many previous studies, which have indicated that the variation in the distribution and frequencies of descriptive traits within wild plant communities is an established ecological fact.

These trait categories are not distributed equally but usually follow an uneven distribution governed by environmental, evolutionary, and genetic factors. Several previous studies have pointed out that the frequency of certain trait categories in wild plants is closely linked to the abundance and geographical distribution of the plant. This disparity leads to the dominance of certain categories (unequal distribution) based on environmental filtering. Such variation in the distribution and frequencies of descriptive traits has been recorded in many wild species, such as *Crescentia cujete* L. (Arango-Ulloa *et al*., 2009), *Senna candolleana* (Lazaro-Nogal *et al*., 2015), *Pistacia atlantica* (Nadjat and Tayeb, 2020), and *Camellia oleifera* (Chen *et al*., 2023). Moreover, such variation in descriptive traits has been observed in genus Arbutus in many regions of the Mediterranean Basin, such as in Turkey (Celikel *et al*., 2008), Spain (Molina *et al*., 2011), Portugal (Lopes *et al*., 2012), Algeria (Boussalah *et al*., 2018), Morocco (Faida *et al*., 2021), and Greece (Aravanopoulos *et al.*, 2022).

Table 3. Frequency and percentage of phenotypic categories for descriptive traits observed in fruits and leaves of Libyan strawberry tree (*Arbutus pavarii* Pamp.) in Al Jabal Al Akhdar.

Plant organ	Trait	Trait class	Code	Frequency	Percentage %
Leaf	Blade Length (BL)	Short	1	46	19.17
		Intermediate	2	155	64.58
		Long	3	39	16.25
	Blade Width (BW)	Narrow	5	49	20.42
		Moderate	7	110	45.83
		Wide	9	81	33.75
	Leaf Shape (LSH)	Elliptic-oblong	5	33	13.75
		Elliptic-ovate	7	207	86.25
	Leaf Size (LS)	Small	3	115	47.92
		Medium	5	99	41.25
		Large	7	26	10.83
Fruit	Fruit Size (FS)	Small	1	75	31.67
		Medium	2	126	52.08
		Large	3	39	16.25
	Fruit Mass (FM)	Light	5	89	37.08
		Medium	7	118	49.17
		Heavy	9	33	13.75
	Fruit Shape (FSH)	Oblate	3	130	54.16
		Spherical	5	98	40.84
		Elongate	7	12	5
Total				240	100

3.2. Distribution of qualitative traits in 24 Libyan strawberry accessions

Table (4) shows the distribution and frequencies of categories and the results of the Chi-square test for four qualitative leaf traits in 24 accessions of Libyan strawberry tree (*A. pavarii* Pamp) in Al Jabal Al Akhdar. The studied traits included: blade length (BL), blade width (BW), leaf shape (LSH), and leaf size (LS). All traits showed significant differences (x^2 *tab*= 61.65 at *df* =46) except for the leaf shape (x^2 *tab*= 35.20 at *df*=23), where the differences were not significant at the level α=0.05. Concerning blade length (BL), it was divided into three categories: long, intermediate, and short. It is clear that intermediate category is dominant and most frequent in most accessions (Table 4). Accsh-7, Accsh-9, and Accsh-20 recorded the highest frequency (*n*=9), indicating that Libyan strawberry tree in Al Jabal Al Akhdar tends to produce intermediate blades. In contrast, long category was sharply limited to only two accessions: Accsh-3 (*n* = 8) and Accsh-1 (*n* = 7), while this category was completely absent in 10 accessions (Accsh-4, Accsh-7, Accsh-8, Accsh-9, Accsh-10, Accsh-15, Accsh-18, Accsh-20, Accsh-21, Accsh-24). Short blades appeared with low frequencies, except for two accessions (Accsh-10 and Accsh-8), which recorded the highest frequency (*n* = 6, *n* = 5 respectively). Chi-square test confirms that the differences are highly statistically significant ($\boldsymbol{x_{gk}^2}$=116.53) at α= 0.05, excluding the possibility of the distribution occurring by chance, and confirming the strong association between the genetic composition of accessions and their morphological expression of trait. In species belonging to the genus Arbutus, there is no single universally preferred leaf length category across all species, as leaf length is determined by genetic factors in addition to environmental conditions such as humidity, temperature, altitude, light, and soil fertility (Lopes *et al*., 2012; Bertsouklis and Papafotiou, 2016; Faida *et al*., 2021). However, in many cases, intermediate leaves are often considered the most suitable and thus the most prevalent.

From a physiological and ecological perspective, intermediate leaves often represent the optimal functional category, as they provide a balance between sufficient photosynthetic area and moderate water loss (Wang *et al*., 2019). That means intermediate leaf is generally the most preferred category, while short leaves dominate under stressful environments, and long leaves are less common and mostly restricted to favorable habitats. Species of the genus Arbutus typically possess sclerophyllous leaves of intermediate size, suggesting a functional compromise between maximizing photosynthetic surface and minimizing transpirational water loss under Mediterranean environments (Gratani and Ghia, 2002).

Regarding blade width (BW), the results showed a wide phenotypic variation among 24 Libyan strawberry (Table 4). The trait was classified into three categories (narrow, moderate, and wide). Moderate category was present in all accessions, and recorded the highest frequency (*n* = 9) in Accsh-4, followed by Accsh-18 (*n*=8), reflecting a state of phenotypic stability for this trait in Libyan strawberry populations. Accsh-11, Accsh-12, Accsh-13, Accsh-14, Accsh-17, and Accsh-22 were clearly characterized by a tendency to produce wide leaves, with Accsh-13 and Accsh-14 recording the highest frequency (*n* = 9). Narrow blade was most common in Accsh-5, Accsh-6, Accsh-7, and Accsh-15, where the highest frequency was recorded (*n*=5). Furthermore, overlap was observed within plants belonging to the same accessions, such as Accsh-10 and Accsh-24, where plants were distributed almost equally among the three categories.

Statistically, the differences observed in blade width among the clans were highly significant ($\boldsymbol{x_{gk}^2}$=120.60), indicating that the trait is closely associated with the genetic pattern and does not represent a mere random distribution. Since these accessions are diverse forms of a native wild plant, this significant variation in leaf width suggests ecological adaptation. accessions with narrow leaves may have evolved in dry environments, while those with wide leaves may have evolved in humid environments. Under conditions similar to those of the Mediterranean basin (hot, dry summers and mild, wet winters), moderate leaf category is often functionally the most suitable from an eco-physiological perspective, as it achieves the best balance between light absorption efficiency and water use economy (Niinemets *et al*., 2007; Wang *et al.*, 2019). Meanwhile, narrow leaves dominate in drier, harsher microhabitats, and wide leaves are restricted to more mesic and sheltered environments. However, in species belonging to genus Arbutus growing in Mediterranean Basin, there is no strict universal preference for leaf-width category, because leaf width varies with species, genetic factors, and local habitat conditions (Gratani and Ghia, 2002; Lopes *et al,* 2012; Faida *et al,* 2021).

As regards to leaf size (LS), the samples were classified into three size categories: small, medium, and large. The results showed significant variation among the 24studied

accessions of Libyan strawberry tree in leaf size. The observed differences among accessions in the frequencies of leaf size categories were highly statistically significant (x_{gk}^2 = 122.71). It was clearly observed that small leaf is dominant and most frequent in most accessions.

Additionally, Accsh-4, Accsh-5, Accsh-7, and Accsh-15 recorded the highest frequency for this category (n = 9), indicating that the accessions of Libyan strawberry tree in Al Jabal Al Akhdar tend to produce small leaves. Medium leaf was the second most frequent, recording the highest frequency (n = 8) in Accsh-17. It also dominated in some accessions (Accsh-20, Accsh-21), recording relatively high frequencies (n = 7). Conversely, the large leaf category was absent in 15 out of 24 accessions, with the highest frequency (n = 5) recorded in Accsh-11. In general, Al-Jabal Al-Akhdar, which is characterized by a long, hot, and dry summer, Libyan strawberry accessions prefer small to medium-sized leaf categories, with an increased frequency of small leaves in habitats exposed to drought. This reflects adaptation to seasonal drought during the summer (adaptive defensive mechanism for survival) while large leaves are relatively rare and often restricted to moist microhabitats.

Under Mediterranean basin conditions, species belonging to Arbutus genus tend to have thick, leathery, and relatively small leaves (sclerophyllous leaves) compared to plants in humid regions. These species do not favor the “large” leaf category because it would constitute a fatal burden in terms of water loss and heat during the summer, nor do they favor “dwarf-like” leaves because they require sufficient leaf area for growth during periods of water abundance. Specifically, these species exhibit a highly specialized evolutionary adaptation, meaning they develop tough, leathery, and relatively limited-sized leaves instead of large, tender leaves (Bertsouklis and Papafotiou, 2016; Aravanopoulos *et al*., 2022; Politi and Aravanopoulos, 2022). Therefore, small to medium-sized, thick, and leathery leaves are the ideal strategy for survival and thriving in Mediterranean climate (Yadav *et al*., 2004). Generally, small or medium leaves with limited area reduce the surface exposed to direct sunlight and dry winds, which significantly decreases the rate of transpiration and helps the plant retain moisture during the dry months (Yates *et al*., 2010, Wright *et al*., 2017). Furthermore, small leaves help to maintain suitable leaf temperatures and water use efficiency in photosynthesis under conditions of high solar radiation and low water availability (Parkhurst and Loucks 1972; Givnish and Vermeij,1976).

Table 4. Frequency of descriptive trait categories of leaves and Chi-square test (x^2) for 24 accessions of Libyan strawberry tree (*Arbutus pavarii* Pamp.) in Al Jabal Al Akhdar.

Accession	Blade length (BL)			Blade width (BW)			Leaf shape (LSH)		Leaf size (LS)		
	Short	Inter-mediate	Long	Narrow	Moderate	Wide	Elliptic-oblong	Elliptic-ovate	Small	Medium	Large
Accsh-1	1	2	7	1	4	5	2	8	1	5	4
Accsh-2	1	7	2	3	5	2	2	8	4	5	1
Accsh-3	0	2	8	3	4	3	1	9	2	4	4
Accsh-4	3	7	0	0	9	1	1	9	9	1	0
Accsh-5	1	8	1	5	5	0	0	10	9	1	0
Accsh-6	1	8	1	5	4	1	0	10	6	4	0
Accsh-7	1	9	0	5	5	0	1	9	9	1	0
Accsh-8	5	5	0	2	5	3	4	6	8	2	0
Accsh-9	1	9	0	4	6	0	0	10	6	4	0
Accsh-10	6	4	0	3	4	3	4	6	7	3	0
Accsh-11	2	5	3	1	2	7	3	7	2	3	5
Accsh-12	0	6	4	0	3	7	1	9	1	6	3
Accsh-13	2	7	1	0	1	9	2	8	2	5	3
Accsh-14	0	8	2	0	1	9	3	7	1	6	3
Accsh-15	2	8	0	5	4	1	0	10	9	1	0
Accsh-16	3	6	1	3	7	0	0	10	7	3	0
Accsh-17	1	5	4	0	2	8	1	9	1	8	1
Accsh-18	4	6	0	0	8	2	3	7	4	6	0
Accsh-19	2	7	1	3	5	2	0	10	7	3	0
Accsh-20	1	9	0	1	7	2	0	10	3	7	0
Accsh-21	4	6	0	0	7	3	2	8	3	7	0
Accsh-22	0	7	3	1	3	6	0	10	2	6	2
Accsh-23	1	8	1	0	6	4	1	9	5	5	0
Accsh-24	4	6	0	4	3	3	2	8	7	3	0
x_g^2	69.92	13.31	33.30	56.78	22.21	41.61	4.59	28.82	57.08	23.91	41.72
$x_{gk}^2(x_{tab}^2)$	116.53 (61.65)			120.60 (61.65)*			33.41(35.20)ns		122.71 (61.65)*		

x^2 for independence: significant when calculated x^2 > tabulated x^2 at df = (r - 1)(c - 1) = 46.

As for leaf shape (LSH), the samples were distributed into two patterns for the trait: elliptic-oblong and elliptic-ovate. The results of statistical analysis using the Chi-square test for independence showed that the observed differences between accessions of Libyan strawberry tree in Al-Jabal Al-Akhdar were not statistically significant (x_{gk}^2 = 33.41 at df = 23). However, it was noted that the elliptic-ovate shape was predominant in all accessions, with Accsh-5, Accsh-6, Accsh-9, Accsh-15, Accsh-16, Accsh-19, Accsh-20, and Accsh-22 recording the highest frequency (n = 10), while the alternative shape (elliptic-oblong) was absent in 8 accessions and recorded the highest frequency (n = 4) in two accessions (Accsh-8 and Accsh-10). The results of the current study are consistent with many previous studies in that the differences observed in the fruit shape index among natural populations of species belonging to the genus Arbutus were not statistically significant (Aravanopoulos *et al*., 2022; Politi and Aravanopoulos, 2022). The fact that differences in leaf shape (LSH), which expresses the ratio of leaf length to width, were not statistically significant in accessions of Libyan strawberry tree is due to several interrelated factors related to evolution and environment. This can be attributed to the fact that these accessions have undergone rigorous and continuous natural selection over thousands of years to adapt to the climate of Al-Jabal Al-Akhdar (hot, dry summers and warm, rainy winters). This environmental pressure has led to evolutionary convergence. Most wild species prevalent in the Mediterranean basin have developed geometrically optimal, evolutionarily optimized, and relatively stable leaf shapes to minimize water loss, making the shape genetically stable and restricted within the same species (Valladares *et al*., 2002; Tsukaya,

2005; Bhatia *et al*., 2021). However, there is potential for moderate flexible responses under distinct environmental gradients (Fritz *et al*., 2018).

Table (5) presents the frequency distributions and Chi-square (x^2) test for the qualitative traits of fruits in 24 accessions of Libyan strawberry tree (*A. pavarii* Pamp.) that grow naturally in Al-Jabal Al-Akhdar. The studied qualitative traits of the fruits were: fruit size, fruit mass (weight), and fruit shape. The frequency distribution of the qualitative traits in 24 accessions of Libyan strawberry tree showed significant differences (x^2 tab = 61.65 at *df* = 46) for fruit size (FS) and fruit mass (FM), while the differences for the fruit shape (FSH) were not significant. Regarding fruit size (FS), small size category showed considerable variation in its frequency among accessions. Its peak occurrence was in Accsh-12 (*n* = 9), whereas it was completely absent in Accsh-2, Accsh-7, and Accsh-15, indicating that this category may require specific environmental conditions that are abundant in some locations and absent in others. Medium size category is the most dominant, widespread, and stable in Al Jabal Al Akhdar, appearing in all accessions without exception, and recorded its highest frequency in Accsh-15 (*n*= 9). This wide spread of medium-sized fruits reflects high environmental flexibility and a strong ability to adapt to slight differences between locations within Al Jabal Al Akhdar. Large fruits recorded the lowest frequencies compared to the other two categories, with the highest frequency (*n* =6) in Accsh-7, and were completely absent in 6 accessions (Accsh-8, Accsh-10, Accsh-12, Accsh-16, Accsh-18, and Accsh-19). This limited distribution suggests that large fruits may be sensitive to environmental factors. The chi-square test for independence confirms that the differences in the distribution and frequency of fruit size categories were highly significant ($\boldsymbol{x_{gk}^2}$ = 99.06), indicating the presence of a real, non-random variation. All of this leads to the conclusion that the distribution of fruit size categories is governed by environmental factors and biological interactions, and is not random. Many studies confirm that the variation in fruit sizes and their distribution in natural populations of wild species aligns with the optimal resource allocation theory and evolutionary pressures, and is not a random process (Lehtila and Larsson, 2005). Fruit size and its frequencies are shaped in response to environmental filters (climate, soil, and resources), in addition to biotic interactions. Environmental conditions, such as temperature, rainfall, and nutrient availability, are the main drivers in determining fruit sizes in wild plants. Previous references indicate a close and precise correlation between gradients of environmental factors and diversity of fruit sizes (Trethowan *et al*., 2023). Similarly, the results of fruit size distribution in Libyan strawberry tree accessions in Al-Jabal Al-Akhdar are consistent with the findings of ecological and evolutionary studies in the genus Arbutus, which indicate that the variation and distribution of fruit size are not random, but are regulated by specific environmental factors and biological interactions (Beyhani *et al*., 2020; Tiglu Kaytanlioglu *et al*., 2024).

In respect of fruit mass (FM), the results show a broad phenotypic variation and heterogeneity among the different Libyan strawberry accessions. Fruit mass (FM) was classified into three main categories: heavy, medium, and light. Statistical analyses using Chi-square test confirmed the presence of highly significant differences ($\boldsymbol{x_{gk}^2}$=97.49) among the 24 Libyan strawberry tree accessions in the distribution of fruit mass. Light fruits were prevalent in Accsh-12 and Accsh-14, which recorded the highest values (*n*=9 and 8, respectively). Medium fruit, which is the most stable and common category, was dominant in most accessions, peaking in Accsh-15 (*n* = 9). In contrast, heavy fruit was present at low rates in most accessions, except for Accsh-1, which recorded the highest value (*n* = 5). A complete absence of heavy fruit was observed in several accessions (Accsh-4, Accsh-5, Accsh-12, Accsh-15, Accsh-16, Accsh-18, Accsh-19). This variation represents a strong indicator of the considerable genetic diversity of Libyan strawberry tree, which is expected and common in wild plant populations compared to cultivated varieties that undergo strict selection, reducing their variation (Smýkal *et al*., 2018). The prevalence of medium fruit mass in most accessions of Libyan strawberries tree indicates that this category represents the optimal adaptive efficiency of this species in Al-Jabal Al-Akhdar. In contrast, the high frequency of light fruits in a number of accessions suggests an environmental adaptation, directing the plant's energy toward producing a larger number of light fruits instead of heavy fruits to ensure survival (reproductive strategy). Meanwhile, the complete absence of heavy fruits in several accessions may be attributed either to specific environmental constraints, such as drought or nutrient deficiency in those sites, which prevent fruit filling, or to genetic factors. These results are consistent with previous studies, which indicated that Fruit mass in

Mediterranean Arbutus species tends to be concentrated within medium category, likely reflecting an adaptive trade-off between reproductive investment, dispersal efficiency, and drought tolerance under seasonally water-limited conditions (Molina *et al*., 2011; Sulusoglu *et al,* 2011; Tigli Kaytanlioglu *et al*., 2024; Cakmak and Yilmaz, 2024).

As for fruit shape (FSH), the differences in the distribution and frequencies of the trait categories among the Libyan strawberry tree accessions in Al Jabal Al Akhdar were not statistically significant ($x_{gk}^2 = 42.83$). However, oblate fruit shape was more common in the majority of accessions, recording the highest frequency ($n = 8$) in two populations (Accsh-1 and Accsh-4), followed by spherical fruit shape, which recorded the highest frequency ($n = 7$) in Accsh-6.

In contrast, elliptical fruit shape was absent in most populations, with the highest frequency ($n = 2$) recorded in three populations (Accsh-10, Accsh-20, and Accsh-23). The absence of significant differences in fruit shape among Libyan strawberry tree accessions may indicate that fruit shape is a relatively conserved reproductive trait under strong genetic control (Liu *et al*., 2024). This pattern of distribution may also reflect the presence of stabilizing selection favoring the optimal fruit shape, which is often close to oblate or spherical form (Sulusoglu *et al*., 2011; Bertsouklis and Papafotiou, 2016).

Furthermore, reproductive traits often exhibit less phenotypic plasticity than vegetative traits (Yang *et al*., 2024), and high within-population variation may reduce statistical significance (Falconer and Mackay, 1996).

Table (5): Frequency of descriptive trait categories of fruits and Chi-square test (x^2) for 24 accessions of Libyan strawberry tree (*Arbutus pavarii* Pamp.) in Al Jabal Al Akhdar.

Accessions	Fruit size (FS)			Fruit mass (FM)			Fruit shape (FSH)		
	Small	Medium	Large	Light	Medium	Heavy	Oblate	Spherical	Elongate
Accsh-1	2	4	4	3	2	5	8	2	0
Accsh-2	0	7	3	3	5	2	4	6	0
Accsh-3	1	7	2	1	8	1	3	7	0
Accsh-4	2	6	2	4	6	0	8	1	1
Accsh-5	2	7	1	3	7	0	5	4	1
Accsh-6	1	5	4	0	7	3	7	3	0
Accsh-7	0	4	6	0	8	2	6	3	1
Accsh-8	7	3	0	4	5	1	6	4	0
Accsh-9	1	8	1	1	8	1	6	4	0
Accsh-10	3	7	0	4	5	1	4	4	2
Accsh-11	4	4	2	7	1	2	4	5	1
Accsh-12	9	1	0	9	1	0	5	5	0
Accsh-13	1	7	2	2	6	2	4	6	0
Accsh-14	7	2	1	8	1	1	6	4	0
Accsh-15	0	9	1	1	9	0	6	4	0
Accsh-16	2	8	0	2	8	0	6	4	0
Accsh-17	5	3	2	5	3	2	5	4	1
Accsh-18	4	6	0	5	5	0	7	3	0
Accsh-19	5	5	0	5	5	0	3	6	1
Accsh-20	1	7	2	2	6	2	6	2	2
Accsh-21	6	3	1	6	2	2	5	5	0
Accsh-22	5	4	1	6	2	2	6	4	0
Accsh-23	5	4	1	7	2	1	4	4	2
Accsh-24	2	5	3	1	6	3	6	4	0
x_g^2	46.92	19.14	33.00	40.70	30.88	25.91	8.09	10.74	24.00
$x_{gk}^2(x_{tab}^2)$	99.06 (61.65)*			97.49 (61.65)*			42.83 (61.65)ns		

x^2 for independence: significant when calculated x^2 > tabulated x^2 at df = (r - 1)(c - 1) = 46

4. Conclusion:

Al-Jabal Al-Akhdar possesses rich plant genetic resources and is considered an important center of plant diversity in the Mediterranean Basin. It is also one of the most significant botanical regions in Libya due to its inclusion of the majority of Libya's endemic species. The results of the current study showed significant differences in the morphological characteristics among accessions of the Libyan strawberry tree (*Arbutus pavarii* Pamp.), one of the most important endemic species in Al-Jabal Al-Akhdar. All the tree or shrubs studied during this research were in their natural environment without the application of any agricultural practices. These differences indicate that the Libyan strawberry plant contains a rich amount of genetic diversity, which developed within and among populations over long periods of evolution. These results point in two directions: first, the necessity of conducting further studies on genetic diversity and employing molecular techniques in these studies; second, the need to conserve this endemic species and protect its habitats, prevent the destruction of its wild populations and their random collection, and thus protect the genetic material of this species. Moreover, the wide variation observed in the studied traits may be of great value to plant breeders as a genetic resource in the future.

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