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RESEARCH ARTICLE

Morphological characterization of 96 wild-grown genotypes of sea buckthorn (*Hippophae rhamnoides* spp.) in eastern Türkiye

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Abstract The geographical and climatic characteristics of Türkiye facilitate the growth of many wild edible fruit species in the country. An important fruit species contributing to this richness is sea buckthorn. Seed-propagated sea buckthorn plants exhibit a rich morphological diversity in the country. In this study, we investigated the morphological diversity of 96 selected wild-grown sea buckthorn genotypes from Erzurum province in eastern Türkiye. Their morphological characteristics were described using 22 criteria according to the International Union for the Conservation of New Plant Varieties (UPOV) "Sea buckthorn descriptor" norms. The results showed a great morphological diversity among the 96 seed-propagated wild-grown sea buckthorn genotypes. In terms of habitus, 28 genotypes were upright, 53 genotypes were semi-upright, and 15 genotypes grew horizontally. The growth pattern of the genotypes was different. We found that 32 genotypes were tree-shaped and 64 genotypes were bush-shaped. Regarding shoot density, 27 genotypes were observed rarely, 49 genotypes were moderate, and 20 genotypes were intense. Our findings provide important information for conducting further research on the preservation of genetic resources and breeding of wild edible sea buckthorn genotypes.

Keywords Wild plants · Diversity · Sea buckthorn · UPOV

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Introduction

Plant genetic resources mark the richness of a country's biological diversity. They include cultivated plants and their wild relatives, village populations and old or local cultivars (Nadeem et al. 2018; Jacimovic et al. 2020; Novikova et al. 2022; Sulusoglu Durul and Memis 2022). Türkiye is internationally recognized for its plant genetic resources. The Near East and the Mediterranean gene centers overlap in the country, and Türkiye is considered by the scientific community to be the country of origin and diversity of many plants. Türkiye is located in the middle of three different phytogeographical regions, including the Mediterranean, Euro-Siberian, and Iran-Turan regions (Guney et al. 2021; Ari et al. 2022).

Türkiye lies partly in the Asian and European continents, and has 12,476 taxa, of which 4,000 are endemic, these taxa are distributed across 78 million hectares. The genetic diversity and richness of plants in Türkiye are mainly related to the great diversity of the topography, climate and other environmental

conditions that vary within short distances (Ercisli 2004; Cakilcioglu and Turkoglu 2010). Throughout history, Türkiye has been a gateway to many civilizations and has hosted some of these civilizations. Migrations led the wild species of many cultivated plants to move to different places, and these migrations increased the genetic diversity in Anatolia (Sehirali and Ozgen 1987).

Wild edible fruit species significantly contribute to the plant biodiversity in Türkiye and are commonly found in natural environments (Gecer et al. 2020; Sagbas et al. 2020). Although these forms have a low yield, they are promising genetic resources for application in plant breeding and genetic engineering due to their high genetic diversity and special characteristics (DeVries and Toenniessen 2001). Although modern cultivars have less genetic diversity than their wild relatives, their agricultural performance (yield, quality, and attractiveness) is higher. A larger genetic pool of wild relatives can help combat future diseases and adapt to adverse environmental conditions (Sehirali and Ozgen 1987).

Sea buckthorn belongs to the *Hippophae* genus of the *Eleagnaceae* family in the order Rosales. The *Elaeagnaceae* family is an important family represented by the genus *Elaeagnus* L., *Hippophae* L. and *Shepherdia* L. (Pan et al. 1989; Aras et al. 2007). The genus is highly adapted to dry climatic conditions. *Hippophae rhamnoides* is widely distributed along the riverbanks of Europe, on the dunes along the Baltic coasts of Germany, Poland and Finland, along the Gulf of Bothnia in Sweden, and in the coastal areas of Britain. In Asia, most *Hippophae* species are distributed around the northern parts of China, throughout the Himalayan regions, in India, Nepal, Bhutan, parts of northern Pakistan, and Afghanistan (Li and Beveridge 2003).

Hippophae rhamnoides L. is represented in temperate Asia and Europe by nine subspecies: ssp. *rhamnoides*, ssp. *fluviatilis* and ssp. *carpatica* in Europe; ssp. *caucasica*, ssp. *turkestanica*, ssp. *mongalica*, ssp. *sinensis,* ssp. *yunnanensis* and ssp. *wolongensis* in Asia; ssp. *sinensis*, ssp. *yunnanensis* and ssp. *wolongensis* in Asia (Lian et al. 2003).

The objectives in fruit breeding might be achieved by evaluating various traits of genetic resources and combining such traits in one cultivar. Although, molecular markers are used, they are expensive and implementing such methods requires sophisticated laboratory equipment. Morphological characteristics need to be recorded for selecting suitable parents and these are also the first choice for describing and classifying the germplasm (Arzani et al. 2008; Cilden 2022; Kadluczka and Grzebelus 2022).

Research on the morphological characteristics of sea buckthorn in Türkiye is highly limited and a comprehensive morphological study on the genetic relationships of the currently grown wild-grown sea buckthorn population has not been conducted. Thus, in this study, we determined the morphological diversity of 96 wild-grown sea buckthorn genotypes, growing in the Erzurum province of Türkiye and obtain through selection based on the UPOV criteria.

Materials and methods

Plant materials for the morphological characterization of 96 selected sea buckthorn genotypes were collected from three districts (Askale, Oltu, and Uzundere) Erzurum province in Türkiye. Information on the location of the genotypes is presented in Table 1. Approximately 3% of the study area had sandy soil, 70.9% of the area had loam, 24.3% of the area had clay loam, and 1.8% are had clay. Approximately 9.3% of the study area had very low organic matter (OM), 34.4% of the area had low OM, 33.3% of the area had moderate OM, 13.1% of the area had sufficient OM and 9.9% of the area had excess OM. The soil slightly alkaline with sufficient or more than sufficient levels of potassium and phosphorus for the needs of the plants, without salinity problems. Erzurum is one of the provinces with the lowest average temperature in Türkiye, and is dominated by a continental type of climate. The winters in Erzurum are quite cold and harsh, while the short summers are hot and dry. This characteristic of the climate also adversely affects vegetation and hinders the development of plants in certain periods. In Erzurum winter lasts for more than 6 months. The temperature drops in October and starts to rise again in April. In Erzurum, the annual average temperature is around 5.6 °C, the coldest months are January and February, and the hottest months are July and August.

Table 1 Information on the 96 sea buckthorn genotypes

Genotypes	District	Altitude	Coordinates		Genotypes	District	Coordinates		
			North	East			Altitude	North	East
ERZ-AS1	Aşkale	1750	39°58′02"	40°50′42"	ERZ-UZ49	Uzundere	1025	40°34′32"	41°36′01"
ERZ-AS2	Aşkale	1755	39°58′01"	40°50′60"	ERZ-UZ50	Uzundere	1024	40°34′41"	41°36′06"
ERZ-AS3	Aşkale	1733	39°58′10"	40°50′47"	ERZ-UZ51	Uzundere	1023	40°34′41"	41°36′06"
ERZ-AS4	Aşkale	1840	39°57′50"	40°53′32"	ERZ-UZ52	Uzundere	1023	40°34′41"	41°36′06"
ERZ-AS5	Aşkale	1729	39°58′10"	40°50′44"	ERZ-UZ53	Uzundere	1023	40°34′53"	41°36′13"
ERZ-AS6	Aşkale	1730	39°58′09"	40°50′42"	ERZ-UZ54	Uzundere	1023	40°34′53"	41°36′13"
ERZ-AS7	Aşkale	1740	39°58′09"	40°50′41"	ERZ-UZ55	Uzundere	1023	40°34′53"	41°36′13"
ERZ-AS8	Aşkale	1729	39°58′09"	40°50′40"	ERZ-UZ56	Uzundere	1022	40°34′55"	41°36′13"
ERZ-AS9	Aşkale	1726	39°58′01"	40°50′53"	ERZ-UZ57	Uzundere	1021	40°34′55"	41°36′12"
ERZ-AS10	Aşkale	1751	39°58′25"	40°50′54"	ERZ-UZ58	Uzundere	1021	40°34′55"	41°36′12"
ERZ-AS11	Aşkale	1732	39°58′25"	40°50′54"	ERZ-UZ59	Uzundere	1021	40°34′55"	41°36′12"
ERZ-AS12	Aşkale	1733	39°58′25"	40°50′55"	ERZ-UZ60	Uzundere	1019	40°34′57"	41°36′15"
ERZ-AS13	Aşkale	1732	39°58′26"	40°50′55"	ERZ-UZ61	Uzundere	1019	40°34′59"	41°36′15"
ERZ-AS14	Aşkale	1696	39°56′47"	40°47′49"	ERZ-UZ62	Uzundere	1019	40°34′59"	41°36′15"
ERZ-AS15	Aşkale	1695	39°56′47"	40°47′50"	ERZ-UZ63	Uzundere	1019	40°34′59"	41°36′15"
ERZ-AS16	Aşkale	1636	39°54′56"	40°40′21"	ERZ-UZ64	Uzundere	1019	40°34′58"	41°36′17"
ERZ-AS17	Aşkale	1636	39°54′54"	40°40′26"	ERZ-OL65	Oltu	1708	40°28′54"	41°46′05"
ERZ-AS18	Aşkale	1637	39°54′51"	40°40′31"	ERZ-OL66	Oltu	1720	40°28′53"	41°46′04"
ERZ-AS19	Aşkale	1641	39°54′51"	40°40′30"	ERZ-OL67	Oltu	1677	40°28′28"	41°46′19"
ERZ-AS20	Aşkale	1637	39°54′51"	40°40′29"	ERZ-OL68	Oltu	1677	40°28′28"	41°46′18"
ERZ-AS21	Aşkale	1637	39°54′50"	40°40′29"	ERZ-OL69	Oltu	1673	40°28′24"	41°46′08"
ERZ-AS22	Aşkale	1637	39°54′50"	40°40′29"	ERZ-OL70	Oltu	1673	40°28′24"	41°46′08"
ERZ-AS23	Aşkale	1679	39°56′19"	40°46′07"	ERZ-OL71	Oltu	1683	40°28′23"	41°46′03"
ERZ-AS24	Aşkale	1679	39°56′21"	40°46′09"	ERZ-OL72	Oltu	1675	40°28′20"	41°45′53"
ERZ-AS25	Aşkale	1679	39°56′20"	40°46′09"	ERZ-OL73	Oltu	1675	40°28′20"	41°45′53"
ERZ-AS26	Aşkale	1694	39°56′44"	40°47′34"	ERZ-OL74	Oltu	1675	40°28′18"	41°45′51"
ERZ-AS27	Aşkale	1694	39°56′44"	40°47′34"	ERZ-OL75	Oltu	1675	40°28′18"	41°45′51"
ERZ-AS28	Aşkale	1694	39°56′44"	40°47′34"	ERZ-OL76	Oltu	1681	40°28′20"	41°45′53"
ERZ-AS29	Aşkale	1694	39°56′44"	40°47′34"	ERZ-OL77	Oltu	1672	40°28′20"	41°45′57"
ERZ-AS30	Aşkale	1694	39°56′44"	40°47′34"	ERZ-OL78	Oltu	1672	40°28′20"	41°46′57"
ERZ-AS31	Aşkale	1694	39°56′44"	40°47′34	ERZ-OL79	Oltu	1661	40°28′30"	41°46′48"
ERZ-AS32	Aşkale	1694	39°56′44"	40°47′34	ERZ-OL80	Oltu	1656	40°28′29"	41°46′49"
ERZ-UZ33	Uzundere	1026	40°34′33"	41°35′58"	ERZ-OL81	Oltu	1656	40°28′29"	41°46′49"
ERZ-UZ34	Uzundere	1026	40°34′33"	41°35′58"	ERZ-OL82	Oltu	1476	40°31′32"	41°51′44"
ERZ-UZ35	Uzundere	1027	40°34′31"	41°35′57"	ERZ-OL83	Oltu	1480	40°31′34"	41°51′44"
ERZ-UZ36	Uzundere	1026	40°34′30"	41°35′58"	ERZ-OL84	Oltu	1475	40°31′30"	41°51′43"
ERZ-UZ37	Uzundere	1026	40°34′30"	41°35′58"	ERZ-OL85	Oltu	1691	40°28′13"	41°45′25"
ERZ-UZ38	Uzundere	1166	40°34′35"	41°35′00"	ERZ-OL86	Oltu	1686	40°28′11"	41°45′24"
ERZ-UZ39	Uzundere	1166	40°34′36"	41°35′00"	ERZ-OL87	Oltu	1686	40°28′11"	41°45′24"
ERZ-UZ40	Uzundere	1166	40°34′36"	41°35′00"	ERZ-OL88	Oltu	1727	40°27′31"	41°44′46"
ERZ-UZ41	Uzundere	1166	40°34′36"	41°35′00"	ERZ-OL89	Oltu	1722	40°27′36"	41°44′50"
ERZ-UZ42	Uzundere	1023	40°34′42"	41°36′06"	ERZ-OL90	Oltu	1709	40°27′44"	41°44′54"
ERZ-UZ43	Uzundere	1024	40°34′42"	41°36′06"	ERZ-OL91	Oltu	1710	40°27′48"	41°44′52"
ERZ-UZ44	Uzundere	1024	40°34′42"	41°36′06"	ERZ-OL92	Oltu	1901	40°28′00"	41°41′03"

Table 1 (continued)

Genotypes	District	Altitude	Coordinates		Genotypes	District	Coordinates		
			North	East			Altitude	North	East
ERZ-UZ45	Uzundere	1023	40°34′39"	41°36′04"	ERZ-OL93	Oltu	1885	40°27′56"	41°41′05"
ERZ-UZ46	Uzundere	1023	40°34′39"	41°36′04"	ERZ-OL94	Oltu	1887	40°27′56"	41°41′05"
ERZ-UZ47	Uzundere	1024	40°34′37"	41°36′03"	ERZ-OL95	Oltu	1885	40°27′55"	41°41′04"
ERZ-UZ48	Uzundere	1026	40°34′31"	41°36′00"	ERZ-OL96	Oltu	1887	40°27′55"	41°41′04"

Determination of morphological features

The morphological features of the genotypes were determined in 2019 and 2020. The data were recorded in the laboratories of Atatürk University, Faculty of Agriculture, Department of Horticulture. The morphological characteristics of the selected genotypes were examined based on the The International Union for the Protection of New Varieties of Plants (UPOV) descriptors for sea buckthorn. The characteristics measured were: plant features (sex, type of growth, attitude of the branches, vigor, density of shoots, and position of inflorescence), shoot (one-year-old shoot: thickness, number of thorns, and length of thorns), leaf (leaf blade: shape, size, the undulation of the margin, the color of the upper side, the intensity of the green color of the upper side, and pubescence of the lower side), fruit (size, shape, skin color, pubescence, length of stalk, the time of initiation of flowering, and the time of initiation of fruit ripening). The UPOV descriptors used to define the morphological features of the genotypes are listed along with their UPOV numbers and values scores in Table 2.

Results and discussions

We used 22 UPOV criteria to determine the morphological relationships in wild grown pre-selected sea buckthorn genotypes collected from three districts of Erzurum provinces located in the eastern Anatolia region in Türkiye.

The 96 sea buckthorn genotypes were evaluated based on the plant features (sex, growth type, attitude of the branches or habitus, vigor, density of the shoots, and position of influorescence), shoot (one-year-old shoot: thickness, number of thorns, and length of thorns), leaf (leaf blade: shape, size, undulation of the margin, color of the upper side, intensity of the green color on the upper side, and pubescence of the lower side), fruit (size, shape, skin color, pubescence, length of the stalk, the time of initiation of flowering, and time of initiation of fruit ripening).

Regarding the type of growth, 28 genotypes showed upright growth type, 53 genotypes showed semi-upright growth, and 15 genotypes grew horizontally (Fig. 1). Habitus showed differences among the genotypes. Among the genotypes analyzed, 32 were tree-shaped and 64 were bush-shaped (Fig. 1). Regarding vigor (branching feature), 22 genotypes were found to be strong, 51 genotypes had medium strength, and 23 genotypes were weak (Fig. 1). When the shoot density of the genotypes was examined, 27 genotypes were rare, 49 genotypes were moderately common, and 20 genotypes were extremely common (Fig. 1). Flowering was recorded in two or older branches (Fig. 1).

In Pakistan, Sabir et al. (2003) reported that most of the sea buckthorn genotypes had semi-erect growth and exhibited shrub growth characteristics. Yadav et al. (2006) investigated the morphological features of 19 wild-grown sea buckthorns in India and found that 79% of the genotypes had bush growth and 21% of the genotypes showed tree growth characteristics. Sezen et al. (2015) conducted a study on wild sea buckthorns and found that 80% of genotypes had bush growth and 20% of genotypes had tree growth characteristics among several sea buckthorn genotypes. Musayev (2013) determined phenological phases, growth, morphological description, productivity, and fruit quality traits of one wild form and four local cultivars of sea buckthorns (Perspektiv, Novost, Itaya, Shafa, and Zafarani) in Azerbaijan using the common description methods of sea buckthorn and found that most plants had semi-erect and horizontal growth habit. Sea buckthorn was originally a tree-shaped plant under subtropical conditions. As climate become colder in the Pleistocene and following

Table 2 The International Union for the Protection of New Varieties of Plants (UPOV) descriptors for sea buckthorn genotypes

UPOV Number	Criteria	Features	Value score
Plant			
1	Sex	Female	1
		Male	2
2	Growth type	Tree-type	1
		Bush-type	2
3	Attitude of branches (Habitus)	Erect	1
		Semi-erect	2
		Horizontal	3
		Arching	4
4	Vigor	Weak	3
		Medium	5
		Strong	7
		Very strong	9
5	Density of shoots	Sparse	3
		Medium	5
		Dense	7
6	Position of influorescence	On one-year-old shoots only	1
		Both on one-year-old and Older shoots	2
Shoot			
7	One-year-old shoot: thickness	Thin	3
		Medium	5
		Thick	7
8	Number of thorns (from middle part to top)	Absent or very few	1
		Few	3
		Medium	5
		Many	7
9	Length of thorns	Short	3
		Medium	5
		Long	7
Leaf blade			
10	Leaf blade: shape	Very narrow elliptic	1
		Narrow elliptic	3
		Narrow ovate	5
11	Leaf blade: size	Small	3
		Medium	5
		Large	7
12	Leaf blade: undulation of margin	Absent	1
		Present	9
13	Leaf blade: color of upper side	Green	1
		Silverish	2
14	Leaf blade: intensity of green color of upper side	Light	1
		Medium	2
		Dark	3
15	Leaf blade: pubescence of lower side	Weak	3
		Medium	5
		Strong	7

Table 2 (continued)

UPOV Number	Criteria	Features	Value score
Fruit			
16	Fruit: size	Small	3
		Medium	5
		Large	7
17	Fruit: shape	Pear-shaped	1
		Ovate	2
		Transverse elliptic	3
		Circular	4
		Elliptic	5
		Oblong	6
18	Fruit: color of skin	Light yellow	1
		Dark yellow	2
		Yellow orange	3
		Orange red	4
		Red	5
19	Fruit: pubescence	Weak	3
		Medium	5
		Strong	7
20	Fruit: length of stalk	Short	1
		Medium	2
		Long	3
21	Time of beginning of flowering	Early	3
		Medium	5
		Late	7
22	Time of beginning of fruit ripening	Very early	1
		Early	3
		Medium	5
		Late	7
		Very late	9

periods the plant become bush-shape. Sezen et al. (2015) investigated several wild-grown sea buckthorn genotypes and found that the shoot density was moderate (63.33%), dense (20.00%), and sparse (16.67%), which matched our results; we found the percentage as 51.04% (moderate), 20.83% (dense), and 28.13% (sparse).

Regarding shoot features of the sea buckthorn genotypes, three different morphological features (mean thickness of one-year-old branches, number of thorns, and average thorn length) were examined based on the UPOV descriptors (Table 1). Among the genotypes examined, the lowest average thickness of the one-year-old branches was 1.45 mm (ERZ-AS-20) and the highest average thickness was 2.94 mm (ERZ-OL-65). The average thickness of the one-year-old branches of the genotypes was found to be thin in 24 genotypes, medium in 33 genotypes, and thick in 39 genotypes (Fig. 2).

The lowest number of thorns (n = 3) was recorded in the ERZ-AS-12, ERZ-AS-29, ERZ-AS-32, ERZ-UZ-40, ERZ-OL-65, ERZ-OL-82, and ERZ-OL-91 genotypes and the highest number of thorns (n = 16) was recorded in the ERZ-AS-6 genotype. No genotype without thorns was found. The number of thorns was very few in 44 genotypes, few in 44 genotypes, moderate in six genotypes and low in two genotypes (Fig. 2).

The lowest average thorn length was 2.50 cm (ERZ-OL-87), and the highest was 10.44 cm

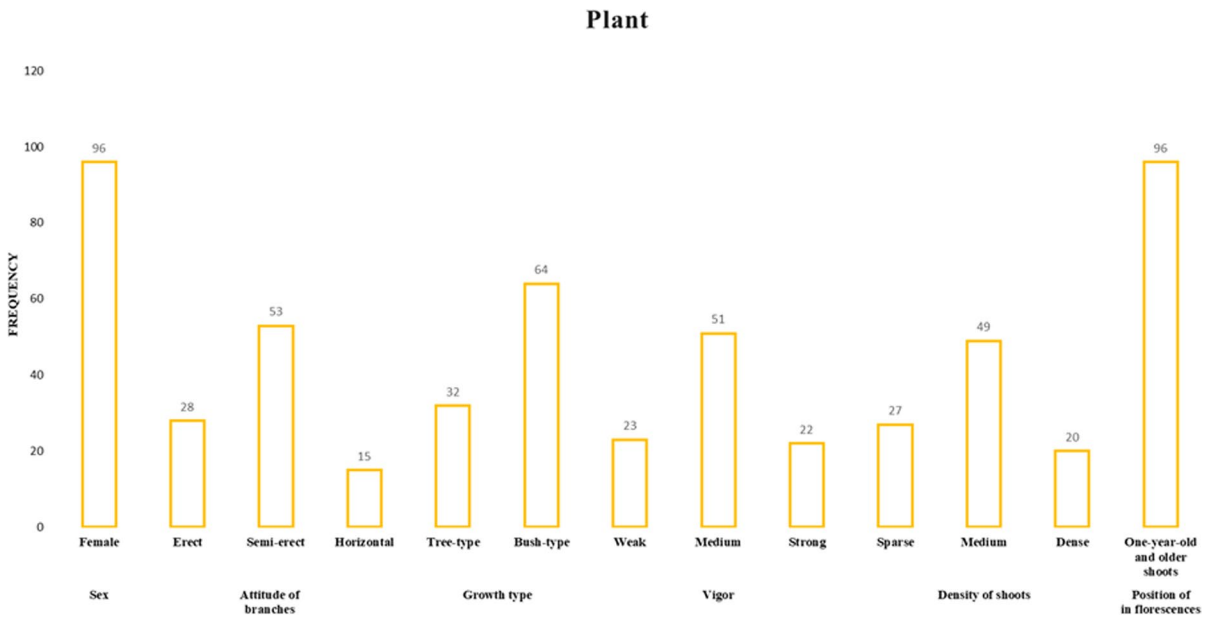


Fig. 1 A histogram of the 96 sea buckthorn genotypes based on plant features

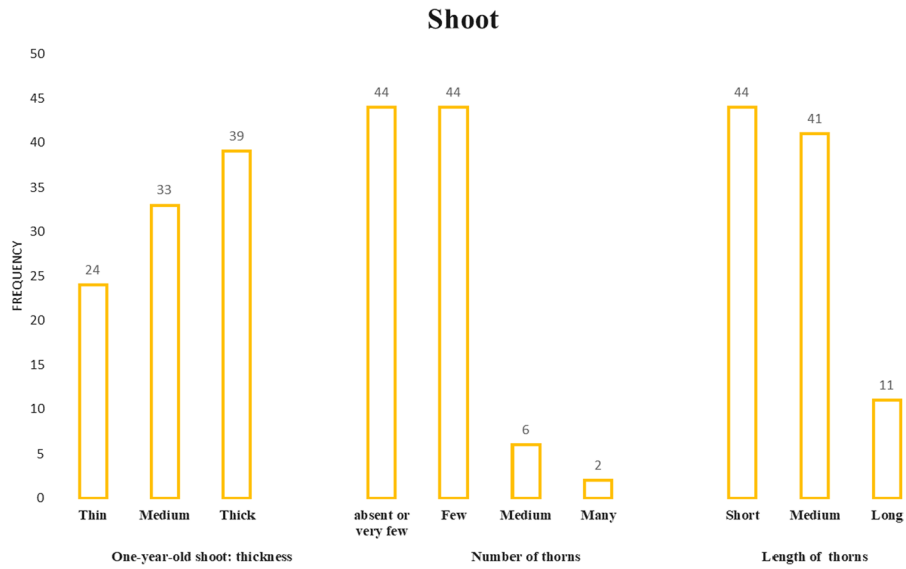


Fig. 2 A histogram of the 96 sea buckthorn genotypes based on shoot features

(ERZ-AS-11). The mean thorn length was short in 44 genotypes, long in 41 genotypes, and long in 11 genotypes (Fig. 2).

In Pakistan, Sabir et al. (2003) found that the number of thorns on the branches was between 49 and 69. Sezen et al. (2015) studied several wild-grown sea buckthorns and found that most of the accessions had few thorns on their shoots (19 accessions) and the remaining of the accessions had a medium number of thorns on their shoots. Musayev (2013) in Azerbaijan, Yao and Tigerstedt (1992) in China and Ahmad et al. (2005) in Pakistan described various shoot features (thickness, density, thorn etc.).

The open pollination of fruit species, along with their heterozygous nature and long periods of growth

and cultivation, promote diversity and this situation is more prominent for seed propagated plants (Baldoni et al. 2006; Aranzana et al. 2019; Li et al. 2022).

The morphological features of leaves, based on six UPOV criteria (leaf blade: shape, size, the undulation of the margin, upper surface color, the intensity of the green color of upper side and pubescence of the lower side) were examined in sea buckthorn genotypes (Fig. 3).

The shape of the leaf blade is narrow elliptical in 18 genotypes, narrowly elliptical in 53 genotypes had narrowly elliptical, and narrow ovate in 25 genotypes (Fig. 3).

The size of the leaf blade was small in 25 genotypes, medium in 59 genotypes and large in 12 genotypes (Fig. 3). Leaf margin serration (undulation of the margin) was not present in all sea buckthorn genotypes (Fig. 3). The upper surface of the leaf blade had the same green color in all sea buckthorn genotypes (Fig. 3). The leaf color intensity was light in 11 genotypes, medium in 33 genotypes and dark in 52 genotypes (Fig. 3).

Sezen et al. (2015) found that the size of the leaf blade of most sea buckthorn genotypes was medium. Mirza (2013) also found that sea buckthorn genotypes and local cultivars had a small to medium leaf blade size. Nawaz et al. (2018) characterised sea buckthorn in Pakistan and found that the color of the upper surface of the leaf blade ranged from dark green to gray. The high variability characteristics of the leaf blade in our samples compared to that in other studies could be due to the large number of genotypes used in this study. We also found that the leaf size of sea buckthorn genotypes was higher in village stands than in wild ones, which might be due to the unintentional management of trees or shrubs via irrigation and better nutrition near farming fields given that leaf size responds strongly to such treatments. Variation among sea buckthorn populations in different locations has been reported in Asia (Sabir et al. 2003; Yadav et al. 2016). All 96 genotypes shown Fig. 4.

We followed the UPOV criteria while analyzing the fruit morphological characteristics of the sea buckthorn genotypes, and seven different characteristics (fruit shape, size, skin color, pubescence, length of stalk, the time of initiation of flowering, the time of initiation of fruit ripening) were examined (Fig. 5). The fruits of sea buckthorn were small in 25 genotypes, medium in 57 genotypes, and large in 14 genotypes (Fig. 5). The fruits were pear-shaped in 37 genotypes, elliptical in 33 genotypes, transversely elliptical in three genotypes, oval in seven genotypes and round in 16 genotypes (Fig. 5). When the external color of the fruits of the genotypes was examined, five different colorations were found (19 genotypes were light yellow, four



Fig. 3 A histogram of the 96 sea buckthorn genotypes based on leaf features

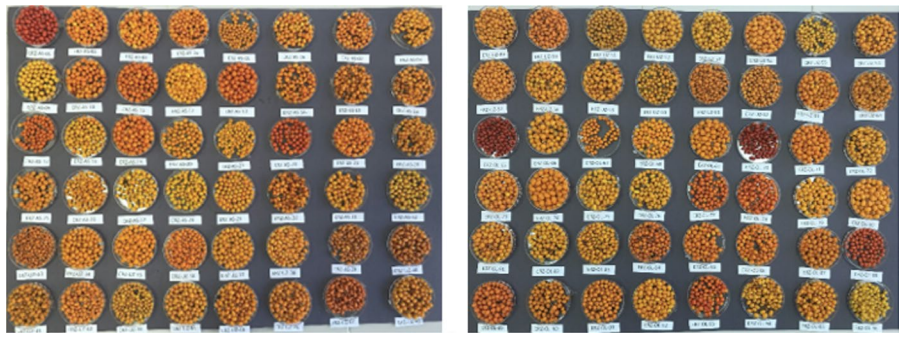


Fig. 4 Color differences among the 96 sea buckthorn genotypes

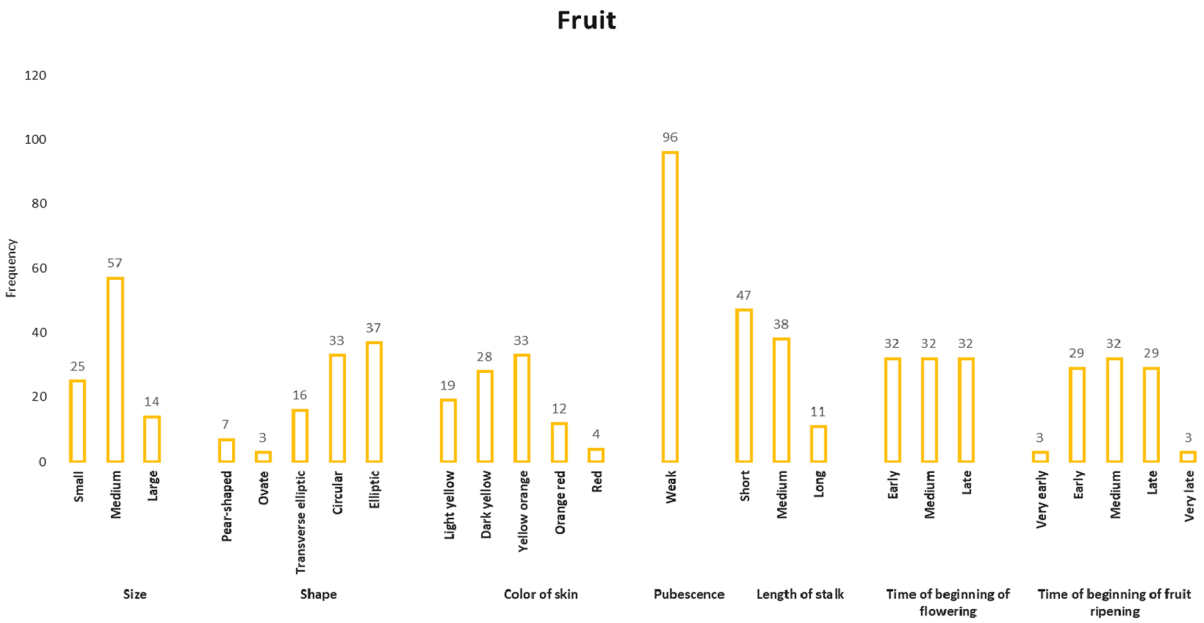


Fig. 5 A histogram of the 96 sea buckthorn genotypes based on fruit features

genotypes were red, 12 genotypes were red orange, 28 genotypes were dark yellow, 33 genotypes were yellow-orange) (Figs. 4, 5 and 6). Fruit pubescence was not observed in any sea buckthorn genotypes (Fig. 5). The length of the fruit stalk ranged from 1.05 mm (ERZ-AS-31) to 3.11 mm (ERZ-AS-29).

The starting time of flowering was early in 32 genotypes, medium in 32 genotypes, and late in 32 genotypes (Fig. 5). Fruit ripening time were observed very early in three genotypes, early in 29 genotypes, medium in 32 genotypes, late in 29 genotypes, and very late in three genotypes. (Fig. 5).

Ilhan et al. (2021) studied sea buckthorn in Sivas province of Türkiye, and found that the fruit color was stated as light yellow in four genotypes, yellow in three genotypes, orange in two genotypes and dark orange in one genotype. In the same study, the shape of the fruits was found to be transversely elliptical in six genotypes, elliptical in two genotypes and pear-shaped in two genotypes. Sezen et al. (2015) described the fruit colors of sea buckthorn genotypes as dark orange, dark yellow, yellow, orange and light yellow. Nawaz et al. (2018) examined 300 sea buckthorn genotypes in Pakistan and described the fruit color as orange and orange-yellow in most genotypes.

The weight of 100 fruits in our study was between 6 and 27 g. Sabir et al. (2003) reported



Fig. 6 The fruits of some sea buckthorn genotypes

that the weights of 100 fruits was in the range of 2.5–39.6 g. Sezen et al. (2015) reported that weight of 100 fruits weight of fruits varied between 15 and 26 g. Ilhan et al. (2021), conducted their study in Sivas province of Türkiye, and found that the weight of 100 sea buckthorn fruits varied between 13.85 and 27.87 g. Nawaz et al. (2018) found that the weight of 100 fruits varied between 8.0 and 14.5 g in Pakistan. Li et al. (2020) reported that the weight of 100 fruits in 78 genotypes of sea buckthorn in China was 10.73 g (*H. rhamnoides* ssp. *sinensis*) and 47.69 g (*H. rhamnoides* ssp. *mongolica*).

The differences in the morphological characteristics found in our study were attributed to the different genotypes used. Ecological differences also contributed to this variability.

Conclusion

To summarize, a comprehensive understanding of the morphological diversity can greatly help in preserving the naturally growing wild sea buckthorn genotypes and facilitating their application in breeding programs. In this study, we described the morphological diversity in wild sea buckthorn genotypes (based on 22 UPOV morphological descriptors) collected from the Erzurum province of Türkiye. The genotypes showed high morphological diversity. Our results indicated that the morphological marker system can be reliably used determine the diversity of the genotypes of sea buckthorn. Our findings may be used as a reference for conducting breeding programs to develop intraspecific or interspecific hybrids of sea buckthorn using these genotypes.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, analysis and interpretation were performed by Gulce Ilhan, Sezai Ercisli and Emine Orhan. The first draft of the manuscript was written by Gulce Ilhan and Sezai Ercisli and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Data collected in this research is available upon reasonable request to the corresponding author.

Declarations

Conflict of interest We declare that we have no conflict of interest.

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