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Evaluation of saltgrass as a fodder crop for livestock

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Abstract: Farmland salinization due to unsustainable agricultural practices has become a worldwide problem. Salt-resistant forage crops, introduced at the primary stages of land reclamation, can provide fodder for livestock, thus adding economic benefit to the process. Saltgrass (*Distichlis spicata*), a wild halophytic grass species distributed in salt marshes in America, is occasionally grazed by livestock and wild animals. In attempts to domesticate this species, we evaluated and ranked the fodder potential of groups of accessions from several sites in North and South America. Ash content never exceeded 110 g kg^{-1}, even when plants were grown with salty water. Crude protein content was variable and averaged 116 g kg^{-1} of DM. Mean yield of metabolizable energy was 6.30 and 5.61 kJ g^{-1} DM for sheep and goats, respectively. Organic matter digestibility (*in vitro*) was higher in sheep than in goats (506 g kg^{-1} and 478 g kg^{-1}, respectively) for all saltgrass accessions. Differences in quality parameters were usually larger within than among groups of accession when sorted according to country of origin or ecosystem. Accessions from the South Atlantic coast of North America and from South America were superior in several parameters. South Atlantic coast accessions were relatively vigorous and were productive under saline conditions, as indicated by their relative growth rate (RGR) in small-scale experiments. Six outstanding saltgrass accessions were chosen for further examination. The results of the present study indicate that saltgrass holds considerable promise for selection and suggest that efforts should continue to identify and characterize additional saltgrass ecotypes.

Keywords: saltgrass; *Distichlis spicata*; accessions; fodder; leafiness; digestible organic matter; metabolizable energy yield; saline

INTRODUCTION

Almost 1 billion hectares of land, which accounts for 10% of the earth's surface, are affected by salinity and over 50% of all irrigated lands have a salinity problem.[1] Most crop plants are glycophytes or non-halophytes that do not express their full genetic potential for growth, development and productivity under salt stress.[2,3] Primary salinization, that is salinization resulting from natural causes, contributes significantly to the global process. However, salt-affected soils are most often the result of human activity, mainly through mismanagement of irrigation systems.[4] In irrigated lands, salinization of the soil occurs where evapo-transpiration rates exceed irrigation rates or where drainage capacity of the soil is low. In most arid and semiarid lands, irrigation that is less in volume than evapo-transpiration is often practiced because of water scarcity. The diminishing supply of good-quality water for irrigation often results in the use of low quality water, high in salinity.[5,6] In addition, low awareness of these problems leads to poor drainage infrastructure, which in turn accelerates soil salinization processes.[4]

The environmental problems of the Aral Sea basin has demonstrated how salinity can be the cause of a food security problem.[7] Livestock production, mainly Karakul sheep, goats and Asian camels, is of major economical importance in the Aral Sea basin. Based solely on grazing, animal performance can be low due to low crude protein and low metabolizable energy intake from the local herbage and shrubs.[8]

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Salt-resistant forage crops can be introduced to salinized lands to serve as a primary stage of the reclamation of former agricultural lands and also provide alternative forage for livestock.

Saltgrass (*Distichlis spicata* L, Poaceae) has potential for being a salinity-tolerant forage crop.[9–11] However, domestication of saltgrass requires a long procedure of selection and breeding, as it is still a wild plant species. In this study, we evaluated a broad collection of saltgrass accessions as fodder crops to select candidate accessions for future breeding programs. Fodder quality of a crop is complex to determine because it involves parameters such as yield, chemical composition, digestibility and palatability. Desirable traits, namely high contents of crude protein (CP), metabolizable energy (ME), organic matter digestibility (OMD) and dry matter (DM), low contents of ash and neutral-detergent fiber (NDF), and a high level of leafiness (LFS) were used to define a quality index (QI) in order to assess the potential of a saltgrass accession to become a forage crop. We also sought possible relationships between geographical origin and quality traits that might guide collection missions aimed at expanding the available saltgrass germplasm. In additional, growth response under a range of salinity levels was used as an indication for the potential performance of selected saltgrass accessions in saline environments.

MATERIALS AND METHODS

Plant material

Plants were collected from several locations in the USA and South America (Table 1). Most of the plants were collected from the wild on May and June 1998. In the USA, plants were collected from a few widely dispersed sites (distances between sites ranged from 10^2 to 10^4 km). In California, several ecotypes were contributed from a collection of saltgrass from various known sites in the Central Valley (Dr Dyer, USDA, Soil Conservation Service, Lockeford, CA). Several ecotypes that originated in other parts of the USA were obtained from a collection in Delaware (Professor Gallagher, College of Marine Studies, University of Delaware, Lewes, DE). For South American ecotypes, each plant was the only representative of a region.

At each site, several (2–5) live rhizomes were dug out, washed from soil and organic matter, wrapped with wet paper and kept in plastic bags in a cool-box (5–15 °C) for 2–5 weeks before being planted in pots containing perlite and peat (1:1). Plants were kept in quarantine for 5 months before being transferred to a greenhouse at Ben-Gurion University of the Negev (Beer Sheva, Israel). When plants were established, one rhizome from each bucket representing a different location was cut and replanted individually in a 1-liter pot and was considered as an accession, as confirmed by

Table 1. Sampling sites of saltgrass ecotypes[a]

Ecotype	Country/state	County/location	I/S	Ecosystem
CT1,CT3	Connecticut	New London/Barn Island	S	TMS
CT2	Connecticut	New London/near Mystic	S	TMS
DE1,2,4,5	Delaware	Sussex/near Lewes	S	TMS
DE3	Delaware	Lewes, UDE collection	S	UO
GA1-8	Georgia	McIntosh/Sapelo Island	S	TMS
AL1	Alabama	Mobile/Deer River	S	TE
AL2	Alabama	Mobile/Dauphin Island	S	TMS
AL3-6	Alabama	Mobile/Heron Bay	S	TMS
UT1	Utah	Goshen	I	ISM
UT2	Utah	Big Salt Lake	I	ISM
UT3	Utah	Vernon	I	RB
UT4	Utah	Jordan River	I	RB
CA1	California	Mendota	I	UO
CA2	California	Riverside/Salton Sea	I	ISM
CA3,13,16	California	Kings/Tulare Lake-bed	I	RB
CA4,14	California	S. Luis Obispo/Soda Lake	I	ISM
CA5,17	California	Fresno/Tranquillity	I	RB
CA6	California	S. Luis Obispo/Morro Bay	S	TE
CA7	California	Merced/Hartley Slough	I	ISM
CA8,15	California	San Joaquin	I	RB
CA9	California	San Diego/Mission bank	S	RB
CA10	California	Tulare/Alpaugh	I	RB
CA11	California	Monterey/Elkhorn Slough	S	TE
CA12,18	California	Kings/Kettleman city	I	RB
CH1	Chile	Tamarugal	I	ISM
CH2	Chile	Juta Valley	I	ISM
Arg1	Argentina	Trelew Chubut	I	RB, TE
Arg2	Argentina	Chinchina La Rioja	I	ISM

[a] I — Inland ecotypes; S — seashore ecotypes; TMS — tidal marsh on seashore; UO — uncertain origin; TE — tidal estuary; ISM — inland saline marsh or lake, seasonally inundated; RB –river or ditch bank, seasonally inundated.

random amplification of polymorphic DNA (RAPD) analysis.[12]

Accessions of three replicates were randomly placed and grown outdoors in pots containing perlite and peat (1:1), drip-irrigated with fresh water (1.5 $dS\,m^{-1}$) and on-line liquid fertilizer (Sheffer 5:3:8 (N:P:K, respectively), Fertilizers & Chemicals Ltd, Haifa, Israel) supplied at 50 ppm N. The above-ground portion of the plants was harvested on July 2002, before the occurrence of any signs of bloom, ie of head emergence. Growth was for three months starting April 2002.

Measurements

Seeking tools to discriminate between saltgrass accessions and evaluate their potential for herbivore use, we defined leafiness as 'LFS', which included additional descriptive parameters. Shortly before harvest, leaf/whole-canopy ratio of each accession, shoot softness, vitality and lushness were determined by visual estimation and each parameter was ranked from 1 (low) to 10 (high). The mean of these estimates for each succession was used as a measure of LFS. These evaluations were made among the saltgrass accessions, and not against other grass species.

Harvested plant material was dried in an oven at 50 °C to constant mass to determine dry matter content. Dry matter was ground to fine powder, which was used for further analyses. Samples were analyzed for nitrogen (N) content by the Kjeldahl method[13] and for ash by burning at 550 °C.[14] Crude protein was calculated as 6.25 × N. Neutral detergent fiber (NDF) content was determined as described by Van Soest *et al*,[15] applying a Fiertec System M6 (Tecator, Haganas, Sweden). All measurements were made in triplicate.

Organic matter digestibility and metabolizable energy yield of the saltgrass samples were estimated *in vitro* using the Hohenheimer Gas Method.[16,17] In this method, the gas produced in anaerobic fermentation of substrate is used to predict the nutritive value. Rumen liquor and particulate matter were collected before morning feeding via a rumen fistula from two sheep and two goats fed on a roughage diet of mainly poor quality wheat straw and some lucerne hay; the liquor was homogenized, strained and filtered through glass wool. Incubation media was prepared as described by Menke *et al*.[16] Samples, each of 200 mg DM, were incubated in triplicate in 100-ml calibrated glass syringes in which 30 ml of the incubation media was added. The glassware was kept at 39 °C and flushed with CO_2 before use and the mixture was kept stirred under CO_2 at 39 °C. Gas production, as determined by piston movement, was measured over 24 h after correcting for gas production due to rumen fluid alone. Gas production (GP, ml per 200 mg DM) and crude protein (CP, $g\,kg^{-1}$ DM) were used to estimate organic matter digestibility (OMD) and *in vitro* metabolizable energy (IVME) yield as follows:[16,17]

$$\text{OMD}\ (\%) = 24.91 + 0.722\,\text{GP} + 0.0815\,\text{CP}$$

and,

$$\text{IVME}\ (\text{kJ}\,\text{g}^{-1}) = 2.20 + 0.136\,\text{GP} + 0.0057\,\text{CP}$$

Calculations

To rank the saltgrass accessions, a modified version of the method described by Conklin *et al*[18] was adopted. The mean of each quality parameter (DM, ash, CP, NDF, ME and LFS) was subtracted from the value obtained by each accession and the result was divided by the SD of the mean to produce a specific parameter index. For example, the equation of the IVME index took the form:

$$\text{IVMEI}_x = (\text{accession IVME} - \text{mean IVME})/\text{SD}$$

In this case, calculations were made for sheep and goats separately, but the average of IVMEI_x for sheep and goats was calculated (MEI_x) and used for further determination of the quality index (QI). QI was calculated for each saltgrass accession as follows:

$$\text{QI} = \text{DMI}_x - \text{AshI}_x + \text{CPI}_x - \text{NDFI}_x + \text{MEI}_x + \text{LFSI}_x + 10$$

Growth response to salinity

Ramets of each accession were cut and rooted in water culture. Accessions that displayed high rates of rooting and of vegetative growth resumption were further examined for their growth response to salinity. Uniform plants ($n = 36$) of each selected accession were transferred to a glasshouse under full sunlight to grow in water culture in 1-liter containers. Salinity level was gradually increased to produce six salinity treatments (1.5, 10, 20, 30, 40, 50 $dS\,m^{-1}$) obtained by $NaCl$:$CaCl_2$ solution at 3:1 ratio, respectively. The experimental design included six blocks for each selected accession. The growth medium containing fertilizers (N:P:K, 5:3:8, respectively, at 50 ppm N) was maintained at a constant volume by adding fresh water when necessary, and was replaced weekly. Aeration with a bubbling system did not have a noticeable influence on growth and, therefore, was discontinued. Plant growth (whole plant fresh weight) was recorded weekly during 10 weeks in summer. Relative growth rate (RGR) became stable at week 6 and thereafter. Therefore, the average RGR of weeks 6–8 was chosen as an indicator of growth response to salinity. Ash content was determined at the end of the experiment (10 weeks), as described above.

Statistical analyses

Statistical differences between groups of saltgrass accessions (country of origin) or between ecosystems of origin (inland *vs*. seashore) were determined using a one-factorial Analysis of Variance (ANOVA) followed by a Fischer's PLSD test. PCA was exercised on the covariance matrix of all quality parameters or on the most important two of them (CP and ME) with the

MVSP package[19] in order to obtain a two-dimensional ordination pattern of saltgrass accessions using various geographical or eco-geographical parameters for sorting.

RESULTS

Forage quality of saltgrass accessions

Mean DM, ash, and NDF contents for all saltgrass accessions examined in the present study were 431, 68.3 and 720 $g\,kg^{-1}$, respectively (Table 2). Crude protein content averaged 116 $g\,kg^{-1}$ and ranged from a low of 69 $g\,kg^{-1}$ to a high of 189 $g\,kg^{-1}$. *In vitro* metabolizable energy yields and organic matter digestibility were higher in sheep rumen fluid than in goat rumen fluid for all saltgrass accessions. Mean metabolizable energy yield for sheep was $6.30 \pm 0.66\,kJ\,g^{-1}$DM, ranging between 4.71 and 8.63 $kJ\,g^{-1}$ DM, whereas in goats, the mean was $5.63 \pm 0.75\,kJ\,g^{-1}$ DM, ranging from 3.21 to 6.79 $kJ\,g^{-1}$ DM. Mean organic matter digestibility (OMD) was $506 \pm 26.4\,g\,kg^{-1}$ for sheep and $478 \pm 25.5\,g\,kg^{-1}$ for goats. LFS averaged 6.96 with large differences between accessions within and, especially, among groups from distinct origins.

PCA analyses (that included all quality parameters) of all saltgrass accessions were carried out to reveal possible clustering patterns according to countries or ecosystem (seashore or inland) of origin. GA accessions clustered separately whereas all other accessions were scattered randomly (Fig 1A). No clustering of inland or seashore accession was observed, despite the segregation of the seashore GA group from the generally mixed scattering (Fig 1B).

In a simpler analysis, where only two quality parameters (CP and ME) were used (Fig 2A), most GA accessions grouped together at the upper left quarter of the array (negative CPI_x and positive MEI_x). In the same analysis, three of four South American accessions were located at the upper right quarter, indicating positive CPI_x and MEI_x. All AL accessions were at the left half of the CP axis (negative CPI_x). The CA accessions, which were the largest group, were scattered throughout all quarters similar to the other accessions (Fig 2A). When analyzed according to inland or seashore origin, about 70% of seashore accessions were left of the CP axis (negative CPI_x), while 70% of the inland accessions were on the right side of the CP axis (Fig 2B). However, the ME axis did not have any discriminating effect on either of the two groups.

Dissection of all quality criteria according to the country of origin revealed no significant differences for DM, ash and NDF contents (Table 2). However, significant differences were found for CP, ME, OMD and LFS. When ranked by quality index (QI), the GA group was significantly better than all groups except for the South American group (Table 2). The GA group obtained the highest LFS, had reasonably high ME and OMD but the lowest CP mean, while the South American group had the highest CP, ME and OMD but a relatively low LFS. All other groups had QI values lower than 10, indicating relatively poorer quality (Table 2); however, individual accessions exhibited relatively high values for one or more parameters. Comparison of inland versus seashore accessions showed a significant advantage in LFS for seashore ecotypes, higher CP content for inland accessions, and no significant difference for all other quality parameters (Table 2). The top six ranked saltgrass accessions, according to QI, are presented in Table 3.

Growth response to salinity

Most saltgrass accessions that were examined under six different levels of water salinity displayed a

Table 2. Dry matter (DM), ash, crude protein (CP) and neutral detergent fiber (NDF) contents, leafiness (LFS), and *in vitro* metabolizable energy (ME) and organic matter digestibility (OMD) yields (using sheep and goat rumen fluids) of 48 saltgrass accessions originating from various regions (states; $df = 6$) or ecosystems (seashore versus inland; $df = 1$) of the American continent

		DM	Ash	CP	NDF	ME sheep	ME goats		OMD		
Origin	*n*	($g\,kg^{-1}$)				($kJ\,g^{-1}$ DM)		ME average	($g\,kg^{-1}$)	LFS	QI
GA	8	439	61.0	95.6	736	6.65	6.44	6.55	505	8.38	11.6
S America	4	405	80.6	143.9	728	7.03	6.52	6.64	538	7.25	10.4
DE	5	432	71.5	130.3	712	6.44	5.45	5.95	493	5.60	9.4
AL	6	454	67.3	98.4	777	6.22	5.90	5.88	466	8.33	9.8
CT	3	437	72.4	142.7	760	5.98	5.36	5.67	445	7.67	9.1
CA	18	428	67.8	119.6	693	6.22	5.37	5.79	480	6.33	9.9
UT	4	411	67.3	127.0	700	5.47	5.20	5.34	462	5.75	8.6
		NS	NS	***	NS	*	***	**	**	***	*
Seashore	27	437	65.6	109.6	728	6.35	5.82	6.09	490	7.32	10.2
Inland	21	424	71.0	127.0	705	6.23	5.52	5.88	488	6.40	9.8
		NS	NS	**	NS	NS	NS	NS	NS	*	NS
Total mean		431	68.3	115.7	720	6.30	5.63	5.92	485	6.96	10.0
SD		34.7	10.6	22.2	529	0.66	0.75	0.71	38.1	1.30	2.04

NS, not significant.

*, **, and *** indicate for significant differences at $p < 0.05$, 0.01, and 0.001, respectively.

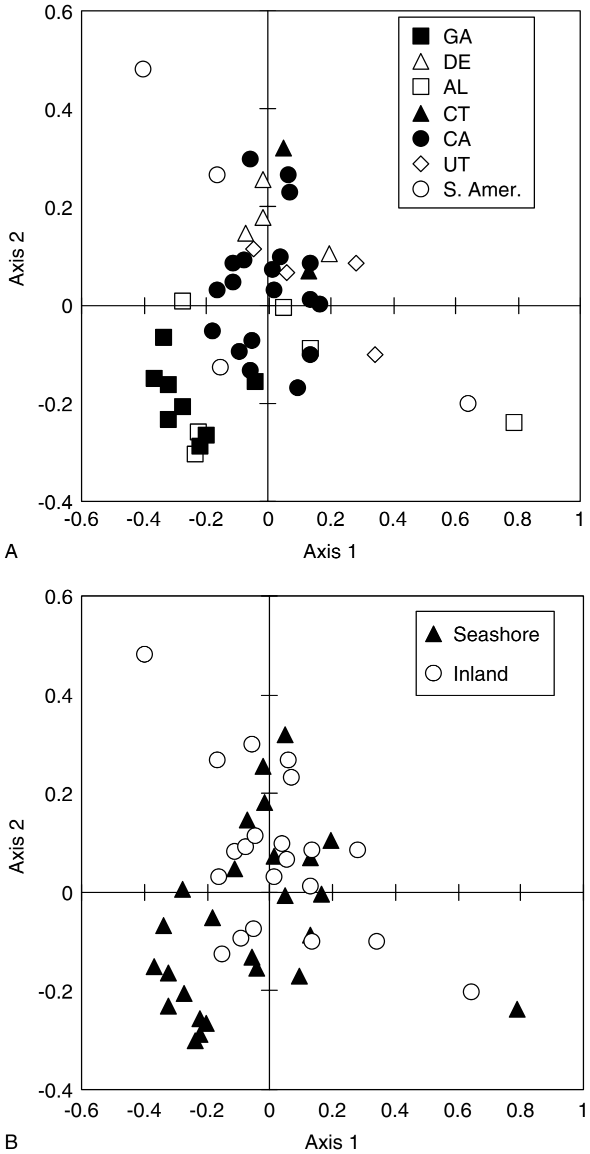

Figure 1. PCA analyses of fodder quality results (all quality parameters included) of 48 saltgrass accessions. A: Accessions are sorted according to country of origin. B: Accessions are labeled according to their ecosystem of origin.

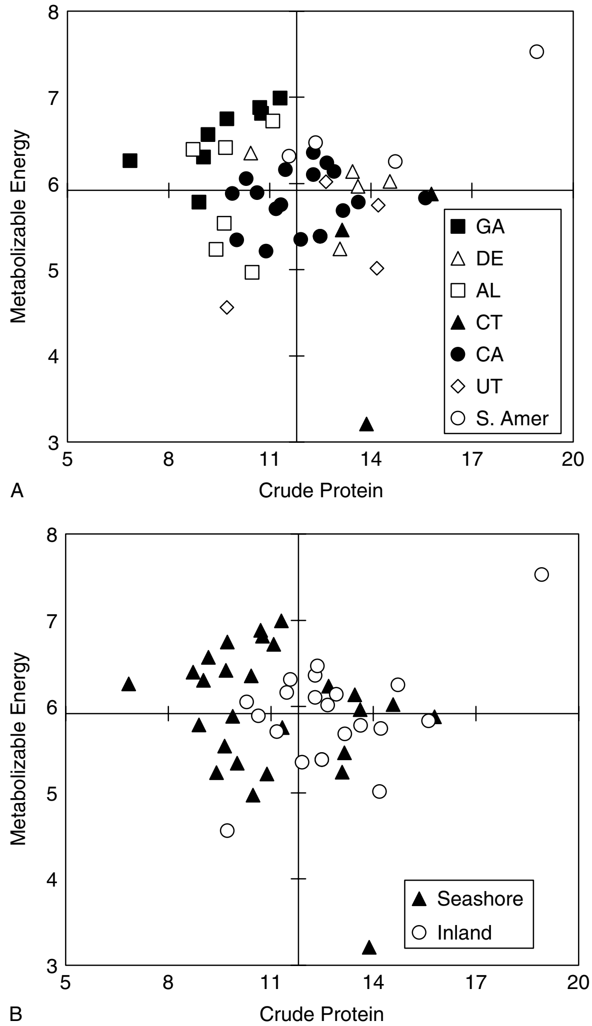

Figure 2. Cluster analyses of 48 saltgrass accessions according to crude protein versus metabolizable energy contents. Accessions are labeled according to country of origin (A) or ecosystem (B).

similar pattern of RGR response to salinity (Fig 3). The highest RGR was obtained when grown with fresh water ($1.5\,dS\,m^{-1}$) but it declined sharply at $10\,dS\,m^{-1}$, and decreased moderately or became stable as salinity was increased up to $50\,dS\,m^{-1}$. In a few exceptional accessions from DE and CA, the RGR pattern was different, beginning its decline only at $30\,dS\,m^{-1}$, yet their initial RGR at fresh water were usually very low.

GA and AL accessions had the highest RGR throughout all salinity levels (including fresh water), with a relatively stable performance ($>0.008\,day^{-1}$) between 20 and $50\,dS\,m^{-1}$. The South American accessions displayed the lowest RGR values ($<0.004\,day^{-1}$), indicating low vigor under highly saline environments ($>20\,dS\,m^{-1}$). From the six accessions selected (Table 3), five were examined for RGR

Table 3. Forage quality properties of the best six saltgrass accessions (Acc), ranked according to the quality index (QI)

Acc	Origin	DM	Ash	CP	NDF	ME	OMD	LFS	QI
		($g\,kg^{-1}$)	($g\,kg^{-1}$ DM)			($kJ\,g^{-1}$ DM)	($g\,kg^{-1}$)		
CH1	Tamarugal, Chile, S America	419	77	189	706	7.53	584	7	14.65
GA2	Sapelo Island, Georgia	436	60	113	679	6.99	536	9	14.59
GA6	Sapelo Island, Georgia	449	70	107	667	6.88	528	9	13.85
GA7	Sapelo Island, Georgia	436	61	92	701	6.57	504	9	12.53
DE3	Lewes, Delaware	501	72	146	672	6.02	505	5	12.50
CA17	Tranquility, California	437	70	136	648	5.78	488	7	12.03

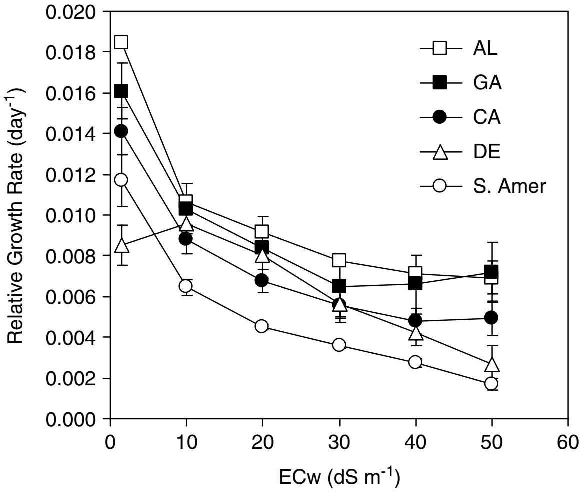

Figure 3. RGR (relative growth rate) response to water salinity level of saltgrass plants with five different origins. Bars above and below the symbols indicate ±1 SE.

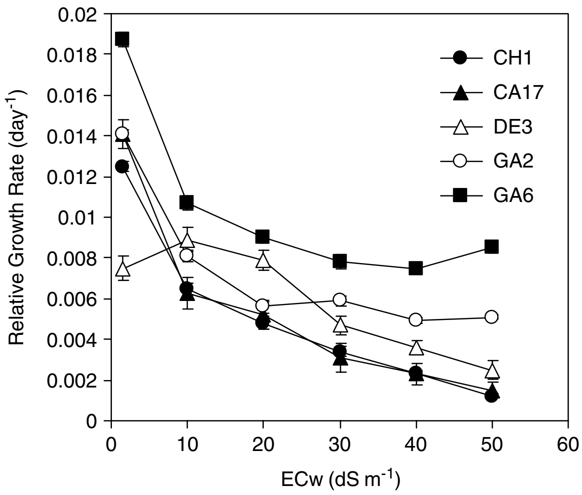

Figure 4. Comparison of RGR response to water salinity level between five accessions (out of six) that displayed the highest quality index (QI) among our saltgrass collection (see also Tables 2 and 3). Values represent means (±SE) of six replications per accession per salinity level.

response to salinity (Fig 4). GA6 showed obvious superior performance at both fresh and saline conditions, even at very high salinity levels. GA2 displayed a similar pattern but at much lower RGR levels. DE3 had substantially low RGR when grown with fresh water, however, it remained stable as salinity was increased to $20\,\mathrm{dS\,m^{-1}}$ and declined sharply at $30\,\mathrm{dS\,m^{-1}}$ and above. CA17 and CH1 displayed the poorest performance even at $10\,\mathrm{dS\,m^{-1}}$.

DISCUSSION

Many trials have been carried out for the purpose of developing halophytes into economically viable crops[20] (see also www.biosalinity.org). Salt accumulation in the aboveground parts of the plant appears to be a crucial parameter, for it limits further development of apparently promising salt-tolerant fodder plant species. For instance, *Atriplex* species were found to be highly productive with seawater irrigation,[11] nevertheless *in vivo* feeding trials showed that *Atriplex* was a poor fodder source due to high ash content, low intake by livestock and low nitrogen digestibility.[21] Saltgrass was not as tolerant as the *Atriplex* species or as other chenopods but it did not concentrate salts in leaves.[22] This was confirmed by Marcum,[23] who examined salt-resistant members of the Chloridoideae sub-family of grass and found saltgrass as the lowest salt-accumulator under high salinity levels. In the present study, ash content of saltgrass averaged $68\,\mathrm{g\,kg^{-1}}$ (Table 2) and, when grown under high salinity levels, it never exceeded $11\,\mathrm{g\,kg^{-1}}$ (Table 4), which was considerably less than in *Atriplex* species (which are usually above $200\,\mathrm{g\,kg^{-1}}$ ash). Therefore, and at least based on the criterion of salt content in edible plant parts, saltgrass seems potentially suitable as a forage species.

Table 4. Ash content ($\mathrm{g\,kg^{-1}}$ DM) of selected saltgrass accessions grown during 10 weeks in water culture at four salinity levels[a]

	Salinity level ($\mathrm{dS\,m^{-1}}$)			
Accession	1.5	10	30	50
AL1	65 ± 2.2	78 ± 4.1	90 ± 2.9	98 ± 3.1
AL3	63 ± 2.8	79 ± 5.0	92 ± 4.3	94 ± 4.9
Arg1	84 ± 3.1	99 ± 4.4	102 ± 3.7	107 ± 3.1
Arg2	86 ± 3.6	94 ± 3.5	96 ± 3.2	102 ± 3.8
CA1	72 ± 2.4	88 ± 2.9	103 ± 3.5	105 ± 3.7
CA4	66 ± 2.5	84 ± 4.2	89 ± 4.1	89 ± 4.7
CA13	70 ± 1.9	90 ± 3.3	97 ± 3.6	96 ± 4.0
CA17	68 ± 2.6	85 ± 4.4	94 ± 4.0	94 ± 3.8
CH1	79 ± 3.4	94 ± 3.6	103 ± 4.4	106 ± 5.6
CH2	75 ± 3.1	95 ± 4.8	100 ± 5.9	99 ± 4.1
CT2	71 ± 2.9	84 ± 3.1	90 ± 3.7	92 ± 4.2
DE1	75 ± 1.8	88 ± 2.9	96 ± 3.5	99 ± 3.3
DE3	74 ± 2.5	82 ± 2.6	90 ± 3.0	91 ± 3.4
GA2	56 ± 1.4	77 ± 1.9	86 ± 2.2	88 ± 2.9
GA3	62 ± 1.6	79 ± 2.4	89 ± 2.8	90 ± 3.2
GA6	66 ± 1.9	76 ± 1.8	81 ± 2.7	82 ± 3.5

[a] Values are means ± SE of six replicates.

Besides low salt accumulation, protein content and metabolizable energy yield are of primary importance when the feed-value of potential fodder is determined.[24] In wild saline environments, saltgrass is grazed readily by livestock[9,10] and wildlife species.[25,26] However, apparently, the contribution of saltgrass to livestock diet is low.[10] In the present study, the mean values of CP, OMD, and IVME (Table 2) put saltgrass at an intermediate range of fodder quality: above straw but below customary forage crops such as alfalfa. Nevertheless, the variability among accessions was considerable, and many accessions displayed traits in the high quality range. For example, 14 accessions (out of 48) exhibited CP values higher than $13\,\mathrm{g\,kg^{-1}}$, 17 had IVME yield (for sheep) above $6.5\,\mathrm{kJ\,g^{-1}}$ DM, and 20 accessions contained more than $520\,\mathrm{g\,kg^{-1}}$ OMD.

This high variability is not surprising because saltgrass is a wild species at the beginning phase of domestication, which typically involves seven phases.[27] Intra-specific variation among saltgrass ecotypes has been reported in the ecological literature for a number of parameters that included growth rate, rhizome morphology and response to disturbance[28] as well as in response to chloride and sulfate salinity and to selenium soil contamination.[29,30] Analyses of genetic and morphologic diversity in our broad collection of saltgrass accessions revealed that in spite of the dominance of clonal reproduction, genetic variability within a population was larger than among populations.[12] We used similar statistical techniques in the present study to evaluate associations between fodder quality traits and country or ecosystem of origin (Figs 2 and 3). Our results demonstrated that variability within a group of origin was high, which supports the conclusions of Ram *et al*[12] that initial selection of saltgrass should rely mostly on performance of individual accessions.

Origin of accessions was able to discriminate among groups of accessions with GA accessions having a significantly higher quality index (QI) than the other groups (Table 2). This discrimination was mainly due to high LFS and ME despite low CP content. In addition, CP and LFS were the parameters in which inland and seashore accessions differed significantly (Table 2 and Fig 2B). Using LFS as an important characteristic in saltgrass supports previous work that 'leafiness' (meaning the ratio of leaves to the entire canopy ratio) can be used as an indicator of fiber content and, consequently, as an instant tool to evaluate fodder quality.[31,32] Indeed, a high fiber content was the major drawback of a single saltgrass accession (Seabrook, DE) examined by Pasternak *et al*.[11] High fiber contents (NDF ranging between 60 and 83%) were found for saltgrass in the present study (Table 2); however, in contrast to expectations, it neither correlated with 'leafiness' ($R^2 = 0.13$) nor with 'LFS' ($R^2 = 0.25$). This may be due to some accessions having relatively large but stiff and spiky leaves while others, with small leaves, were much softer. Therefore, in saltgrass at least, fiber content should be determined directly. Although LFS is subjective, it provides a useful discrimination tool. However, the exact relationship of LFS to herbivore preference needs to be investigated further.

Vigor may be a good indicator of the productive potential of saltgrass as a crop in fresh water. Relative growth rate (RGR) is a sensitive physiological parameter for vigor because it ignores initial differences in plant size, on one hand, while a small difference in RGR builds a large difference in biomass over a relatively short period, on the other hand. Difficulties in obtaining sufficient numbers of plants restricted experiments to fewer accessions. However, differences in RGR were observed between accessions on the basis of country of origin (Fig 3). With fresh water, accessions originating from the South Atlantic coast of USA exhibited higher RGR values than other accessions, which agrees with the results for LFS. Nevertheless, if grown in saline environments, selected accessions should exhibit high, stable performance at various salinity levels rather than just survive. Despite a general sharp decline in RGR with increased salinity (Fig 3), the AL and, to a lesser extent, GA accessions again demonstrated superior RGR values under highly saline conditions compared with other groups. It is noteworthy that the performance of the DE accessions tended to improve under mild salinity levels but decreased sharply when salinity was high. This is in agreement with previous findings of Gallagher,[33] though it appears to be an exception to the general pattern of saltgrass growth-response to salinity.

Six saltgrass accessions with the highest QI values were selected for further studies (Table 3). The QI as calculated in our study does not use a weighted scale for parameters. With different selection goals, parameters could be weighted differently, which may change the ranking results. Three out of the six accessions originated from Georgia, USA. However, the protein contents in the GA group must be improved, perhaps through enhanced fertilization, which is under current investigation. Furthermore, the relatively poor performance of the one accession from South America under saline conditions (Fig 4) does not mean that all accessions from South America are poor performers. Additional collections of saltgrass from South America are needed to more accurately evaluate their potential as a forage crop.

Being a pioneer plant, saltgrass can be useful in the initial steps of reclaiming salinized former farmland.[22,33] Because of its poor ability to compete with other plant species when salinity declines,[34,35] saltgrass can be easily replaced with other more valuable crops. These features strongly support earlier opinions[36] that saltgrass is suitable for domestication as a forage crop for saline environments. Our selected saltgrass accessions are currently being examined in small field trials in Turkmenistan and in Israel. Additional efforts to identify and characterize new saltgrass ecotypes should be continued.

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