Analysis of Russian thistle (*Salsola* species) selections for factors affecting forage nutritional value

JAMES H. HAGEMAN, JAMES L. FOWLER, MARGARET SUZUKIDA, VIRGINIA SALAS, AND ROXANNE LECAPTAIN

Abstract

The need for forage plants that are productive in, and adapted to, semiarid conditions prompted us to examine the range and independence of assortment of nutritional qualities of wild stands of Russian thistle (*Salsola* species). Seventy selections from a 5-state area of the southwestern United States were planted in observational plots and analyzed for crude protein, acid detergent fiber, lignin, nitrate, water-soluble oxalate, in vitro digestibility, and ash content at 2 stages of maturity. Values on a dry matter basis of crude protein (5.4 to 22.3%), acid detergent fiber (20.1 to 48.8%), acid detergent lignin (3.1 to 10.4%), nitrate (0.1 to 5.1%), water-soluble oxalate (0.2 to 9.1%), plant height (40 to 180 cm at second harvest), stage of development (midbloom to complete seed development at second harvest), and degree of prickliness (soft to extremely prickly at second harvest) were determined for each of the 70 selections at 2 harvest times. The color, branch density, and degree of leafiness were examined at the second harvest only. Values for in vitro digestibility (45.1 to 66.3% organic matter disappearance) and ash (12.7 to 30.5% of dry wt) were determined for a subset of 22 samples. About 10% of the selections had a composite of properties which would suggest they they would make moderate to good forages.

Key Words: crude protein, in vitro digestibility, acid detergent fiber and lignin, nitrate, water soluble oxalates

Authors are professor, Department of Chemistry, associate professor, and research assistants, Department of Agronomy and Horticulture New Mexico State University, Las Cruces 88003.

The assistance of Professor M. Southward in performing the statistical analysis and of R. Estell II in performing the in vitro digestibility assays are gratefully acknowledged.

Research was funded in part by the NMSU Plant Genetic Engineering Laboratory Grant 1-4-24255.

Manuscript accepted 4 November 1987.

Plants of the annual, ruderal forb *Salsola iberica* (or *S. pestifer* or *S. kali,* see Beatley 1973) and related species can provide forage for grazing cattle for 8 months out of the year on southern New Mexico ranges (Nelson et al. 1970), and are considered fair to excellent forages on western range lands (Esplin et al. 1937, Cook et al. 1954, Nelson et al. 1970). During periods of drought, Russian thistle (*Salsola* species) hay has provided major sustenance for cattle in the western United States. For example, farmers in western Kansas harvested 400,000 tons of Russian thistle in 1934 for silage and hay (Cave et al. 1936). Potential nutritive value of Russian thistle plants for preparing hay or silage has been recognized for some time (Bailey and Gustafson 1902, Cave et al. 1936, Donaldson and Goering 1940), and its use in preparing standard diets for farm animals has been described (Harris et al. 1968). More recently, its nutritional potential was confirmed with plants grown under controlled conditions in the greenhouse (Farmer et al. 1976) and under cultivation in the field (Fowler and Hageman 1978, Hageman et al. 1978). Little effort has been expended in the United States to improve rangelands by deliberately introducing selected plants of the genus *Salsola,* but work has been done in the Soviet Union to promote the growth of several species including *Salsola orientalis* (Abdraimov 1981). Worldwide importance of making more efficient use of arid and semiarid lands for food production by introducing and improving new plant species has been discussed by a number of authors (McKell 1975, Upchurch 1981, Hinman 1984).

To achieve our long-range goal of domesticating *Salsola* for use as a forage, it was essential to know whether positive and negative nutritional factors assort independently in plant populations already established in the desert Southwest. No systematic studies have been done to assess the range of potential nutritive values, or potentially toxic components such as nitrate or oxalate, of the 3 species of Russian thistle (*S. iberica, S. paulsenii,* and *S. collina*) described by Beatley (1973), and introgrades thereof, in spite of the fact that these are widely distributed and grazed by livestock in the semiarid southwestern United States.

We describe here physical, chemical, and biological properties of plants from 70 selections of *Salsola* species gathered over a 5-state area and grown under uniform, irrigated field conditions. Results suggest considerable genotypic and phenotypic variation exists within these populations, and positive and negative characteristics of nutritional significance assort independently. Thus, it should be possible to obtain improved forage species of *Salsola* by traditional selection and breeding methods. Several selections had composites of properties which should make them good forage plants, whereas many more of the selections would be predicted to be fair to poor forages.

Materials and Methods

Seeds of 514 individual plant selections were collected from mature *Salsola* plants from 5 western states (Arizona, California, Nevada, New Mexico, and Texas) between November 1983 and March 1984. Plants with a wide range of phenotypic variability, and from a large number of different environmental sites were selected. Seeds were harvested by cutting a single plant at its base and threshing it by hand on a large aluminum pan (1 m^2). Seeds and debris were stored in paper bags until they were cleaned using a Clipper seed cleaner. Cleaned seeds were stored at 22° C until planted. Seeds were planted at the Leyendecker Plant Science Research Center (14 km south of Las Cruces, New Mexico). The soil, Armijo clay loam (fine montmorillonitic, thermic Typic Torrent), was disked, leveled, fertilized (with 224 kg/ha of 18-46-0), listed in 76-cm rows, and irrigated. When suitably dry, beds were mulched and later harrowed to flatten the tops of rows, cultipacked, irrigated with a sprinkler system to soften clods and firm bed tops and, once dry on top, were again cultipacked to provide a firm, well-pulverized seedbed.

The 514 selections of *Salsola* seeds were planted at a depth of 2 cm and covered by the press wheel only using John Deere 71 Flexiplanters fitted with cone seeders. Seeds were planted at a rate of 5 g/7.6 m of row in observation plots with 324 of the selections planted in 2-row plots of 7.6 m and 190 of the selections (in cases where seed was limited) in single-row plots. Alleys of 1.5 m separated the ends of the rows. After planting, the field (0.63 ha) was irrigated 3 times for stand establishment (25, 26, and 28 May 1984) using a sprinkler system. Plots were further irrigated on 29 June by sprinkler with 4.1 cm of water. Most of the water for plant maintenance, however, came from rainfall (15.9 cm).

Seventy selections representing a cross-section of phenotypes among the 514 original selections were chosen for more detailed study. Physical characteristics of plant height, stage of maturity, degree of prickliness, canopy color, relative canopy density, and relative degree of leafiness were determined. Chemical analyses of crude protein, acid detergent fiber (ADF), acid detergent lignin (ADL), nitrate, and water soluble oxalates were made on 2 harvests. Samples representing a range of protein content, 22 of the 70 selections, were chosen for in vitro digestibility analyses. Plants were harvested at 50 and 118 days after planting (DAP) by cutting a 0.5-m section of plants (10–20 plants) from the center of a row at a height of about 10 cm from the ground. Plants were immediately dried in a forced-draft oven at 65° C until constant weight was reached. Partially dried material was passed through a large Wiley mill fitted with a 6-mm mesh screen. A thoroughly mixed 50–100-g subsample was ground in a small Wiley mill fitted with a 40-mesh screen and stored in screw-capped glass jars. Total dry matter was determined by drying duplicate 1-g portions of the ground subsamples at 110° C for 24 h according to the method of Harris (1970); the water content of partially dried samples averaged less than 4%. All values reported here for chemical analyses were calculated on a 100% dry-weight basis.

Crude Protein

A slightly modified version of the AOAC micro-Kjeldahl method (AOAC 1980, p. 858) was used for crude protein determinations. Samples (0.200 g) were digested using circa 0.5 g of Kelpac Powder No. 2 (Curtin Matheson Scientific) and 4 ml of concentrated H_2SO_4. Twenty ml of deionized H_20 were added after digestion to dissolve solids. For distillation, a few grains of Zn dust and 20 ml of 50% NaOH were added. Distillate (30 ml) was collected in a 2.9% boric acid solution containing methyl purple indicator, and titrated to the end point with 0.1 N HCl. All assays were done in duplicate or triplicate.

Acid Detergent Fiber and Lignin

The AOAC method (AOAC 1980; p. 134-135) was used, except that Hyflo Super-Cel (Fisher Scientific) replaced asbestos for the crucible mats. All assays were done in duplicate or triplicate using 1-g samples.

Nitrate

The procedure of Cataldo et al. (1975) was followed without modification. All samples were analyzed in duplicate and the results expressed as percent NO_3^-.

Oxalates

The AOAC method (AOAC 1980, p. 541-542) was modified slightly using procedures outlined by Baker (1952) to accommodate a dried plant sample, rather than a canned vegetable product, and to allow for the determination of water-soluble as well as total (soluble and insoluble) oxalates. Insoluble oxalates are not toxic to animals because they are not absorbed, but excreted without effect (Kingbury 1964). Oxalates were determined on duplicate subsamples by titration with 0.01 N $KMn0_4$. Results are expressed as percent oxalate as oxalic acid.

Mineral Ash Analyses

The AOAC method (AOAC 1980, p. 125) was slightly modified for the ashing of samples. Duplicate 1-g samples were ashed in aluminum weighing pans for 4.5 to 5 h at a temperature of 500 to 600° C in a muffle furnace to achieve complete ashing of samples. A few samples were ashed in fritted glass crucibles rather than aluminum weighing pans for comparison purposes. No differences were seen in the results obtained by the 2 methods.

In Vitro Dry Matter and Organic Matter Disappearance

The in vitro digestibility analyses were performed in triplicate using the method of Tilley and Terry (1963), with slight modifications, by staff in the NMSU Animal Science Nutrition Lab. The following modifications were made. A 0.5-g sample was suspended in a total volume of 35 ml (4:1, McDouglas solution:rumen fluid). After flushing with CO_2, the vessels were covered with a perforated cap and acid pepsin digestions were stopped by freezing. Samples were filtered through Whatman No. 541 paper.

Phenotypic Measurements and Characteristics

Plant height, stage of maturity, and degree of prickliness at each harvest date were determined. Plant height was measured in centimeters from the top of the bed to the uppermost part of the plant in several locations within the plot, and the mean value was recorded. The stage of maturity was determined on the basis of flowering with plants grouped into 5 stages: prebloom—no apparent flowers; early bloom—flowers just beginning to show; midbloom—approximately half of the plant in flower; late bloom—plants fully covered with flowers and seed beginning to set; and mature—most seed fully developed. Degree of prickliness was determined by touch. The prickliness of *S. iberica* is caused by a single needle-like spine on the tip of each leaf and floral bract.

Results and Discussion

The ultimate goal of the research described here is to select and

Table 1. Mean values and ranges of physical and chemical factors useful in predicting forage value in 70 field-grown *Salsola* plant selections at 2 harvest dates.[1]

	Harvest 1 50 days after planting		Harvest 2 118 days after planting	
Physical/chemical factor	Mean ± S.D.[2]	Range	Mean ± S.D.	Range
Plant height (cm)	57 ± 12	30 - 75	113 ± 32	40 - 180
Crude protein[3]	14.4 ± 3.5	9.2 - 22.5	10.4 ± 3.0	5.4 - 17.5
Acid detergent fiber[3]	27.4 ± 3.0	20.1 - 34.2	34.7 ± 5.2	26.5 - 48.8
Acid detergent lignin[3]	4.3 ± 0.6	3.1 - 6.1	6.8 ± 1.2	4.7 - 10.4
Nitrate[3]	0.76 ± 1.2	0.1 - 6.2	0.4 ± 0.4	0.1 - 1.8
Water soluble oxalates[3]	4.4 ± 1.2	1.9 - 9.1	1.9 ± 0.8	0.2 - 4.1

[1]Complete descriptions and values for individual *Salsola* selections are available from the authors upon request.
[2]S.D.-standard deviation of the sample mean.
[3]Percent dry weight.

breed varieties of *Salsola* which can be cultivated as forage crops or used to improve range forage in semiarid regions.

Observations on 70 *Salsola* selections (of the total of 514 planted) revealed that selections varied from each other in height (Table 1), color (reddish-brown, red, yellow green, green and blue-green), prickliness (intensely prickly to soft at 118 days after planting), canopy density (very dense to open), leafiness (very high ratios of leaf-to-stem to low ratios) and time to maturity (less than 50 to more than 118 days after planting). Although several of the physical properties are of obvious importance with regard to forage value, the most important observation made was that within a given selection the plants were remarkably uniform with respect to these physical descriptors (and often strikingly different for plants of selections in neighboring rows). Thus, it should be possible to isolate and breed a *Salsola* variety with a readily recognizable set of phenotypic characters. In addition, some of these descriptors may correlate with nutritionally important factors. For example, none of the selections which had a reddish color was found to have a high protein content (all 14% or less).

The highest crude protein values were generally found in younger plants and, as a rule, decreased as plants matured. In 10 selections, crude protein content did not change, or increased slightly, during the period examined; however, this property did not appear to correlate in any obvious way with other physical characters. At 50 days after planting (DAP), 17 selections had crude protein content as high as that typical of alfalfa at first cutting in Dona Ana County, New Mexico (18.8±0.9%). In most cases, but not all (3 exceptions), high crude protein levels were associated with high nitrate content.

The quality of the protein found in plants at 50 DAP was examined by carrying out amino acid analysis on acid hydrolyzates of 9 selections, representing plants with crude protein contents of 9.6–20.4%. Although proline, tryptophan, and methionine were not determined in this study, the average values of all other amino acids showed little variation from one plant selection to another, were nutritionally well-balanced, and were essentially the same (data not shown) as values previously reported (Hageman et al. 1978).

The acid detergent fiber content, in contrast to protein, tended to increase as the plants matured, but 4 exceptions to this trend were seen. Acid detergent fiber content of plant selections harvested at the same time were fairly uniform, varying by only a factor of 1.7 at both 50 and 118 DAP. One remarkable selection had about 49% acid detergent fiber at 118 DAP; the same selection was low in nitrate, oxalate, and protein but was highly prickly. Another selection was also high in fiber, low in nitrate, oxalate, and protein, but retained a soft and leafy character until 118 DAP. Thus, certain desirable and undesirable characters appear to assort independently.

Of all characters examined, nitrate content was the one that varied most dramatically. At 50 DAP, selections examined varied from 0.1 to 6.2% nitrate (more than 60 fold). Forty-seven selections had nitrate levels below 0.45%, even at early stages of growth, which would be considered quite safe in a forage (Crawford et al. 1961, Murphy and Smith 1967, and references therein). In fact, cattle have been reported to graze, without ill effects, on forages containing an average of 2% nitrate (Heath et al. 1985). As with protein content, we found that nitrate levels generally decreased, often sharply, as plants matured, which is consistent with reports on other forages used for livestock grazing (Crawford et al. 1961). Six selections did have nitrate levels (2.4–6.1% at 50 days after planting) that might be toxic. Since 3 of the selections examined had high crude protein content, but only moderate or relatively low nitrate levels, protein and nitrate content might be selected independently.

Water soluble oxalates varied in these samples (Table 1), but without exception older plants had less oxalate than younger plants. At 50 DAP, several strains contained oxalic acid levels that might be toxic to sheep (in the absence of calcium supplements), but by 118 DAP, nearly all strains contained levels of oxalate (<3%) that would be safe even for sheep (Davis 1973).

No consistent level of toxicity for oxalates has been established in ruminants. We measured soluble oxalate levels in *Salsola*

Table 2. Mean values and ranges of ash content and in vitro digestibility indicators of 22 selections of *Salsola* at 2 harvest dates.[1]

	Harvest 1 50 days after planting[2]		Harvest 2 118 days after planting[3]	
Digestibility indicators	Mean ± S.D.[4]	Range	Mean ± S.D.	Range
Ash content	24.2 ± 2.9	21.3 - 30.5	15.8 ± 2.0	12.7 - 20.7
DMD[5]	68.5 ± 2.1	64.7 - 72.1	59.6 ± 4.4	51.6 - 67.7
OMD[6]	62.1 ± 2.2	58.9 - 66.3	53.7 ± 4.8	45.1 - 62.8

[1]Values for individual *Salsola* selections are available from the authors upon request.
[2]Average protein and acid detergent fiber for samples from Harvest 1 are 14.9 and 21.7%, respectively.
[3]Average protein and acid detergent fiber for samples from Harvest 2 are 11.0 and 34.6%, respectively.
[4]S.D.-standard deviation of the sample mean.
[5]DMD-percent dry matter disappearance.
[6]OMD-percent organic matter disappearance.

Table 3. Correlation coefficients among forage nutritive properties of *Salsola*.

	CP	ADF	ADL	NITRATE	OXALATE	ASH	DMD	OMD
DAY	–0.51**	0.72**	0.80**	–0.21**	–0.77**	–0.81**	–0.68**	–0.64**
CP		–0.78**	–0.65**	0.66**	0.73**	0.74**	0.52**	0.52**
ADF			0.85**	–0.43**	–0.77*	–0.86**	–0.76**	–0.77**
ADL				–0.32**	–0.78**	–0.77**	–0.77**	–0.73**
NITRATE					0.42**	0.57**	0.19*	0.20*
OXALATE						0.88**	0.67**	0.64**
ASH							0.80**	0.78**
DMD								0.99**

*,**Significant at 5% and 1% levels, respectively.

because of reports from Australia of its toxic effect on sheep grazing on drought-stressed *Salsola kali* (Mathams and Sutherland 1952); however, no reports of oxalate toxicity in cattle grazing *Salsola* have appeared. James et al. (1975) claimed plants with levels of soluble oxalate under 10% are not toxic to ruminants, and Heath et al. (1985) have pointed out that rumen bacteria can efficiently degrade oxalate. Oxalate toxicosis and tolerance in ruminants has been reviewed recently (Smith 1986).

In vitro digestibility (Table 2) compared favorably with the range seen for alfalfa hay (53 to 70.4%), and was generally higher than that reported for grasses (Norris et al. 1976, Heath et al. 1985). Earlier work on range samples has shown calcium levels in *Salsola* plants were high compared to those of most grazed species, and phosphorus levels were adequate for cattle (Nelson et al. 1970).

Pearson correlation coefficients were determined for a number of the components analyzed in this study (Table 3). Most values are similar to those expected for typical forages. Weak correlations between oxalate and nitrate suggest these characters are assorting independently. Interestingly, both oxalate and ash displayed fairly strong positive correlations with organic matter disappearance. We believe this may be accounted for, in part, by the presence of digestible calcium oxalate, which declines with maturity.

In summary, we have shown that selections of wild stands of *Salsola* grown under uniform field conditions have a wide degree of phenotypic expression of characters potentially important for forage production and that positive and negative factors can assort independently. In addition, 7 of the current 70 selections which were analyzed appeared to be suitable for cultivation as forages, or for introduction in range situations, because desirable factors were moderate to good and the undesirable traits were low. Further selection, breeding, and analysis will be required to test the reproducibility of these properties. As Davis (1973) stressed in an analogous study of *Astralagus* (milkvetch) species, other factors in addition to the ones measured here may be important in determining which plants might make the greatest improvement in range forage value.

Literature Cited

Abdraimov, S.A. 1981. Creation of cultivated pastures in the desert zone of Kazakhstan USSR. Problem Desert. Dev. 5:31-37. (Engl. transl. of Prob. Osoeniya Pustyn).

A.O.A.C. 1980. Official methods of analysis. 1980. Association of Official Analytical Chemists. 13th Ed. Washington, D.C.

Bailey, E.H.S., and C.F. Gustafson. 1902. Nutritive value of Russian thistle. Kansas State Board of Agr. Quart. Rep. 24-27 June.

Baker, C.J.L. 1952. The determination of oxalates in fresh plant material. Analyst 77:340-344.

Beatley, J.C. 1973. Russian-thistle (*Salsola*) species in western United States. J. Range Manage. 26:225-226.

Cataldo, D.A., M. Maroon, L.E. Schrader, and V.L. Youngs. 1975. Rapid colorometric determination of nitrate in plant tissue by nitration of salicylic acid. Comm. Soil Sci. and Plant Anal. 6:71-80.

Cave, H.W., W.H. Riddell, and J.S. Hughes. 1936. The digestibility and feeding value of Russian thistle hay. J. Dairy Sci. 19:285-290.

Cook, C.W., L.A. Stoddart, and L.E. Harris. 1954. The nutritive value of winter range plants in the great basin. Utah Agr. Exp. Sta. Bull. 372.

Crawford, R.F., W.K. Kennedy, and W.C. Johnson. 1961. Some factors that affect nitrate accumulation in forages. Agron. J. 53:159-162.

Davis, A.M. 1973. Protein, crude fiber, tannin and oxalate concentrations of some introduced *Astralagus* species. Agron. J. 65:613-615.

Donaldson, F.T., and K.J. Goering. 1940. Russian thistle silage. Agron. J. 32:190-194.

Esplin, A.C., J.E. Greaves and L.A. Stoddard. 1937. A study of Utah's winter range. Composition of forage plants and use of supplements. Utah Exp. Sta. Bull. 277.

Farmer, D.A., J.L. Fowler, and J.H. Hageman. 1976. Evaluation of protein and nutritive fiber content of cultivated Russian thistle. Agron. J. 68:691-692.

Fowler, J.L., and J.H. Hageman. 1978. Nitrogen fertilization of irrigated Russian thistle forage. I. Yield and water-use efficiency. Agron. J. 70:989-992.

Hageman, J.H., J.L. Fowler, and D.A. Schaefer. 1978. Nitrogen fertilization of irrigated Russian thistle forage. II. Some nutritional qualities. Agron. J. 70:992-995.

Harris, L.E., J.M. Asplund, and E.W. Crampton. 1968. An international feed nomenclature and methods for summarizing and using feed data to calculate diets. Utah Agr. Exp. Sta. Bull. 479.

Harris, L.E. 1970. Nutrition research techniques for domestic and wild animals. Vol. I. Utah State Univ., Logan.

Heath, M.E., R.F. Barnes, and D.S. Metcalfe. 1985. Forages. The science of grassland agriculture. 4th ed. Iowa State Univ. Press, Ames.

Hinman, C.W. 1984. New crops for arid lands. Science 225:1445-1448.

James, L.F., M.J. Allison, and E.T. Littledike. 1975. Production and modification of toxic substances in the rumen. *In:* McDonald, I.W. and A.C.I. Warner (Eds.), Digestion and metabolism in the ruminant, Univ. of New Zealand Publishing Unit, Armidale, Australia.

Kingsbury, J.M. 1964. Poisonous plants of the United States and Canada. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Mathams, M.C., and A.K. Sutherland. 1952. The oxalate content of some Queensland pasture plants. Queensland J. Agr. Sci. 9:317-334.

McKell, C.M. 1975. Shrubs—a neglected resource of arid lands. Science 187:803-809.

Murphy, L.S., and G.E. Smith. 1967. Nitrate accumulations in forage crops. Agron. J. 59:171-174.

Nelson, A.B., C.H. Herbel, and H.M. Jackson. 1970. Chemical composition of forage species grazed by cattle in arid New Mexico range. New Mexico Agr. Exp. Sta. Bull. 561.

Norris, K.H., R.F. Barnes, and J.S. Shenk. 1976. Predicting forage quality by infrared spectroscopy. J. Anim. Sci. 43:889-897.

Smith, G.S. 1986. Gastrointestinal toxifications and detoxifications in ruminants in relation to resource management. Chap. 18. *In:* K. Rozman and O. Hanninen (Eds.) Gastrointestinal Toxicology. Elsevier Science Publishers, Amsterdam.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Brit. Grassl. Soc. 18:104-111.

Upchurch, R.P. 1981. New crops for arid lands. p. 773-798. *In:* J. T. Manassah and E.J. Briskey (eds.). Advances in food-producing systems for arid and semiarid land. Acad. Press, New York.