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Forage potential of *Salsola* species in arid-saline rangelands

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Abstract: We investigated the forage potential of 12 *Salsola* species including *S. arbuscula*, *S. abarghuensis*, *S. dendroides*, *S. crassa*, *S. imbricata*, *S. incanescens*, *S. nitraria*, *S. kerneri*, *S. orientalis*, *S. richteri*, *S. tomentosa*, and *S. yazdiana* in the Southern rangelands of the Great Salt Desert. The results showed a great significant variation among forage quality and quantity of the *Salsola* species. The greatest fresh and dry forages were obtained in *S. yazdiana* (4.54 and 1.53 kg m^{-2}, respectively) followed by *S. dendroides* (3.02 and 1.13 kg m^{-2}, respectively). The *S. tomentosa* had the greatest ash content by 20.2%, which significantly was higher than others; whereas the greatest crude protein was observed in *S. incanescens* and *S. crassa*. The lower acid detergent fiber (ADF) and neutral detergent fiber (NDF) as appropriate forage quality indices were achieved in *S. dendroides*, *S. imbricata*, and *S. arbuscula*. Furthermore, *S. dendroides* and *S. incanescens* had the greatest dry matter digestibility (59%) and metabolizable energy (8%). Tissue water content in halophytes was a valuable index for salinity tolerance and forage quality, which is missed in the literature. Higher tissue water content (72.0% in *S. crassa* and 71.4% *S. kerneri*) could probably lead to lower water consumption in small ruminants. Based on the finding, *Salsola* species had low energy (7.1% on average) and approximately high protein content (8.5% on average), but some species such as *S. incanescens* and *S. dendroides* followed by *S. imbricata* had better forage quality; so they could be considered alternative forage plants in arid land regions. However, forages of these species should be used in mix with common forages due to the low energy level.

Key words: Crude proteins, desert, detergent fiber, digestibility, halophyte, metabolizable energy

1. Introduction

Forage production using nonconventional water resources is inevitable in regions with severe limitations of freshwater. Halophytes, such as *Salsola* have the potential to produce forage with saline and hypersaline water. *Salsola* L. is a genus in the family Amaranthaceae, which are widespread in all saline and arid lands of the world, as native species in southwestern Asia, North Africa, and Europe, and as introduced species in America and Australia (Akhani et al., 2007). Saltwort is the common name for various members of *Salsola* genus, due to their high salinity tolerance. *Salsola* is the ancestor of 40–50 *Salsola*-related genera containing over 350 of both C_3 and C_4 species (Pyankov et al., 2002). Despite initial assumptions, some *Salsola* species are known to have different cross-sectional leaf anatomy, for example, *S. webbii* is lacking a Kranz or garland type anatomy; however, it has two peripheral palisade parenchyma cells layers with minor veins below. It is considered an example of a reversion to non-Kranz anatomy in *Salsola* species (Pyankov et al., 2010).

Salsola species have an important role in the reclamation of saline pastures, because these species have promising potential as a forage plant with good quality, as well as the high ability for seed production (Masters et al., 2007; Attia-Ismail, 2018). It is reported that all *Salsola* species could supply a considerable amount and quality of forage, which are suitable for grazing (Temel et al., 2015). It has been well-reported that *Salsola* species greatly differ in forage quality (Panahi et al., 2012; Temel et al., 2015; Zare et al., 2019). In general, forage quality could be defined as the potential of a plant to produce the desired livestock response. However, the forage quality varies between species and closely depends on several factors such as woodiness, phenology, leafy status, growth stage, soil conditions, climatology, harvesting, and vegetation types (Panahi et al., 2012).

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Other characteristics that affect forage quality are forage acceptability, nutrients digestibility, ions concentration, and fibbers content. As crude fiber increases, the fodder digestibility and energy content are decreased; consequently, forage intake drops dramatically (Hoffman et al., 2003; Panahi et al., 2012). Forage digestibility was closely related to cell wall characteristics so that cell content is digestible even at mature stages (Pinkerton, 1996).

Several researchers investigated the quality and potential of *Salsola* forage. For example, Temel et al. (2015) by evaluating the nutritive value of some *Salsola* species, showed that *S. dendroides* followed by *S. nitraria* and *S. oppositifolia* had the greatest yield and nutritional values. Similarly, Panahi et al. (2012) reported that *S. arbuscula* had less forage quality compared with *S. orientalis* and *S. tomentosa*; however, these species had higher quality at the vegetative stage. Temel and Keskin (2019) also reported that the best quality forage of *Salsola* species was obtained during early growing season due to forming soft-succulent offshoots and leaves, as opposed to the woodier plant material at later growth stages. Zare et al. (2019) indicated that the species with more crude protein, dry matter digestibility, and metabolizable energy and lower acid and neutral detergent fibers could be candidates for forage production with acceptable nutritive value. They also reported that *S. tomentosa* was better in forage production than the other examined *Salsola* species, and could be fed by goat and camel during vegetative stage in late winter and early spring. With a glance at literature, although there are different types of *Salsola* species, a little research has been done to compare their forage production. Therefore, to make a reliable decision, different species should be compared in a study with approximately the same conditions.

The objective of this study was investigating the forage potential of 12 *Salsola* species from the southern rangelands of the Great Salt Desert (GSD), in the northwest of Yazd Province, Iran with two environmental factors limiting plant production, drought and salinity.

2.Materials and methods

This study was done at the southern rangelands of the Great Salt Desert (GSD) in 2018–2019. The target area was specifically in the northwest of Yazd Province, a province in GSD. This area has desert climate with below 100 mm annual precipitations and located in 32.5320°–53.8159°NW, 32.5323°–54.2788°NE, 31.9730°–54.0912°SW and 32.0072°–54.2976°SE (Figure 1). The geographical characteristics of the sampled points are shown in Table 1. Large salty habitats are found in the central Iranian great deserts named the Dasht Kavir. Dasht Kavir, also known as Kavir Namak and the GSD, is a large desert lying in the middle of the Iranian plateau. Vegetation in the GSD is adapted to the hot and arid climate as well as to the saline soil in which it is rooted (Akhani, 2006; Akhani et al., 2007).

First of all, *Salsola* species with dominant distribution in the rangelands were identified, which included *S. arbuscula* Pall. (*Xylosalsola arbuscula* (Pall.) Tzvelev), *S. abarghuensis* Assadi (*Caroxylon abarghuense* (Assadi) Akhani & Roalson), *S. dendroides* Pall. (*Nitrosalsola dendroides* (Pall.) Theodorova), *S. crassa* M.Bieb. (*Climacoptera crassa* M.Bieb.), *S. imbricata* Forssk. ex J.F.Gmeli., *S. incanescens* C.A.Mey. (*N. incanescens* (C.A.Mey.) Theodorova), *S. nitraria* Pall. (*N. nitraria* (Pall.) Tzvelev), *S. kerneri* (Wol.) Botsch., *S. orientalis* S.G.Gmelin (*N. orientalis* (S.G.Gmel.) Theodorova), *S. richteri* (Moq.) Kar (*X. richteri* (Moq.) Akhani & Roalson), *S. tomentosa* (Moq.) Spach. (*Kaviria tomentosa* (Moq.) Akhani), and *S. yazdiana* Assadi (*C. yazdianum* (Assadi) Akhani & Roalson). An identification key (Hakimi Meybodi and Sadeghinia 2009) was used to identify species in addition to the personal experiences of authors (Table 2). Photos of these species are shown in Figure 2.

A 1 m^2 quadrat was used for sampling at vegetative stage, and four quadrats were randomly placed for harvesting each species. Previous reports indicated that the greatest forage quality of *Salsola* is at vegetative stages (Panahi et al., 2012; Temel et al., 2015; Zare et al., 2019). Samplings were done at this stage and the samples were instantly placed in plastic bags to keep the moisture. The bags were immediately transferred to the laboratory for measurements. Primary weight was regarded as fresh weight. Dry weight was measured after placing the samples in paper bags in oven 70 ± 2 °C for 48 h. Six species were in shrub form, and it could not be possible to obtain a complete sample. For these species, some branches of this year in full (leaves and stems) were samples. These samples were used for determining the tissue water content. Fresh and dry forages just were measured for *S. abarghuensis*, *S. dendroides*, *S. crassa*, *S. incanescens*, *S. nitraria*, and *S. yazdiana*.

Using the fresh (FW) and dry weight (DW), the tissue water content (TWC) was calculated based on the following equation (Equation 1):

$$TWC = \frac{FW - DW}{FW} \times 100 \qquad (1)$$

The forage nutritive value of the *Salsola* species was assessed by examining ash, crude protein, acid and neutral detergent fiber, dry matter digestibility, and metabolizable energy. Nitrogen (N) concentration was measured using Kjeldahl; and accordingly, crude protein (CP) was calculated based on Equation 2.

$$CP = 6.25 \text{ x } N \qquad (2)$$

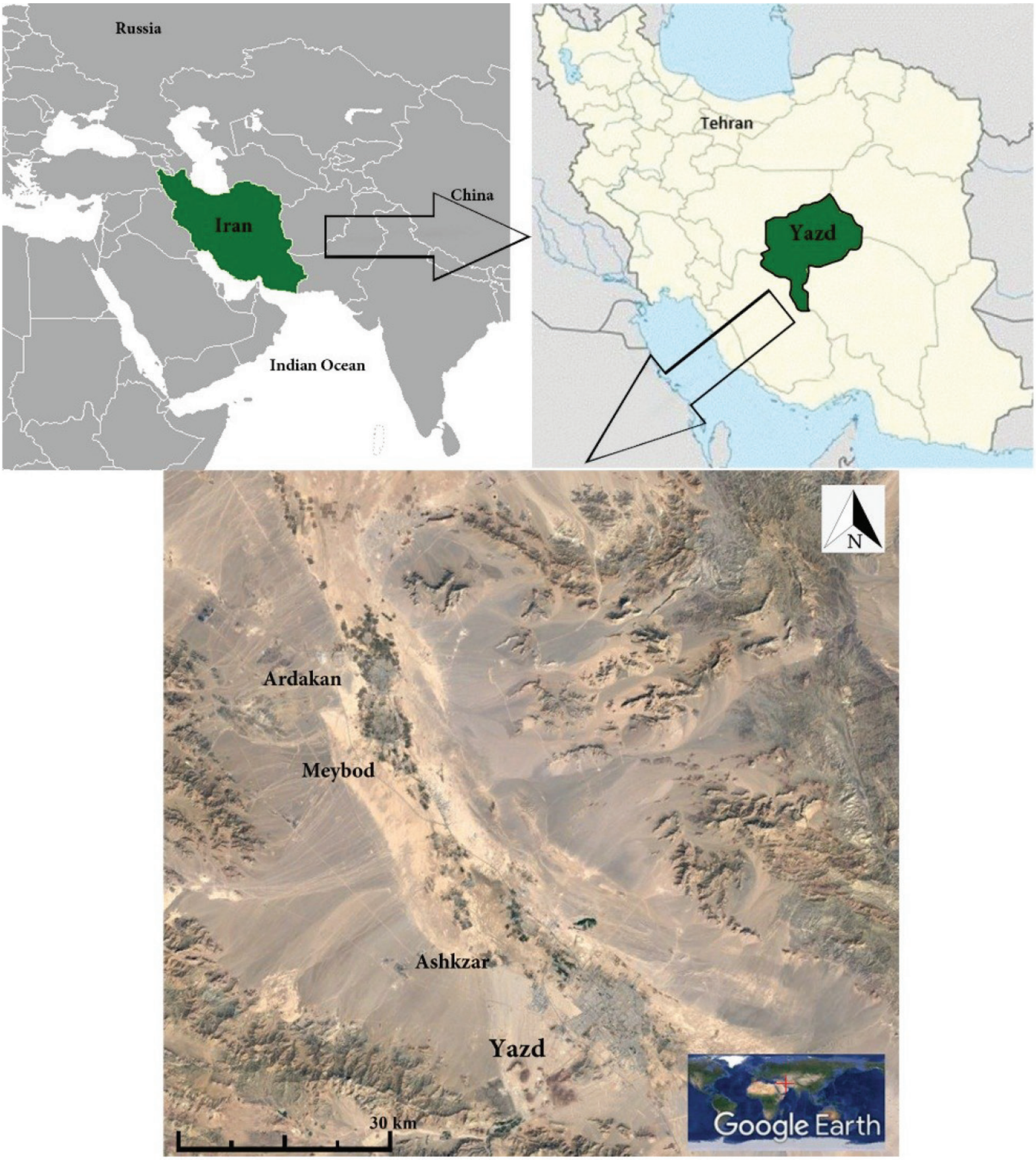

Figure 1. Geographical position of the surveyed rangelands (32.5320°N–53.8159°E in the northwest, 32.5323°N–54.2788°E in the northeast, 31.9730°N–54.0912°E in the southwest, and 32.0072°N–54.2976°E in the southeast). The map is obtained from Google Earth Pro 7.3.3.7786.

Table 1. The geographical characteristics of the sampled points.

Scientific name	Region	Geographic coordinate	Altitude(m)	Soil properties		
				Taxonomy	pH	EC (dS m^{-1})
Salsola arbuscula Pall.	Meybod	32.0610° N– 54.1768° E	1148	Entisol	7.69	22.4
S. abarghuensis Assadi	Meybod	32.060° N– 54.1769° E	1145	Entisol	7.69	20.8
S. dendroides Pall.	Meybod	32.0614° N–54.1766° E	1148	Entisol	7.69	24.3
S. crassa M.Bieb.	Ashkzar	32.0542° N– 54.2365° E	1133	Aridisoil	7.32	15.2
S. imbricata Forssk. ex J.F.Gmeli.	Meybod	32.0614° N– 54.1771° E	1150	Entisol	7.69	21.1
S. incanescens C.A.Mey.	Ardakan	32.5106° N– 53.8860° E	979	Aridisoil	7.66	18.3
S. nitraria Pall.	Ashkzar	32.0525° N– 54.2360° E	1132	Aridisoil	7.32	22.0
S. kerneri (Wol.) Botsch.	Meybod	32.0616 ° N– 54.1768° E	1147	Entisol	7.69	25.2
S. orientalis S.G.Gmelin	Meybod	32.0617° N– 54.1767° E	1148	Entisol	7.69	27.5
S. richteri (Moq.) Kar.	Meybod	32.0605° N– 54.175° E	1142	Entisol	7.69	30.7
S. tomentosa (Moq.) Spach.	Meybod	32.0609° N– 54.1758° E	1144	Entisol	7.69	25.1
S. yazdiana Assadi	Meybod	32.0607° N– 54.1762° E	1145	Entisol	7.69	23.9

n=4

Table 2. Distinctive features of the investigated *Salsola* species.

Classic name	New nomenclature	Habitat	Type	Leaf	Stem	GBIF ID†
Salsola arbuscula Pall.	*Xylosalsola arbuscula* (Pall.) Tzvelev	Perennial	Shrub	Hairless, fleshy	Woody	3759758
S. abarghuensis Assadi	*Caroxylon abarghuense* (Assadi) Akhani & Roalson	Perennial	Bush	Alternate, fleshy	Woody	3760085
S. dendroides Pall.	*Nitrosalsola dendroides* (Pall.) Theodorova	Perennial	Bush	Tiny, alternate, fleshy	Woody	6035757
S. crassa M.Bieb.	*Climacoptera crassa* M.Bieb.	Annual	Bush	Hairless, alternate,	Herbaceous	6035769
S. imbricata Forssk. ex J.F.Gmeli.	-	Perennial	Shrub	Hairy, fleshy	Woody	6035698
S. incanescens C.A.Mey.	*Nitrosalsola incanescens* (C.A.Mey.) Theodorova	Annual	Bush	Alternate, fleshy	Woody, thick bottom	3758104
S. nitraria Pall.	*Nitrosalsola nitraria* (Pall.) Tzvelev	Annual	Bush	Alternate, hairy	Herbaceous	3757246
S. kerneri (Wol.) Botsch.	-	Perennial	Shrub	Long, hairless, opposite, fleshy	Woody	3757876
S. orientalis S.G.Gmelin	*Nitrosalsola orientalis* (S.G.Gmel.) Theodorova	Perennial	Shrub	Alternate, underside hairy, fleshy	Woody	6035630
S. richteri (Moq.) Kar.	*Xylosalsola richteri* (Moq.) Akhani & Roalson	Perennial	Shrub	Alternate, fleshy	Woody	4940520
S. tomentosa (Moq.) Spach.	*Kaviria tomentosa* (Moq.) Akhani	Perennial	Shrub	Alternate, underside hairy, fleshy	Woody, Very branched	6035542
S. yazdiana Assadi	*Caroxylon yazdianum* (Assadi) Akhani & Roalson	Perennial	Bush	Alternate, hairy	Woody	3755675

n=4
† Global Biodiversity Information Facility ID

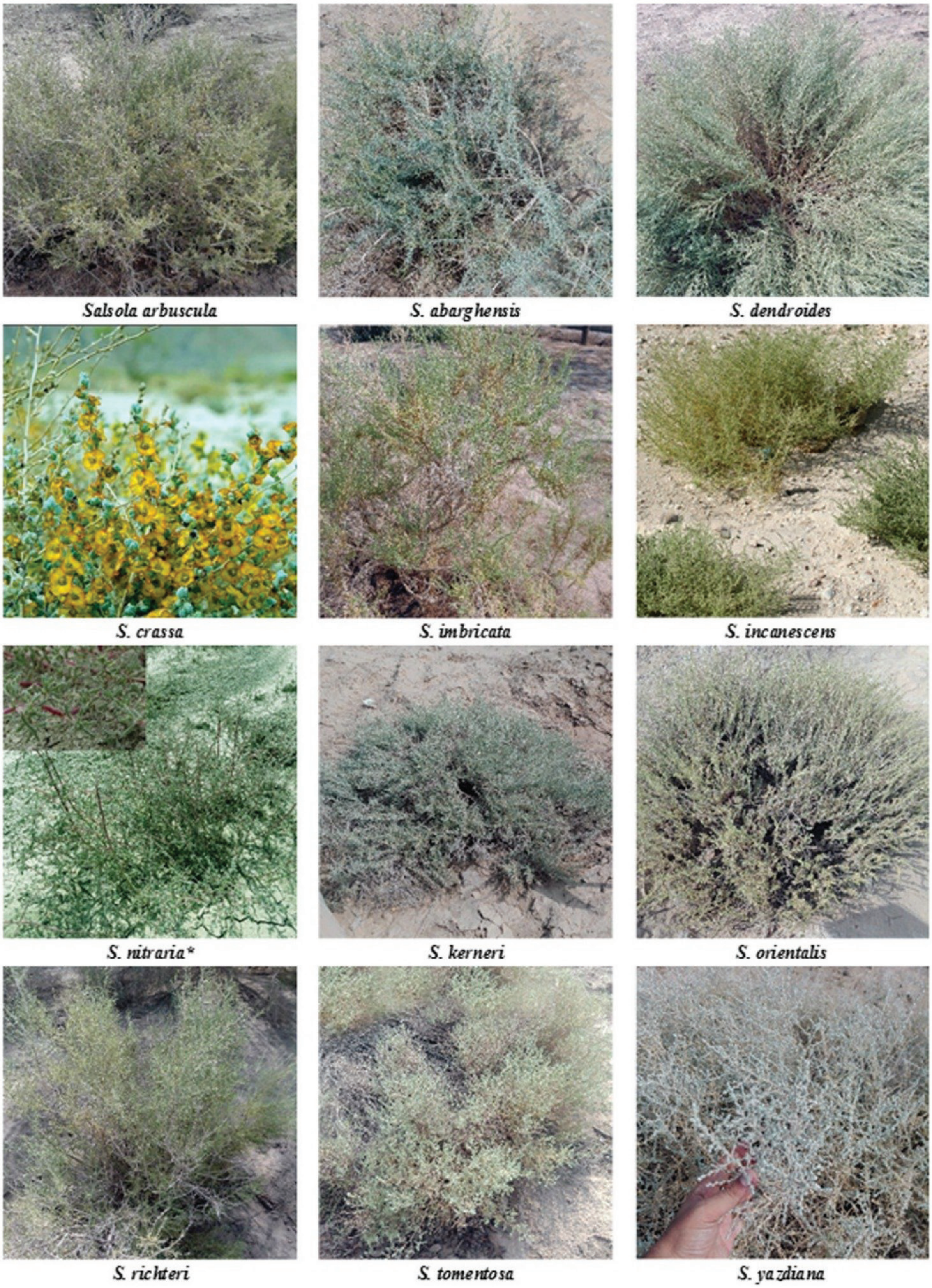

Figure 2. Photos of the investigated *Salsola* species at the sampling places (all photos are taken in the surveyed rangelands, except *S. nitraria,* which belongs to Serdar Ölez, Ankara, Turkey, 2018.)

This method for nitrogen determination is described from the digestion stage to the determination of ammonium.

Protocol of Van Soest et al. (1991) was followed for the determining acid detergent fiber (ADF) and neutral detergent fiber (NDF). Then, dry matter digestibility (DMD) and metabolizable energy (ME) were calculated using the following equations 3 and 4 (Oddy et al., 1983):

$$DMD = 83.58 - (0.824 \times ADF) + (2.262 \times N) \quad (3)$$

$$ME = (0.17 \times DMD) - 2 \quad (4)$$

In the Van Soest et al. (1991) method, the crusivers of the Fibertech system were filled with 1 g of each oven-dried sample and moved to a fiber analysis system (Foss Tecator, 2010, Fiber Tech analyzer, Sweden).

Soil salinity in the area was estimated using EM38 device as a nondestructive technique in electromagnetic induction (EMI) way. The EM38 is a portable field instrument designed to estimate soil electrical conductivity (EC) up to 1500 mm depth as a rooting zone (Narjary et al., 2019). The EC of saturated soil extract (EC_e) of each point was obtained based on regression of EM38 readings (as EC_a) with measured EC_e in three samples. For this purpose, three soil samples were taken in each region and EC_e and pH were measured using a pH-meter (Metrohm, 827 pH lab) and an EC-meter (WTW, Terminal Le3 InoLab).

Quantitative ranking was used to determine the best *Salsola* species. To do this, 12 species were descendingly sorted for the important traits (i.e. TWC, ash, CP, ADF, NDF and DMD) and the species with the better value of each trait got 1, and the next species that had a significant difference got 2 and so on until the last species. Greater values for TWC, CP, and DMD and smaller values for ash, ADF, and NDF were considered better. Finally, the average of these rankings was used for the overall ranking of the species. The mean separation was done using Duncan's multiple range test (DMRT) at 1% probability level. *Salsola* species were grouped using cluster analysis based on the important traits (i.e. TWC, ash, CP, ADF, NDF, and DMD). The statistical analysis was completed by SAS version 9.4 software (SAS Institute, Cary, North Carolina, USA).

3. Results

Among the *Salsola* species, *S. arbuscula*, *S. imbricata*, *S. kerneri*, *S. orientalis*, *S. richteri*, and S. *tomentosa* were in the form of shrub and *S. abarghuensis*, *S. dendroides*, *S. crassa*, *S. incanescens*, *S. nitraria*, and *S. yazdiana* had an herbaceous bush form (Table 2). The greatest fresh and dry forage was observed in *S. yazdiana* (4.54 and 1.53 kg m^{-2}, respectively) followed by *S. dendroides* (3.02 and 1.23 kg m^{-2}, respectively); while *S. crassa* had the least fresh and dry forage by 1.93 and 0.54 kg m^{-2}, respectively (Figure 3). Tissue water content (TWC) had a limited range from 60% to 72% between the *Salsola* species (Figure 4). The greatest TWC was observed in *S. crassa* (72.0%) and *S. kerneri* (71.4%), while *S. arbuscula* had the least TWC (60.3%). Ash content varied significantly between the *Salsola* species (Figure. 4), where *S. tomentosa* with 20.2% ash had the greatest value, and the least ash equal to 9.9% was measured in *S. incanescens*. Except for *S. incanescens*, all *Salsola* species had ash by more than 10% (Figure 4). Different *Salsola* species had varied crude protein (CP) as shown in Figure 5, so the greatest CP values were obtained in *S. incanescens* (12.3%) and *S. crassa* (11.6%). On the contrary, *S. tomentosa* and *S. yazdiana* had the least CP of 6.17% and 6.39%, respectively.

Less ADF and NDF indices were desirable factors for forage quality. Therefore, *S. dendroides* (33.4%) and *S. imbricata* (34.2%) were considered the species with the least ADF (Figure 6), whereas *S. dendroides* (30.6%),

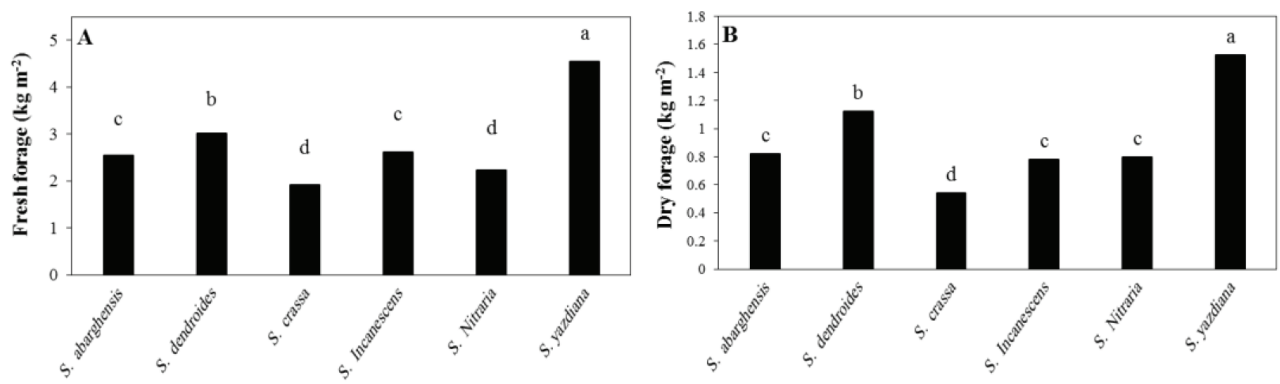

Figure 3. Variations in fresh forage (A) and dry forage (B) among the *Salsola* species. Means with similar superscripts are not significantly different based on Duncan's multiple test ($P \leq 0.05$, n = 4).

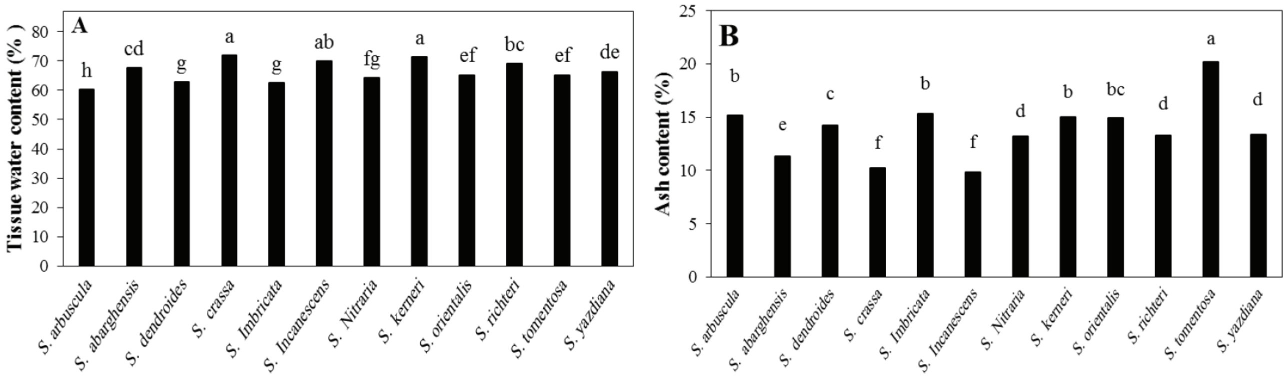

Figure 4. Variations in tissue water content (A) and ash (B) among the *Salsola* species. Means with similar superscripts are not significantly different based on Duncan's multiple test (P ≤ 0.05, n=4).

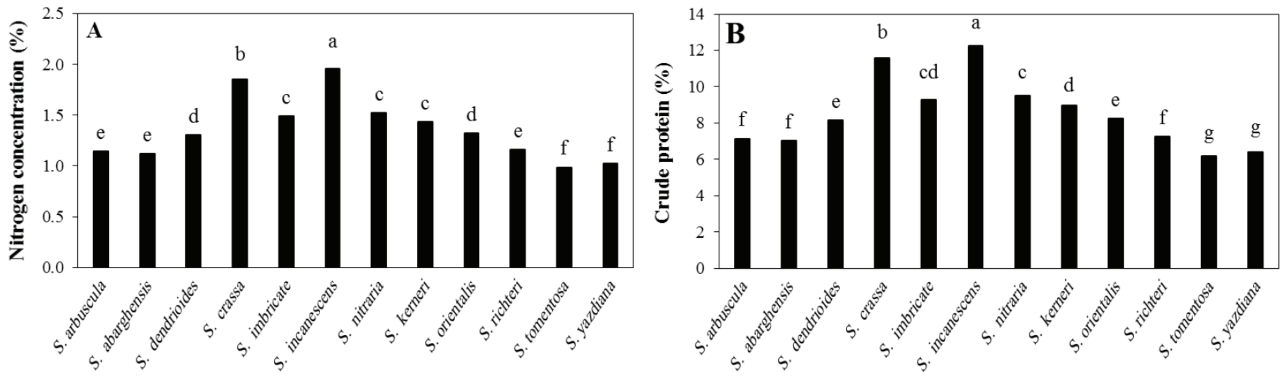

Figure 5. Variations in nitrogen concentration (A) and crude protein (B) among the *Salsola* species. Means with similar superscripts are not significantly different based on Duncan's multiple test (P ≤ 0.05, n = 4).

S. arbuscula (35.4%), and *S. imbricata* (35.6%) were the species with the least NDF. On the other side, *S. richteri* had the greatest ADF (47.3%) and NDF (49.3%) values. The DMD and ME were significantly different between *Salsola* species (Figure 7), as these values were ranged from 47% to 59% and from 6% to 8%, respectively. The greatest DMD of 59.0% and 58.9%, as well as, the greatest ME of 8.03 and 8.02 MJ kg^{-1}, were observed in *S. dendroides* and *S. incanescens,* respectively. Alternatively, *S. richteri* and *S. yazdiana* had the least DMD (47.3% and 47.8%) and ME (6.0% and 6.1%).

The result also showed that ash content was significantly and negatively correlated with nitrogen concentration and CP values (Table 3). Furthermore, N and CP had a significant and positive correlation with DMD and ME values. The results correlation analysis also documented that ADF and NDF were significantly and negatively correlated with DMD and ME values.

4. Discussion

We found the *Salsola* species in two forms: herbaceous bush (or forb) and shrub. Bush and shrub are almost the same terms for such plants, in which herbaceous bushes are lower plants that their stems and leaves usually touch the ground, but shrubs have thicker foliage and are bigger plants, though are not as tall as trees (Gillson and Hoffman, 2007; Mauseth, 2016). *Salsola* species with the herbaceous bush form were *S. abarghuensis*, *S. dendroides*, *S. crassa*, *S. incanescens*, *S. nitraria*, *S. yazdiana*, and *Salsola* species with the shrub from included *S. arbuscula*, *S. imbricata*, *S. kerneri*, *S. orientalis*, *S. richteri*, and S. *tomentosa*. The lower quality of shrub compared to bush species might be

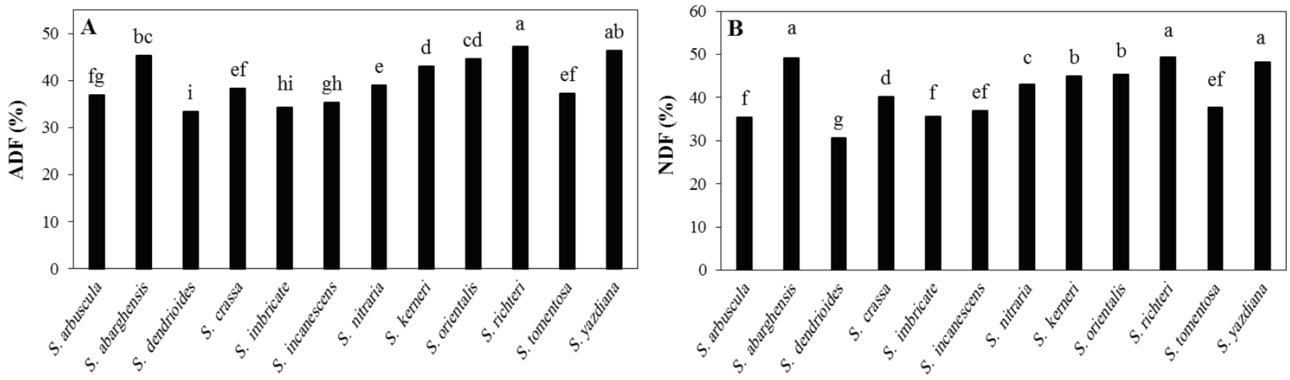

Figure 6. Variations in acid detergent fiber (ADF, A) and neutral detergent fiber (NDF, B) among the *Salsola* species. Means with similar superscripts are not significantly different based on Duncan's multiple test (P ≤ 0.05, n = 4).

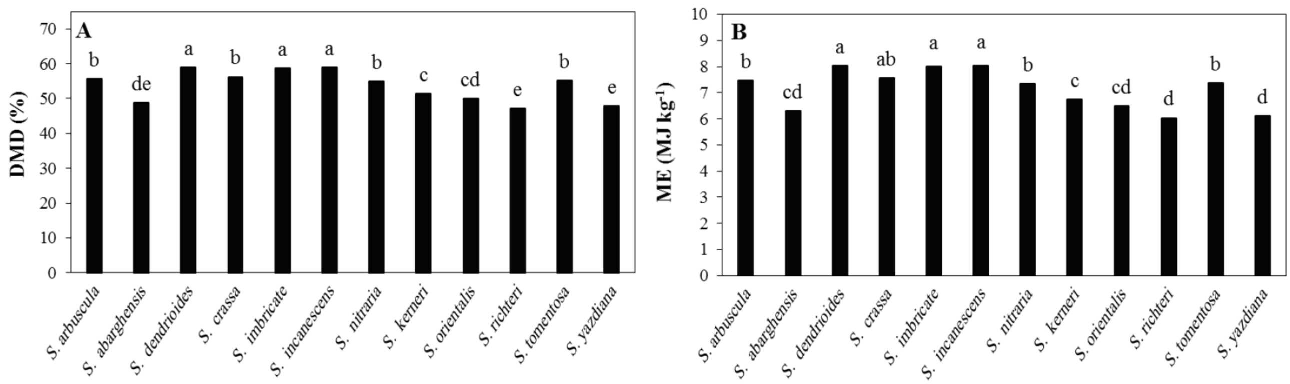

Figure 7. Variations in dry matter digestibility (DMD, A) and metabolizable energy (ME, B) among the *Salsola* species. Means with similar superscripts are not significantly different based on Duncan's multiple test (P ≤ 0.05, n = 4).

Table 3. The results of correlation analysis among the qualitative traits of forage.

	TWC†	ash	N	CP	ADF	NDF	DMD	ME
TWC	1.000							
ash	−0.505 ns	1.000						
N	0.453 ns	−0.625*	1.000					
CP	0.453 ns	−0.625*	1.000	1.000				
ADF	0.390 ns	−0.127 ns	−0.435 ns	−0.435 ns	1.000			
NDF	0.477 ns	−0.225 ns	−0.288 ns	−0.288 ns	0.963**	1.000		
DMD	−0.288 ns	0.018 ns	0.658*	0.658*	−0.990**	−0.932**	1.000	
ME	−0.288 ns	0.018 ns	0.658*	0.658*	−0.990**	−0.932**	1.000	1.000

ns: nonsignificant, * and **: significant at 5% and 1% probability levels, respectively
† TWC: tissue water content, N: nitrogen concentration, CP: crude protein, ADF: acid detergent fiber, NDF: neutral detergent fiber, DMD: dry matter digestibility, ME: metabolizable energy

due to greater accumulation of structural carbohydrates in cell walls, less water content of leaf and stem, thickening of the stem, less leaf to stem ratio, and woodiness (Arzani et al., 2004; Panahi et al., 2012).

Among the surveyed species, 25% were annual, and the rest were perennial. In general, the quality of annual species was better than that of the perennial species. The quality scores of the annual and perennial species were 1.94 and 3.31, respectively. As mentioned, the surveyed region is located in an arid region with very low precipitation (50–80 mm annual precipitations) and high evapotranspiration (2000 mm annual reference ET). In this region, soil evolution has been through anthropogenic activities, which lead to forming an anthropic epipedon as an agricultural surface horizon. Soil taxonomy in these regions has evolved from entisol to aridisol by till and cultivation over decades (Rabenhorst, 2016). Therefore, annual species are inhabited in the aridisol taxonomied soils, which are reflected in the presence of annual *Salsola* species (*S. crassa*, *S. incanescens*, and *S. nitraria*) in the Ashkzar and Ardakan regions (in the surveyed region) with aridisol taxonomy, whereas perennial species commonly grow in the regions with entisol taxonomy, such as the pristine soils (Rabenhorst, 2016).

The amount of foliage production could be the most important criteria for selecting a halophyte as a forage plant. Forage production was assessed via fresh and dry matter, in which *S. yazdiana* and *S. dendroides* were the greatest in these terms. Attia-Ismail (2018) reported that taking the antinutritional factors (i.e. saponin, flavonoids and alkaloids) into account, *Salsola* species have enough quantity and quality to feed by sheep, goats, and camels. In determining the quality of halophyte forage, salts content of soil has an important role that leads to less shoot proteins content (Nikalje et al., 2019; Temel and Keskin, 2019). Decreased CP values in saline conditions could be due to reduction in nutrient uptake from saline soils, which lead to reduced synthesis or enhanced degradation of proteins, low amino acid availability, and denaturation of enzymes associated with protein synthesis (Hedayati-Firoozabadi et al., 2020).

Despite the limited range (60%–70%) of TWC, it could be a proper and simple index for determining forage quality. *S. crassa* and *S. kerneri* had the greatest TWC, which could be an important and determining factor. In fact, greater TWC in succulent halophytes especially at flowering stage helps the plants to tolerate salt stress (Rasouli and Amiri, 2015). There is a relationship between water consumption of livestock and TWC of forage halophytes, such that higher TWC decreases water consumption by 25% in goats and 60% in sheep (Gihadi and El-Shaer, 1994). Although tissue water content also is an important and simple factor determining a well-qualified forage, little attention has been paid to it. Furthermore, it can be indicated that the plants grown in aridisol (Ashkzar and Ardakan in present research), where soil water availability is higher, usually have better performance (Gillson and Hoffman, 2007).

We found that *S. tomentosa* had the greatest ash content among the species; even ash content in this species was 2.1-fold greater than that in *S. incanescens*. However, in the east of Iran, Zare et al. (2019) showed that ash content was higher in *S. yazdiana* (5.81%) than *S. tomentosa* (4.22%). In the other study in the central desert of Iran, Abtahi and Zandi Esfahan (2017) reported that *S. arbuscula* at the flowering phase has the greatest ash (5.5%). However, the greatest ash content of *S. yazdiana* was found at the seeding stage (6.9%) in the Zare et al., (2019) study. The findings of Temel and Keskin (2019) in the northeast of Turkey indicated that maturation process reduced nutrient contents of *S. ruthenica*. Indeed, the ash content in the 92% of *Salsola* species is more than 10%. Generally, halophytes contain considerably high ash levels (Zare et al., 2019). It has been stated that Na^+, K^+, and Cl^- are the most frequent ions contributed in ash content of the halophytes (Waldron et al., 2020); however, species belonging to Amaranthaceae had acceptable free oxalates contents (Hedayati-Firoozabadi et al., 2020). This is focused on whether or not higher ash content in plant tissue is better for good quality forage. Increasing amount of ash could be attributed to greater uptake and accumulation of minerals from the soil (Masters et al., 2007). A significant positive relationship has been reported between the amount of ash and water absorbed in the native Australian shrubs (Norman et al., 2010). Therefore, the issue of forage quality of halophytes is always very complex due to their salt content in ash (Masters et al., 2007). In nonsaline conditions where the major part of minerals are nutrients, high ash could be considered an index for better quality of forage. However, this is not only true for halophytes in saline conditions, but could also be vice versa (Ranjbar and Pirasteh-Anosheh, 2020).

Another important issue is the role of ash in halophyte ability to survive in saline environments (Norman et al., 2013). The lower ash content (less than 13% in *S. incanescens*, *S. crassa*, and *S. abarghuensis*) indicated that not much salt is taken from the soil. Norman et al. (2010) reported a wide range of ash content among the shrub forage, between 4% and 35%. Chenopods have greater ash content and salt concentrations when grown in saline environments compared with halophytic grasses or legumes (Norman et al., 2013).

Although the reported values for forage quality of halophyte plants such as ash and fiber are acceptable and sometimes as high as some grasses, many precautions should be taken, especially with regard to ash (Masters et al., 2007); because more than 50% of the absorbed minerals are Na^+ and Cl^- ions, which are considered to be antinutritional agents (Nikalje et al., 2019). Nevertheless, in current research, there is a close negative relationship between ash content and CP values. In brief, high amount of ash content reduces forage value of halophytes. Since ash does not have energy value, energy for livestock feed is obtained from the digestion of organic matter (Norman et al., 2013). Furthermore, livestock need to use more energy to excrete salts in the ash, such as sodium chloride and potassium chloride (Masters et al., 2007; Norman et al., 2013). Attia-Ismail (2018) listed the content of some minerals in forage halophyte plants and indicated that these forages could be a source of some minerals to supply livestock demands. Temel and Surmen (2015), in saline rangelands of Turkey's Iğdır Plain, also reported greater mineral concentration in *Kalidium capsicum*, *S. dendroides*, and *S. nitraria* than other evaluated halophyte species; however, nutrients concentrations of all species were adequate for livestock requirements. In another region of Turkey, Temel and Keskin (2019) reported that *S. ruthenica* could sufficiently supply the daily nutrient requirements of grazing small ruminants. Interestingly, Rasouli and Amiri (2015) indicated that higher ash content in the flowering stage helps succulent halophytes to tolerate salinity. Of course, ash is not directly involved in salinity tolerance; however, it is a by-product of the salts accumulation in the vacuoles, and is involved in preventing plant toxicity and adjust osmotic potential.

In the current research, *S. incanescens* and *S. crassa* had the greatest CP values, while *S. tomentosa* and *S. yazdiana* had the least. The results of Panahi et al. (2012) showed the CP value was the greatest in *S. tomentosa,* and the least belonged to *S. orientalis*. Based on Nicol (1987), a plant containing CP < 5% is not suitable, 5% < CP < 7% is suitable, and CP > 7% is very suitable forage plant. Accordingly, all *Salsola* species had normal CP values; however, 83.3% of them were very desirable in terms of CP. Nitrogen content and CP values had a significant and positive relationship with DMD and ME indices. Assadi and Yazdi (2011) introduced CP, DMD, and ME as the most relevant factors for quality examination in forages. Zandi-Isfahan et al. (2010) reported varied CP, DMD, and ME between halophyte species and indicated that species containing more CP, DMD, and ME values had better forage quality (Zandi-Isfahan et al., 2010).

Salsola species had a varied amount of fibers. Acid detergent fiber primarily represents cellulose, lignin, and ash, while NDF indicates the total cell wall constituents, including hemicelluloses. Lignin content is considered a major cell wall constituent that limits nutrient availability for ruminants (Abd El-Rehman, 2008). Therefore, ADF and NDF are usually two indices used to compute digestibility and intake potential, respectively. As ADF and NDF are increased, forage quality is decreased (Hoffman et al., 2003). The least ADF and NDF, which means more desirable forage quality, were found in *S. dendroides*, *S. imbricata*, and *S. arbuscula*. Similarly, Arzani et al. (2004) stated the amount of ADF and NDF are varied among species due to different storage ability in seeds. As ADF increases, structural carbohydrates such as cellulose are accumulated in the cell wall, a process called lignification (Panahi et al., 2012).

The threshold values of ADF and NDF are different. By reviewing different reports (Nicol 1987; Arzani et al., 2004), it can be concluded that ADF > 45% is not suitable, 45% > ADF > 35% is suitable, ADF < 35% is very good, whereas NDF > 50% is not suitable, 50% > NDF > 40% is suitable, NDF < 40% is very good. Accordingly, 25% of *Salsola* species should be rejected due to high ADF; however, all the species were accepted in terms of NDF. Furthermore, 16.7%, 41.7%, and 16.7% of the species had poor, good, and premium ADF, respectively. On the other side, 25%, 33.3%, and 41.7% of *Salsola* species were good, premium, and prime in terms of NDF values.

Dry matter digestibility and metabolizable energy were varied among different *Salsola* species, as *S. dendroides* and *S. incanescens* had the greatest DMD and ME values. The ME actually is the amount of energy in the feed without lost energy in urine and feces (Attia-Ismail, 2018). Results of Panahi et al. (2012) where they that reported the greatest DMD and ME were obtained in *S. tomentosa* agree with our findings. However, their results where they reported that the least DMD and ME were related to *S. arbuscula* were in contrast with our findings. All *Salsola* species had DMD higher than 47% and ME higher than 6%, so as Nicol (1987) indexed, all *Salsola* species had optimum DMD and ME values. It has been reported that DMD < 40% is not suitable, 40% < DMD < 60% is suitable, and DMD > 60% is very good, also ME < 5 MJ kg^{-1} is not suitable, 5 MJ kg^{-1} < ME < 8 MJ kg^{-1} is suitable, and ME > 8 MJ kg^{-1} is very good. Although there is a belief that halophytes have low energy content, Ismail and Ismail (2017) indicated that energy content of halophytes are similar to those of common forage plants such as alfalfa, sorghum, and maize. Indeed, DMD and ME are decreased with the progress of plant growth in almost all *Salsola* species (Panahi et al., 2012). This reduction in DMD and ME is related to increasing structural carbohydrates in stems (Arzani et al., 2004). The results of the current research documented a close relationship between ADF and NDF with DMD and ME values. These two factors, DMD and ME, are among the most relevant factors for forage quality evaluation (Assadi and Yazdi, 2011; Ismail and Ismail, 2018).

Most vegetation in GSD includes halophytes and/or xerophytes, such that 365 species belonging to 151 genera and 44 families have been reported in saline ecosystems in GSD (Akhani, 2006), and *Salsola* was one the most important genera. However, based on the molecular phylogenetic analysis, Akhani et al. (2007) as well as Wen et al. (2010) introduced a new classification for these genera. They reported three new genera named: *Pyankovia*, *Kaviria*, and *Turania*, and resurrected four previously described genera (*Caroxylon*, *Climacoptera*, *Kali*, and *Xylosalsola*). Our results from the cluster analysis (Figure 8) revealed that the greatest similarity was observed between *S. abarghuensis* and *S. yazdiana*, about 88%, which have the most botanical affinity.

According to the ranking of *Salsola* species based on the measured qualitative traits, *S. incanescens*, *S. crassa*, and *S. dendroides* were considered the greatest forage quality, followed by *S. imbricata* (Table 4). At 75% similarity as a criterion, *Salsola* species could be grouped into five groups (Figure 8):

1. *S. abarghuensis*, *S. yazdiana*, *S. richteri*, *S. orientalis*, *and S. kerneri*
2. *S. crassa* and *S. incanescens*
3. *S. dendroides*, *S. imbricata*, and *S. arbuscula*
4. *S. tomentosa*
5. *S. nitraria*

Table 4. Ranking of the *Salsola* species based on the qualitative traits of forage.

Name	TWC†	ash	CP	ADF	NDF	DMD	General ranking
S. incanescens	1	1	1	1	2	1	1
S. dendrioides	4	2	2	1	1	1	2
S. imbricate	4	3	2	1	2	1	3
S. crassa	1	4	1	2	3	2	4
S. tomentosa	3	4	4	2	2	2	5
S. arbuscula	4	4	3	2	2	2	5
S. nitraria	3	5	2	2	3	3	5
S. kerneri	1	5	2	3	4	4	6
S. orientalis	3	6	2	3	4	4	7
S. richteri	2	6	3	4	5	5	8
S. abarghuensis	2	6	3	4	5	5	8
S. yazdiana	2	7	4	4	5	5	9

†TWC: tissue water content, CP: crude protein, ADF: acid detergent fiber, NDF: neutral detergent fiber, DMD: dry matter digestibility
n=4

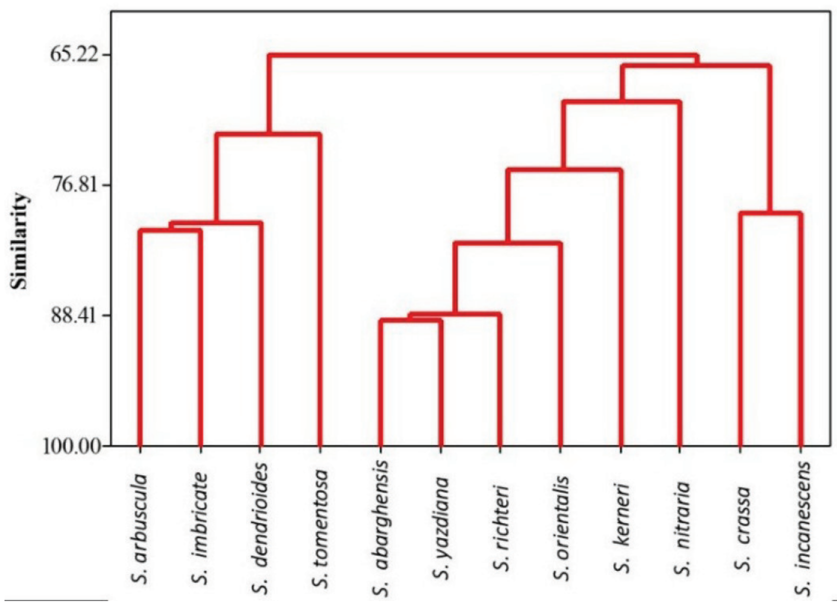

Figure 8. Dendrogram of cluster analysis for grouping of the investigated *Salsola* species.

5. Conclusion

Our results showed that investigated *Salsola* species had different growth habits and growth forms (33% annual, 67% perennial; 50% herbaceous bush, 50% shrub). *Salsola* species, in general, had low energy level and high protein content. Tissue water content could be a valuable and straightforward trait presenting an index for their salinity tolerance and forage quality. It was revealed that *S. incanescens* and *S. dendroides* were the species with the greatest quality forage, followed by *S. imbricata*. Therefore, these halophytes could be considered alternative forage plants in arid land regions, but due to the low energy level of *Salsola* species, they should be used in mix with other forages. The results also revealed that *S. abarghuensis* and *S. yazdiana* had 88% similarity, the two species with close origins. Content of minerals, preference value in rangelands, and presence in livestock diet are recommended for further research.

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