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Morphology, biochemistry, and management of Russian olive (*Elaeagnus angustifolia* L.) accessions in Gilgit-Baltistan, northern Pakistan

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Abstract

Russian olive (*Elaeagnus angustifolia* L., Elaeagnaceae) is a native multi-purpose medicinal shrub or tree of temperate Asian regions and an integral component of high altitude terraced agroforestry systems of Gilgit-Baltistan, northern Pakistan. The strong increase in deforestation, urbanisation, and the loss of ethnically-based medication practices in local communities are gradually leading to depletion of its stands and knowledge of its use. In view of these circumstances, this study was undertaken to characterise Russian olive accessions as a first step towards the conservation of this important wild plant genetic resource. Ninety-three fruits (including seeds) and leaves were sampled to determine morphological variability among accessions. In addition, the phenolic composition of fruit pulp of 40 fruits was determined. To assess the local importance of the species, 42 Russian olive collectors and traders were interviewed. Data were analysed using PCA followed by clustering. Fruit traits across groups were equally shared. Elevation enhanced fruit and seed dimensions especially length ($r = 0.606$ and 0.515, respectively) and weight ($r = 0.618$ and 0.695, respectively). Bioactive substances such as DPPH and flavonoids in the sampled fruits exceeded most values found in the literature by a factor of 100 and 30, respectively. The socio-economic household analysis highlighted that Russian olive harvest and trade are important additional income strategies. On average, about 90 € (ca. 16000 PKR) were earned annually per household ranging from about 35 € to about 205 €. Data yielded a mixed picture on morphological and biochemical diversity as well as the socio-economic background, but indicated that northern regions of Pakistan are an important centre for biodiversity of this species in Central Asia, which merits improved marketing.

Keywords: Biodiversity, flavonoid content, medicinal plant, oleaster, phenolic content, principal component analysis, tannin content, two-step cluster analysis

1 Introduction

The northern regions of Pakistan, including Gilgit-Baltistan, are situated at the junction of the Himalaya, the Hindukush, the Karakorum, and the Pamir mountain ranges, making it an area of rich topographic features and comparatively high plant diversity (Pei, 1992). Many of the plant species growing in Gilgit-Baltistan are used by local people as food, fodder, timber wood, fire wood, and medicine (Shinwari, 2010).

Elaeagnus angustifolia L. (Russian olive or oleaster, locally known as *ghundair*) is one of those traditionally used species in terraced agroforestry systems of northern Pakistan (Fig. 1a-b). It belongs to the Elaeagnaceae family, which consists of three genera, namely *Elaeagnus* L., *Shepher-*

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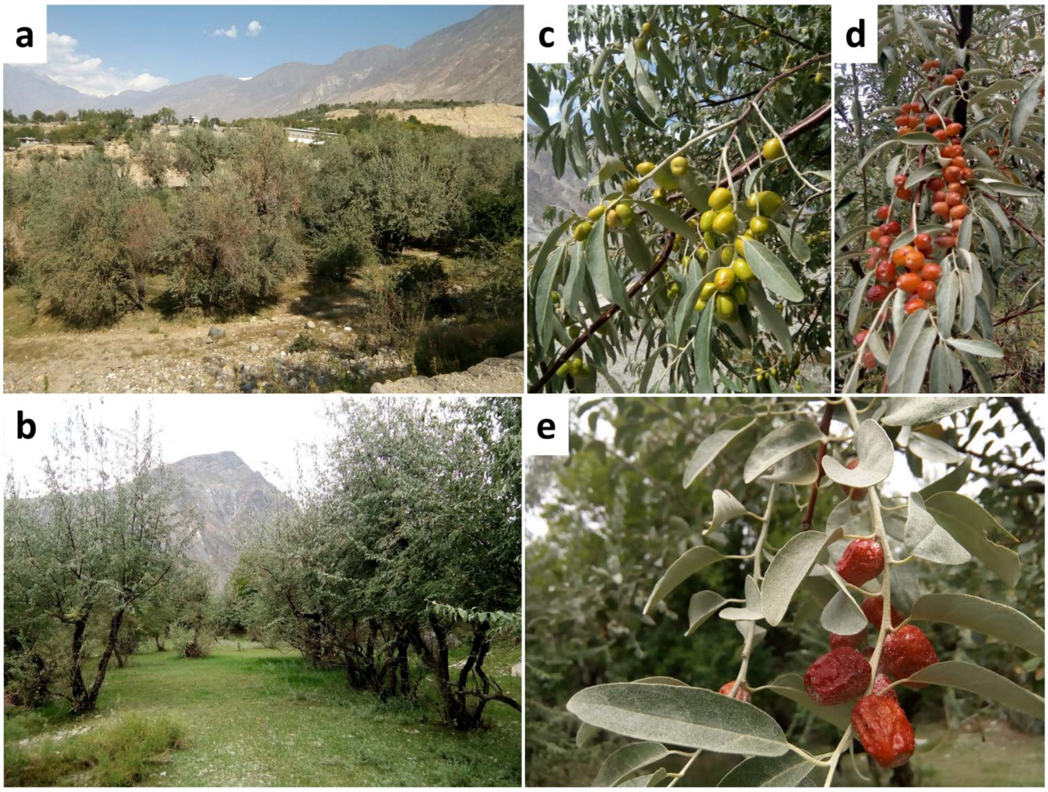

Fig. 1: *Elaeagnus angustifolia (Russian olive) individuals, their leaves and fruits in wild and cultivated settings. a) Grove in Bunji-Gilgit, b) Individuals planted in rows on pastureland at Gupis-Ghizer, c) unripe drupes, d) near-ripe drupes, e) mature drupes.*

dia Nutt., and *Hippophae* L. including 77 species worldwide (Sun & Lin, 2010). In the flora of Gilgit-Baltistan, Russian olive is yet unexplored and one of the potentially most important multi-purpose plant species (Khan & Khatoon, 2008; Shedayi *et al*., 2014). It grows as either a shrub or a small deciduous tree of up to 10 m height and usually forms dense thickets in the wild (Ersoy *et al*., 2013). The species is insect-pollinated, a well-known nectar source, and out-crossing (Katz & Shafroth, 2003). The dispersal of Russian olive fruits (Fig. 1c-e) and seeds usually occurs in fall and winter, primarily by birds (Kindschy, 1998), vertebrates (Borell, 1962), and through fluvial transport (Pearce & Smith, 2001).

The species' natural range is still under debate, but it can be found in the Mediterranean and Irano-Turano region as well as in south-west Asia (Sudnik-WójcikowskaIva *et al*., 2009). In Gilgit-Baltistan, Russian olive spreads naturally along roadsides, field borders, river banks, and dry river beds as its seedlings are tolerant of shade and trees grow well even under high light intensity (Shafroth *et al*., 1995; Lucchesini & Mensuali-Sodi, 1996). There are also some reports indicating that Russian olive plays a vital role in maintaining ecosystem functions in hyperarid areas because of its tolerance to salinity, drought, and soil alkalinity (Wang *et al*., 2006; Asadiar *et al*., 2013). In agricultural settings, Russian olive is also commonly used for the rehabilitation of low quality and contaminated soils where it can play a significant role in carbon sequestration and conservation of natural habitats (Pilinszky *et al*., 2015), especially through vegetative propagation by root suckers (Katz & Shafroth, 2003).

Almost every part of this plant species can be used ranging from leaves, flowers, and fruits to the stem, bark, and trunk (Mehrabani *et al*., 2012). In many countries, Russian olive is used for the production of pharmaceuticals, for human nutrition and as an ornamental plant. In traditional medicine, Russian olive fruit, pulp powder and/or flower decoction is known for the effective treatment of tetanus, flatulence, asthma, amoebic dysentery, jaundice, vomiting, nausea, rheumatoid arthritis, and osteoarthritis (Wang *et al*., 2006; Nikniaz *et al*., 2014; Panahi *et al*., 2016). Due to the presence of different secondary metabolites, antioxidants, and antimicrobial activities, Russian olive extracts have also been reported to effectively treat mastitis in-addition to its use as a natural insecticide in agriculture and as preservative agent in the food industry (Okmen & Turkcan, 2013; Torbati *et al*., 2016).

In addition to its use as a medicinal and food plant, Russian olive is one of the most important fuel and fodder plants in Gilgit-Baltistan (Shedayi *et al.*, 2014) and thus also occasionally planted by farmers as hedges or scattered in orchards (Fig. 1b and c). Like many other medicinal plants of the region, it is particularly affected by land use changes driven by increasing population growth and urbanisation, overgrazing, and associated soil-slope erosion events. This study was conducted to determine the morphological, phenotypic, and biochemical variation in Russian olive germplasm collected from different locations in the region as well as to record the socio-economic conditions of the collectors and traders of this vulnerable plant genetic resource.

2 Materials and methods

2.1 Sample collection and data recording

Ninety-three fully developed Russian olive trees were recorded from three different districts (Ghizer: n = 23, Gilgit: n = 48, Hunza: n = 22) of Gilgit-Baltistan, northern Pakistan (Fig. 2). Location coordinates and altitudes were recorded with a hand-held GPS receiver (Vista HCx eTrex, accuracy ± 2 m, GARMIN® Ltd., Southampton, Ireland). Altitudes ranged from 1470 m to 2470 m above sea level (mean 1732 m). The latitudinal and longitudinal area spanned a rectangular from 35°38'18.5" to 36°59'23.3" N and 73°9'18.72" to 74°52'12.3" E.

For each individual, diameter at breast height was measured with a tape to the nearest cm. Thereafter, four fruits and leaves were randomly picked from each individual. Morphological analysis was based on the study of Asadiar *et al.* (2012) with minor modifications: Quantitative leaf traits - length and width at the widest point of the lamina, length of petiole (in cm each). Qualitative leaf traits for both plant tissues were: presence of speckles on leaves, colour of abaxial and adaxial leaf surface, as well as the shape of the leaf lamina, leaf apex, leaf margin and leaf base. Quantitative fruit traits - fruit length, fruit width, seed length, seed width, pedicel length (in mm each, measured with a venier caliper), fruit weight, seed weight, and pulp weight in g each (measured with an electronic scale to the nearest 0.05 g). In addition, minimum and maximum number of fruits per inflorescence was determined. Qualitative fruit traits included colour of the ripe fruit, type of fruit surface, stiffness of fruit pedicel, presence of wings on fruit surface, fruit and seed shape. Later on, the following composite traits were calculated: leaf area assuming an ellipse shape, leaf and fruit shape indices by dividing width by length, fruit volume assuming an ellipsoid shape, and pulp percentage after subtracting seed weight from total fruit weight. In addition, a set of biochemical substances were determined from 40 individuals, whereby n = 13 individual fruit samples from each district (Gilgit, n = 14) were randomly picked. Antioxidant activity of the plant extract was determined according to Xu *et al.* (2016) by measuring the 2,2-diphenyl-1-picrylhydrazyl (DPPH radical) activity. Radical scavenging activity based on absorbance (Abs) was calculated as

$$(\text{Abs}_{control} - \text{Abs}_{sample}) \; / \; (\text{Abs}_{control}) \times 100$$

where $\text{Abs}_{control}$ and Abs_{sample} is the absorbance of DPPH + methanol and + sample (i.e. extract or standard), respectively. Do and colleagues' (2014) protocol was applied to determine total flavonoid content (TFC). Total phenolic content (TPC) and tannin content (TC) were determined based on the Folin-Ciocalteu method according to the protocols of Gusti *et al.* (2017) and Afify *et al.* (2012), respectively. TFC, TPC, and TC were expressed in quercetin (QE), ethanolic gallic acid (GAE), and ethanolic tannin acid (TAE) equivalents per gram dry plant extract, respectively. In addition, 32 collectors and 10 traders involved in Russian olive collection were

Fig. 2: *Elevation map displaying locations of surveyed Elaeagnus angustifolia (Russian olive) accessions in Gilgit-Baltistan, Pakistan, 2017. Differently shaded and outlined circles indicate accessions from three districts. (source: DIVA-GIS project, http://www.diva-gis.org/gdata)*

interviewed in the study region (Ghizer: n = 9, Gilgit: n = 28, Hunza: n = 5). Recorded standard socio-economic data including ethnic and religious backgrounds as well as household specific data such as marital status, numbers of family members, occupations, years involved in Russian olive harvest as well as income and sale variables.

2.2 Statistics

Descriptive statistics were employed to analyse the variation of quantitative morphological, phenotypic, and biochemical parameters including the coefficient of variation (CV in %). Relationships among quantitative traits were determined by Pearson correlations. Kruskal-Wallis tests were applied to assess differences across groups at $p < 0.05$. Quantitative traits were subjected to principal component analysis (PCA). The principal components (PC) with Eigen-values >1 (Kaiser criterion) were selected. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was applied in order to reject variables of correlations smaller than 0.6. The reduced morphological parameter set were then subjected to minimum variance analyses with squared Euclidian distances (Log_e) in MVSP v3.12f (Multivariate statistical package, Kovach Computing Services, Pentraeth, Anglesey, UK) to assess the level of dissimilarity among accessions. The 'elbow-criterion' (Leyer & Wesche, 2007) based on consecutive eigenvalues was used to determine the most likely number of clusters.

To determine livelihood specific differences of the 42 interviewed households, a categorical principal component analysis (CATPCA) was performed, followed by a two-step-cluster analysis. Both techniques are suitable for the integration of all data scales (nominal, ordinal, and metric) simultaneously (Chiu *et al.*, 2001; Linting *et al.*, 2007). All statistical analyses were carried out using SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Plant traits

Analysis of quantitative dendrometric traits indicated major variability among all accessions collected (Table 1). Overall, stem diameters ranged from 6 to 65 cm with a low CV (Table 1). The number of fruits per inflorescence showed moderate levels of variation (Table 1).

Fruit traits across groups were equal. Variation was largest for pulp weight and fruit volume, while the variation for other traits was moderate to low (Table 1). Elevation had a positive effect on fruit and seed dimensions especially on lengths (r = 0.606 and 0.515) and weights (r = 0.618 and 0.695; Supplement Table S1).

Frequency distributions of fruit related qualitative traits indicated that the dominant colour of ripened fruits was yellowish brown (70 %) and red (30 %). Scales were very common (98 %), while hairs were rare (2 %) and fruit pedicels were slender (98 %). Rips were visible for 37 % of the individuals, while overall fruit shape ranged from obovoid (58 %), ovate (29 %), ellipsoid (9 %), and round to conical (each 2 %). Seed shape was almost balanced with ovate (50.5 %) and narrow-long (49.5 %) seeds.

Leaves were rather monomorphic; leaf area was with 42 % (Table 1) the most variable parameter. The frequency distribution of leaf related qualitative traits revealed that all sampled accessions had speckles. The abaxial colour was predominately silvery (99 %) or yellowish white (1 %), while the adaxial color was ferruginous (71 %) or yellowish white (29 %). The shape of the lamina was mostly oblong-elliptic (53 %), round-ovate (32 %), and lanceolate (15 %). Leaf apex was acute-acuminate (77 %) or round-obtuse (23 %). Leaf margins ranged from entire (75 %) to revolute (25 %), while leaf base ranged from round-obtuse (53 %) to attenuate-cuneate (47 %).

Out of 20 morphological variables entered, 17 variables, matching the sampling adequacy criterion, were retained for the final PCA and subsequent cluster analyses. PCA revealed that the first five PCs had Eigen-values >1, cumulatively accounting for 81.2 % of the total quantitative variation (Table S1); KMO = 0.761, $p < 0.001$. Thereby, all fruit parameters (n = 5, incl. pulp weight) explained 41.4 % of the variation on PC1 (range of fruit parameters to PC1 correlations: r = 0.831 to 0.876). The second PC accounted for 14.4 %, whereby seed parameters (excl. seed weight) contributed most (range of seed parameters to PC2 correlations: r = 0.616 to 0.814). The remaining three PCs accounted for 25.5 %.

The cluster analysis of all quantitative traits separated the 93 accessions of *E. angustifolia* into two clusters with particular morphological characteristics each and a tendency of generally larger morphological traits for Cluster-1 (Fig. 3, Table 1). All locations were represented within both clusters, although a concentration of individuals from Hunza is observed in Cluster-1.

The variation of biochemical compounds found (ordered in increasing order of CV) was lowest for DPPH (range: 4 to 92 % of inhibition), higher for TPC (129 to 597 mg GAE g^{-1}) and TFC (26 to 233 mg QE g^{-1}), and highest for tannin content (1 to 36 mg TAE g^{-1}; Table 2). We found no correlation between chemical compounds and the three collection regions.

Table 1: *Average dendrometric, fruit and leaf morphological parameters of 93 Elaeagnus angustifolia (Russian olive) accessions from Gilgit-Baltistan (northern Pakistan).*

Dendrology	*n*	*DBH*	*No of fruits per inflorescence*		***Pulp***	*Weight*	
		cm	*min*	*max*		*g*	*%*
Ghizer	23	32^{a}	4	6		0.9^{a}	69^{a}
Gilgit	48	16^{c}	5	7		0.8^{a}	69^{a}
Hunza	22	21^{b}	5	7		0.4^{b}	60^{b}
Cluster-1	30	23	3^{b}	5^{b}		1.1^{a}	72^{a}
Cluster-2	63	20	6^{a}	8^{a}		0.5^{b}	63^{b}
Total mean	93	21	5	7		0.7	66
CV		26	57	49		69	17

Fruit	*n*	*Length*	*Width*	*Shape index*	*Volume*	*Weight*	*Pedicel length*
		mm			*mm*^{3}	*g*	*cm*
Ghizer	23	16.9^{a}	11.3^{a}	0.69	9643^{a}	1.2^{a}	3.4
Gilgit	48	16.2^{a}	11.5^{a}	0.72	9944^{a}	1.2^{a}	3.2
Hunza	22	13.9^{b}	9.8^{b}	0.71	6113^{b}	0.6^{b}	2.5
Cluster-1	30	19.3^{a}	13.0	0.69^{b}	14216	1.5^{a}	3.4
Cluster-2	63	13.9^{b}	9.8	0.72^{a}	5864	0.8^{b}	2.8
Total mean	93	15.6	10.9	1	8558	1.0	3.0
CV		23	20	14	62	57	49

Seed	*n*	*Length*	*Width*	*Shape index*	*Volume*	*Weight*
		mm			*mm*^{3}	*g*
Ghizer	23	15.3	5.1	0.35	1769	0.3^{a}
Gilgit	48	15.3	5.2	0.35	1875	0.3^{a}
Hunza	22	13.6	4.9	0.36	1464	0.2^{b}
Cluster-1	30	16.8^{a}	5.5^{a}	0.33	2184^{a}	0.4^{a}
Cluster-2	63	13.6^{b}	5.0^{b}	0.37	1487^{b}	0.3^{b}
Total mean	93	14.6	5.1	0.36	1712	0.3
CV		21	19	22	48	35

Leaf	*n*	*Length*	*Width*	*Shape index*	*Area*	*Petiole length*
		cm			*cm*^{2}	*cm*
Ghizer	23	6.5	1.7	0.27	35.	1.2
Gilgit	48	6.9	1.7	0.26	36.7	1.2
Hunza	22	6.1	1.8	0.30	35.0	1.1
Cluster-1	30	7.0^{a}	1.7	0.25^{a}	37.4	1.3^{a}
Cluster-2	63	6.4^{b}	1.8	0.29^{b}	36.3	1.1^{b}
Total mean	93	7	2	0.27	37	1.1
CV		23	31	30	42	28

DBH: diameter at breast height, CV: coefficient of variation. Superscripted letters (a–c) indicate significant differences at $p < 0.05$ among groups (non-significance is indicated by the absence of letters).

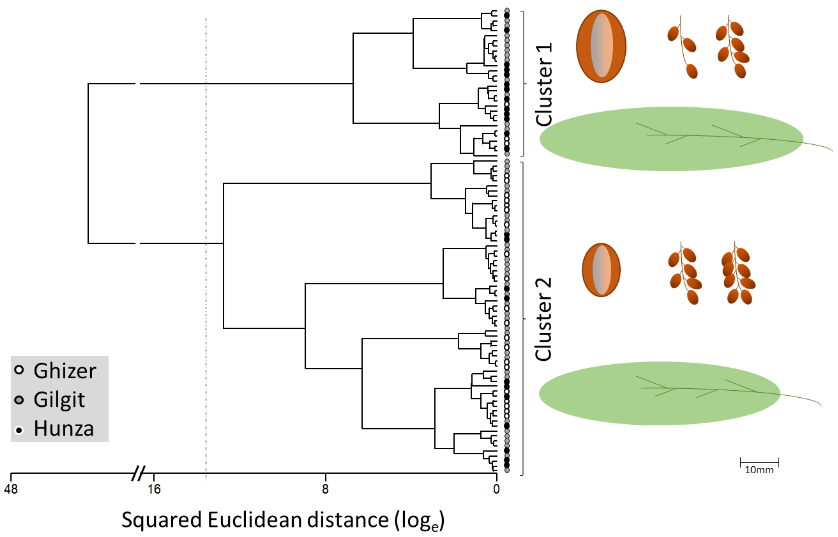

Fig. 3: *Minimum variance clustering with squared Euclidean distance (log$_e$) of 93 accessions of Elaeagnus angustifolia (Russian olive) from Gilgit-Baltistan, northern Pakistan. Grey dashed line indicated the most likely number of clusters according to the 'elbow' criterion.*

Table 2: *Bio-chemical parameters of 93 accessions of Elaeagnus angustifolia (Russian olive) from Gilgit-Baltistan (northern Pakistan).*

	DPPH *Inhibition %*	*TPC* *mg QE g^{-1}*	*TFC* *mg GAE g^{-1}*	*TC* *mg TAE g^{-1}*
Ghizer	51.4^{b}	95.9^{b}	318.5^{ab}	6.6^{ab}
Hunza	73.8^{a}	65.2^{b}	240.3^{b}	5.2^{b}
Gilgit	72.3^{ab}	132.3^{a}	396.4^{a}	14.9^{a}
CV %	31.6	53.1	33.9	90.3
Total mean	66.0	98.7	320.4	9.1

DPPH = 2,2-diphenyl-1-picrylhydrazyl, TPC = Total phenolic content, TFC = Total flavonoid content, TC = Tannin content. Different letters (a–b) aside values indicate significant ($p < 0.05$) differences among groups.

3.2 *Socio-economic household characteristics*

Family size of households harvesting Russian olive averaged 6.6, whereby about 25 % of them were involved in the collection of fruits and/or their trade. Family members have been involved in Russian olive collection mostly since their childhood. On average, two people were responsible for harvest at rather distant collection sites (>12 km) with daily harvests between 11 to 20 kg. On average, about 90 € (ca. 16000 PKR) were earned annually from Russian olive fruits per household ranging from about 35 € to about 205 €. The two-step cluster approach revealed two equally shared (n = 21, each) livelihood strategies, defined as specialized large-scale collectors (SLSC) and non-specialized small-scale collectors (NSSC). The SLSC livelihood strategy comprised Sunni and Shia households. Their average annual income amounted to 110 € and marketing was often done by the family members themselves. NSSC households instead adhered to the Ismaili faith, with comparatively low harvest quantities (<10 kg), at close vicinities (1-5 km) to the homesteads, and low annual income from fruit sale (65 €). On average, one person was involved in fruit harvesting. Only a few farmers from Ghizer received well-recognized varieties from traders and planted them in rows or scattered in their orchards.

4 Discussion

The present study provides evidence of a significant morphological/phenotypic diversity among the sampled accession of *E. angustifolia* in Gilgit-Baltistan. Dendrological characteristics indicated the presence of large individuals with respect to stem diameters of up to 65 cm that compare well to stem diameters of other cultivated fruit crops in the sample area such as walnut (*Juglans regia* L.), mulberry (*Morus alba* L.), and apricot (*Prunus armeniaca* L.).

Compared to Turkish accessions, fruit length and width of our sampled accessions were 46 % and 43 % (Ersoy *et al.*, 2013) and 38 and 40 % (Akbolat *et al.*, 2008) smaller. Also seed length showed a 39 % lower value, while seed width was nearly similar (2 % difference). Another study from India (Raj *et al.*, 2010) compared five varieties and found similar ranges of fruit and seed dimensions as in our study, though one variety was larger by 33 % (fruit length) and 18 % (fruit width).

Although the overall leaf trait variability exhibited rather low CV values, measurements still indicated pronounced differences for leaves. Inter-individual variation of leaf dimensions is a well-known character in perennial species including Russian olive (Klich, 2000), which is mainly governed by exposure to sun at different strata. Leaf traits (also fruit traits) lack certain explanatory power in our example as only four samples per individuals were taken. The use of a larger number of repetitions such as n = 10 per individual would have been statistically advisable.

The correlation matrix across parameters revealed in part unexpected relationships. For instance, fruit to seed dimensions may be expected to be positively correlated as found in our study with moderate to strong significant correlations. Petiole length on the other side, showed low to moderate correlations to other parameters though this effect is rather difficult to explain. Elevation, interestingly, showed moderate, but significant effects indicating larger fruit and seed dimension at higher altitudes. Although literature does not provide sufficient evidence, it may be related to cooler temperatures and higher precipitation regimes at higher altitudes that allow a sufficiently long development of fruits as similarly reported for coffee in Costa Rica (Muschler, 2001). Larger fruit sizes of Cluster-1 could be also the result of higher nutrient availability (manure, mineral fertiliser), which can be expected in agricultural settings. However, we did not assess the chemical soil status and can therefore not evaluate on this further. Also, fruit set (fruits per inflorescence) seemed to negatively influence fruit and seed dimensions suggesting that Russian olive can be also horticulturally managed by thinning out fruits for larger fruit sizes of the remaining ones as practiced for commercial crop species such as apples or oranges. In the case of Russian olive, however, it is questionable if such management intensification is economically interesting as the fruit is basically used as medicine with a comparatively low quantitative demand.

Most studies applying PCA can already explain the largest fraction of variation with the first two to three principal components (Bartomeus *et al.*, 2015; Sá *et al.*, 2018). Our analyses needed four components to explain 74 % of the variation and three to explain 65 %. The relatively low Eigen-values indicate a high morphological variation in the studied accessions and hence confirms a large variation within a relatively small sampling area of approximately 5000 km² that may harbour interesting plant materials for future breeding and domestication purposes.

Numerically, large morphological variation was comprised by Cluster-1, while a rather small one was gathered in Cluster-2. The dendrogram indicated a high degree of variation among accessions, but no apparent link between morphological diversity and geographic distance, which might be related to an undirected and random dispersal of Russian olive plant material such as seeds by birds (Kindschy, 1998) in the study region. Eventually also trans-planting (cuttings, seedlings) by humans cannot be excluded, together with the millennia old trade of non-agricultural and agricultural commodities along the silk road (Spengler, 2019). Whether the recorded and sampled individuals have been planted or are of wild nature, could be not finally clarified as our sampling took place along roadsides and on cultivated areas that are often inhabited, at least managed by people. It is therefore probable that Russian olive individuals have been purposively planted in times when the need for wood and maybe medicinal products was higher than today. Moreover, there is evidence based on seed remains that Central Asian piedmonts were once covered with dense forests of diverse taxa including Russian olive (Spengler, 2019). The peripheral Central Asian region of northern Pakistan might be hence a refuge area for this fruit bearing species. Current records at the IUCN database (IUCN, 2019) propose northern regions of Pakistan and surrounding areas as a main centre of distribution. Moreover, Russian olive has been introduced lately into countries, where it has become an invasive species on marginal areas (Simberloff & Rejmánek, 2011) emphasizing the species' pioneering character.

Overall, biochemical contents in the sampled fruits exceeded most values found in the literature. The radical scavenging activity measured through DPPH was about twice (51 %) to trice (74 %) as high as accessions from Turkey (Cansev *et al.*, 2011), but on average one third smaller than accessions sampled from Iran (Faramarz *et al.*, 2015). The flavonoid contents were about 100-fold (98 mg QE g^{-1}) higher than those found by Saboonchian *et al.* (2014) in leaves and flowers from Iran, while fruit flavonoid values for this species to our knowledge seem to be completely lacking. Only Abizov *et al.* (2008) determined flavonoids and phenolcarboxylic acids together as 1.4 %, which would be in our case 30-fold higher (10 % + 32 % = 42 %; 98.7 mg QE g^{-1} and 320.4 mg GAE g^{-1}, respectively). Tannin in contrast was about 80 % (9.1 mg GAE g^{-1}) lower than the values stated in the review of Tehranizadeh *et al.* (2016). It must be stated that parameters such as age and health of individuals or time of picking may have resulted in this large variation, which prevents an analysis of underlying factors, especially under field conditions.

The socio-economic household analysis highlighted that Russian olive harvest and trade follows a purely additional income strategy. On markets, the fruits are not easily encountered and if so, they are only seasonally available and often of poor quality (infestations by insects, contamination with dirt and dust; pers. observations) indicating non-existing quality standards and limited demand. Interestingly, Russian olive harvest and trade was rather in the hand of non-Ismaili people though Ismaili people are considered natives of the studied region. This might be explained by the fact that newcomers make use of such rather unexploited resources faster than natives. It may however, confirm that Russian olive has been only lately introduced – a fact that seems also valid for sea buckthorn (*Hippophae rhamnoides* L.) in northern regions of Pakistan as traditional knowledge about harvest and processing is largely lacking (Nawaz *et al.*, 2019). This is furthermore supported by the absence of individuals in non-managed and unsettled areas, at least in the Hunza Valley which calls for a more exhaustive sampling in other regions of Gilgit-Baltistan.

5 Conclusions

Our study shows a high morphological diversity of Russian olive within and between the sampled accessions. Existence of variability is critical for any crop improvement and conservation program. It underlines potential for further screening of Russian olive individuals for improved ecotypes/superior individuals that might be used for future propagation and breeding purposes. Although highly valued as a medicinal and soil remediating species, information on accession and population related parameters of Russian olive and the influence of environmental and/or genetic factors on species performance is scarce. We therefore suggest more in depth studies including larger sampling areas and sample sizes.

Supplement

Table S1: Correlation coefficients among dendrological and fruit related quantitative traits of 93 accessions of *Elaeagnus angustifolia* (Russian olive) from Gilgit-Baltistan (northern Pakistan). This supplement is available online at: https://doi.org/10.17170/kobra-202007291507 .

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Conflict of interest

The authors declare no conflict of interest. The donors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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