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Preference by sheep and goats among hay of eight tall fescue cultivars[1]

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ABSTRACT: Grazing ruminants use both visual cues and taste in selecting their diet. Preference during grazing may not be the same when forage is dried for hay and cut into lengths prior to feeding in confinement. Eight cultivars of tall fescue (*Festuca arundinacea* Schreb.), previously evaluated for preference while grazed, were harvested three times over a period of 2 yr. The hays were air-dried, baled, and passed through a hydraulic bale processor prior to feeding. Five experiments were conducted. All three harvests were evaluated with sheep and the last two also with goats, using six animals each time. During an adaptation phase, hays were offered alone as meals. In the experimental phase, every possible pair of hays (28 pairs) was presented for a meal. Data were analyzed by multidimensional scaling and by traditional analyses. Preference was significant among cultivars in all experiments. Multidimensional scaling showed that selection was based on two criteria with two dimensions being significant. Sheep preferred KENHY followed by KENTUCKY 31 and STARGRAZER but preferenced against BARCEL. HIMAG, MO-96, and C1 were intermediate and MOZARK was variable. Goats were similar to sheep in preferring KENHY followed by STARGRAZER and selected against MOZARK and BARCEL. KENTUCKY 31, HIMAG, MO-96, and C1 were intermediate. In all five experiments, the general association was positive for available carbohydrate fractions and negative for fiber fractions that contribute to cell wall rigidity.

Key Words: Dry Matter, Festuca, Food Preferences, Goats, Sheep

 J. Anim. Sci. 2001. 79:213–224

Introduction

The preference exhibited by ruminants in selecting a diet when grazing is complex (Forbes and Kyriazakis, 1995) and involves aspects of plant morphology (Craigmiles et al., 1964) and learned associations with postingestive feedback effects (Provenza et al., 1994). In a recent study, Shewmaker et al. (1997) reported that yearling heifers showed a grazing preference among eight tall fescue cultivars. In determining preference with grazing animals, however, the morphological development of the plant can alter animal preference (Craigmiles et al., 1964), as can the constituents in the plant (Provenza, 1995). This could be a direct effect of preference for or against a constituent or an indirect effect of a learned positive or negative association with a postingestive consequence. Further, constituents of fresh plants can be altered through drying when forage is harvested and cured as hay. Forage morphological variation that may have influenced preference among the eight tall fescue cultivars evaluated by Shewmaker et al. (1997) was essentially not addressed. Such assessment requires harvesting of the forage and further processing prior to feeding to minimize morphological variation among cultivars. The objective of this study was to determine short-term preference rank of the same eight tall fescue cultivars evaluated under grazing by Shewmaker et al. (1997) when forage was harvested, dried and chopped, and fed as hay. The relationship between forage constituents and animal preference was also determined using multiple dimensional scaling procedures.

Materials and Methods

Source and Production of Hays

Well-established stands of eight tall fescue cultivars seeded in September 1991 from endophyte-free seed provided the forages for this study. The experimental-

[1]Cooperative investigation of the USDA, ARS, and the North Carolina ARS, Raleigh, NC 27695-7643 and USDA, ARS, Kimberly, ID 83341. The use of trade names does not imply endorsement by USDA, ARS, or by the North Carolina ARS of the products named or criticism of similar ones not mentioned.

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Received December 20, 1999.
Accepted August 28, 2000.

hay site was a surface-irrigated Portneuf silt loam (coarse-silty, mixed, mesic Durinodic Xeric haplocalcid) soil at the USDA Northwest Irrigation and Soil Research Laboratory near Kimberly, ID. The eight tall fescue cultivars were BARCEL, C1, and HIMAG (a first-generation and a second-generation selection, respectively, for high Mg and Ca concentrations and reduced K/(Ca + Mg) [Mayland and Sleper, 1993]); KENHY; KENTUCKY 31 (**KY-31**); MISSOURI 96 (**MO-96**); MOZARK, and STARGRAZER.

The experimental site was previously used in a cattle grazing preference study (Shewmaker et al., 1997) and consisted of four pastures with three blocks of each of the eight cultivars randomly assigned within each block. This resulted in 12 plots of each of the eight cultivars. At the beginning of each period of hay production, the area was clipped to an 8-cm stubble, top-dressed with 50 kg N/ha, and immediately irrigated. At harvest, 6 of the 12 replicates were cut in sequence between 1300 and 1800 to an 8-cm stubble on one day and the other six replicates the next day. Each day the hays of the same cultivar were physically mixed and allowed to field-dry. The process of harvesting the random plots (randomized when established) and mixing the hays prior to drying reduced the likelihood of differentially developing diurnal gradients in nutrients among cultivars. When dry, each cultivar from the appropriate 12 plots was composited and baled, and all hays were stored together in a metal building. All entries were cut at the late vegetative growth stage, which occurred after approximately 47 d of regrowth, with harvest taken July 10, 1995, and July 8 and August 21, 1996. The experimental hays made in 1995 were shipped that fall to Raleigh, NC and evaluated for preference in the winter of 1996. Hays harvested in 1996 were shipped to Raleigh, NC in the fall of 1996 and evaluated for preference in the winter of 1997.

Vegetative CAROSTAN flaccidgrass (*Pennisetum flaccidum* Griseb) and headed TRIUMPH tall fescue were harvested for hay at Raleigh, NC and fed to animals when they were not being used to evaluate the experimental hays in 1996 and 1997, respectively. All hays were stored in the same metal building at Raleigh until each experiment was initiated. Just prior to feeding, the hays were passed through a hydraulic bale processor (Van Dale 5600, J. Starr Industries, Fort Atkinson, WI) with stationary knives spaced 10 cm apart. The processed hays were cut into lengths of 7 to 13 cm. This procedure avoided leaf loss and minimized any morphological differences that may have been present among cultivars.

Preference Experiments

Five preference experiments were conducted consisting of forage from harvests in 2 yr and using two animal species. Three experiments were conducted with sheep and two with goats. Six animals were used to evaluate hays in each experiment. In Exp. 1 (hay harvested July 10, 1995), Dorset × Blackbelly (F_1) ewes were used (mean BW = 58 kg), whereas Katahdin ewes were used in Exp. 2 (hay harvested July 8, 1996; mean BW = 54 kg) and 3 (hay harvested August 21, 1996; mean BW = 56 kg). Spanish goats were used to evaluate the hays from the two harvests in 1996 and designated as Exp. 4 (hay harvested July 8; mean BW = 44 kg) and Exp. 5 (hay harvested August 21; mean BW = 44 kg). Animals were held in individual pens approximately 1.5 × 2 m during each experiment and provided free access to water and salt. The protocol for animal care and health was approved by the North Carolina State University Institutional Animal Care and Use Committee.

During an adaptation or training period (Kyriazakis et al., 1990), single meals of each hay were offered prior to each experiment to allow the animal to associate the hay with postingestive metabolic response and taste produced by the forage. This training period lasted 8 d and the order in which the forages were offered to each animal was randomized. During the experimental phase, each possible pair of the eight hays (28 pairs) was presented. Each pair of forages was presented side by side and each animal was offered approximately 0.75 kg of each hay. The order of presentation of the pairs and the left-right position of the hays in the pair were randomized in all experiments. The weight of the hay was determined before and approximately 30 min after offering the feed and after feeding. The intermediate weight was used to calculate an initial intake rate, and the final weight permitted calculation of DM consumed after adjusting for the DM content of the hay. In all experiments care was taken to prevent consumption of all of the preferred hay and therefore to always offer a choice between the two hays in the pair. In Exp. 1, which lasted 28 d, only one experimental meal was offered each day. The experimental meal was offered at 0830 and the animals were allowed approximately 4.0 h to feed. The standard forage (CAROSTAN flaccidgrass) was fed for ad libitum consumption about 1700 and removed the following morning at 0600. In the other four experiments an experimental meal was offered at 0830 and another pair offered at 1330, reducing the length of each experiment to only 14 d. The standard forage (TRIUMPH tall fescue) was fed for ad libitum consumption about 1700 and removed the following morning at 0600. The weight of hay was determined approximately 30 min after offering the feed and after feeding.

Masticate Experiment

To test for possible differences in the physical degradation of the eight cultivars during mastication, six esophageally cannulated steers (not part of the preference trial) were used to obtain a masticated (extrusa) sample of each of the forages. The steers (mean BW = 582 kg) were offered the hays one at a time in random order. Extrusa were quick-frozen in liquid N, stored frozen, and subsequently freeze-dried. For each hay from each steer, duplicate 15-g samples were dry-sieved into nine particle sizes using a Fritsch vibrator system (Annalysette, The Tekman Co., Cincinnati, OH). Freeze-dried samples separate easily during sieving and dried samples can be used for forage quality analysis without the losses of soluble material that may occur with wet sieving. Vibration was applied for 5 min and any clusters of particles were gently separated. Then the screens were rotated 180° and another 5 min of vibration was applied, after which the weight of particles on each screen was determined. The sieve sizes (U.S.A. Standard Testing Sieve, Fisher Scientific, Springfield, NJ) used were 5.6, 4.0, 2.8, 1.7, 1.0, 0.5, 0.25, and 0.125 mm. The weight that passed the 0.125-mm sieve was also recorded. These weights, expressed as cumulative percent oversize, were used to estimate mean and median particle size (Fisher et al., 1988) and to estimate percentages of large (> 1.7), medium (≤ 1.7 mm but > 0.5), and small (≤ 0.5) particles. Samples of the three particle size classes were further analyzed for NDF, CP, and an estimate of in vitro true DM disappearance (**IVTDMD**) as described below.

Laboratory Analyses

In each preference experiment, forage analyses were conducted on subsamples collected each time an experimental hay was fed in a pair (n = 7). Samples of the same cultivar were then composited by animal and represented the forage offered to each animal. Subsamples of the standard hays were also obtained and pooled for each experiment and analyzed for CP and IVTDMD. Experiment 1 was an exception. In this case, samples were further composited across animals, resulting in one sample for each cultivar. All samples included variation within the hay source and, in Exp. 2 through 5, laboratory variation in the means (n = 6). The composite sample was dried at 75°C in a forced-draft oven and composition values were reported on a DM basis. Samples were ground to pass a 1-mm screen in a cyclone mill. Wet analyses were conducted on the standard hays with CAROSTAN flaccidgrass (Exp. 1) averaging 112 g/kg CP and 763 g/kg IVTDMD and TRIUMPH tall fescue (Exp. 2 through 5) averaging 172 g/kg CP and 737 g/kg IVTDMD. All experimental hay samples were scanned in a near-infrared reflectance spectrophotometer (NIRS) and the "H" statistic (0.5) was used to identify samples with different spectra. These samples were selected for use in laboratory analyses for the development of prediction equations.

In vitro true DM disappearance was determined for all hay and masticate samples. Ruminal inoculum was collected from a cannulated, mature Hereford steer fed an alfalfa hay with about 10% orchardgrass. After a 48-h incubation with ruminal inoculum in a batch processor (Ankom Technology Corp., Fairport, NY), samples were extracted with neutral detergent solution for determination of IVTDMD.

Fiber fractions were sequentially estimated (NDF, ADF, ADL, and AIA) according to Van Soest and Robertson (1980) in a batch processor (Ankom Technology Corp., Fairport, NY) for all samples of the hays. Hemicellulose was determined by subtracting ADF from NDF and cellulose by subtracting lignin and ash from ADF. The only fiber fraction determined for the masticated samples was NDF. Crude protein was estimated as 6.25 times the percentage of N determined by AutoAnalyzer (Technicon Industrial Systems, Tarrytown, NY) for both masticate and hay samples (AOAC, 1990).

The total nonstructural carbohydrates (**TNC**) of the hay samples were analyzed by an adaptation (Fisher and Burns, 1987) of the method described by Smith (1969). The TNC were fractionated by differential solubility into monosaccharides, disaccharides, fructans, and starch. Starch was determined by digesting to glucose with amyloglucosidase and reading the monomer concentration on a YSI Model 27 Industrial Analyzer (Yellow Springs Instrument Co., Yellow Springs, OH).

A total of 603 samples from the preference experiment were scanned in the NIRS consisting of "as-fed" hay samples and associated "weigh-back" samples from the five experiments and served as the base population. From these, 329 samples were chosen for potential laboratory analyses, of which 9 to 32 samples, depending on the variable, were classified as outliers and removed before developing the calibration equation. A total of 527 samples were scanned in the masticate experiment and served as the base population. From these, 123 samples were chosen for potential laboratory analysis, of which 4 to 20 either had insufficient sample (depending on particle size class) or were determined to be outliers and removed from calibration equation development. Laboratory values were then used to develop NIRS calibration equations from which each observation was predicted (Table 1).

Statistical Analysis

The experimental design allowed statistical analysis by multidimensional scaling (Buntinx et al., 1997) as well as by traditional analyses (SAS Inst. Inc., Cary, NC). Multidimensional scaling (**MDS**) is used to develop a spatial arrangement representing the differences expressed as selective forage intake by the animals. For MDS, the difference in preference between a pair of hays was expressed by subtracting the amount of the least preferred hay from the most preferred hay and dividing by the sum of the two intakes. In this way, preference was expressed numerically as a relative difference or distance. If the animal consumed equal quantities of the hays in the pair, then the difference ratio is equal to zero and no preference or distance between the hays was expressed. If only one of the pair was consumed, then the difference ratio is equal to one and the maximum difference in preference between hays is expressed (Buntinx et al., 1997). The Proc. MDS of SAS (SAS Inst. Inc.) is an iterative fitting procedure for data

Table 1. The range for each forage constituent predicted by near-infrared reflectance spectrophotometry, its SE of calibration (SEC), and SE of cross-validation (SECV) for both the preference and masticate experiments

Variable	Prefernce exp. n	Range	SEC	SECV	Masticate exp. n	Range	SEC	SECV
		g/kg				g/kg		
IVTDMD[a]	309	753–904	19.7	21.4	117	824–924	9	11
CP	297	121–239	2.9	3.6	100	119–237	3	5
NDF	318	423–560	6.0	7.0	119	402–544	10	11
ADF	318	218–293	2.7	3.2	—	—	—	—
Lignin	313	9–19	1.2	1.3	—	—	—	—
AIA	321	7–21	1.2	1.5	—	—	—	—

[a]IVTDMD = in vitro true dry matter disappearance.

assumed to express distances or relative differences between stimuli (e.g., feeds) in an unknown number of orthogonal dimensions. After specifying the assumed number of dimensions, a least squares fit is approximated using an array of points representing the stimuli. The coordinates of the points are adjusted iteratively until the reduction in residual sum of squares is below a specified level. The residual sum of squares is calculated by comparing the "distance" between the points representing the stimuli and the observed distances or differences between the stimuli. In effect, a map is developed with points representing each stimulus. The positions are adjusted until the maximum sum of squares is explained given the limitation of the specified number of dimensions. The order of fit is dimension one first, which will generally include the most important variables (most sums of squares), followed by dimension two, which will generally include the second most important variables (second most sums of squares), then dimension three, etc. In the current study, one, two, and three dimensional maps were developed and evaluated in a stepwise manner based on the number of estimated parameters and the additional sum of squares explained by the additional dimensions. After the maps were developed, correlation and regression techniques were used to relate the feed coordinates in each dimension with observations of forage composition.

Each experiment was also tested by analysis of variance after averaging intake of each hay (averaged across each combination, n = 7) by each animal. The analysis of variance only included terms for animal and hay. Within the hay treatments, means were separated using the minimum significant difference (MSD) from the Waller-Duncan k-ratio *t*-test (k = 100). Simple linear correlation was used to examine the relationship of DM intake to nutritive value and stepwise multiple regression was used to associate nutritive value estimates ($P \leq 0.15$ for entry) with each dimension identified in the MDS procedures and with short-term DMI and DMI rate.

Results and Discussion

Animal Preference

Multidimensional scaling revealed that selection between hays by both sheep and goats was associated with two dimensions. A relative importance calculation (based on model sums of squares) indicated that dimension one was more important, with an index value of 100, compared with 17 to 26 for dimension two in the sheep experiment and 19 to 20 in the goat experiment. KENHY was used as a positive control based on DMI by assigning it positive coordinates in all experiments. The full range in stimulus coordinates by hay, the dimension weight given by the various animals, and the relative importance of each dimension are presented in Appendix Table 1.

Dimension one shows the strong preference for KENHY exhibited by sheep in all three experiments (Figure 1) and to a lesser extent for STARGRAZER in Exp. 1 and 2 and KY-31 in Exp. 3. Sheep avoided BARCEL in all three experiments and STARGRAZER in Exp. 3. In dimension two, sheep preferred KY-31 in Exp. 1 and 2, MOZARK in Exp. 3, and HIMAG in all three experiments but avoided MOZARK in Exp. 1 and 2, C1 in Exp. 1 and 3, MO-96 in all three experiments, and BARCEL in Exp. 3.

In dimension one, both goat experiments showed a strong preference for KENHY followed by KY-31 in Exp. 4 and avoidance of MOZARK and BARCEL in both Exp. 4 and 5 (Figure 2). In dimension two a strong preference was noted for STARGRAZER in both Exp. 4 and 5 and against BARCEL in Exp. 5. In general, both animal species highly preferred or avoided the same hays. Generally, a positive rank of a hay in both dimensions, upper right sector in Figures 1 and 2, would represent preference whereas a negative rank in both dimensions, lower left-hand sector of Figures 1 and 2, would indicate avoidance. Considering all five experiments (Figures 1 and 2), KENHY was highly preferred, occurring in the positive sector in all five experiments, followed by KY-31 with four occurrences and STARGRAZER with three

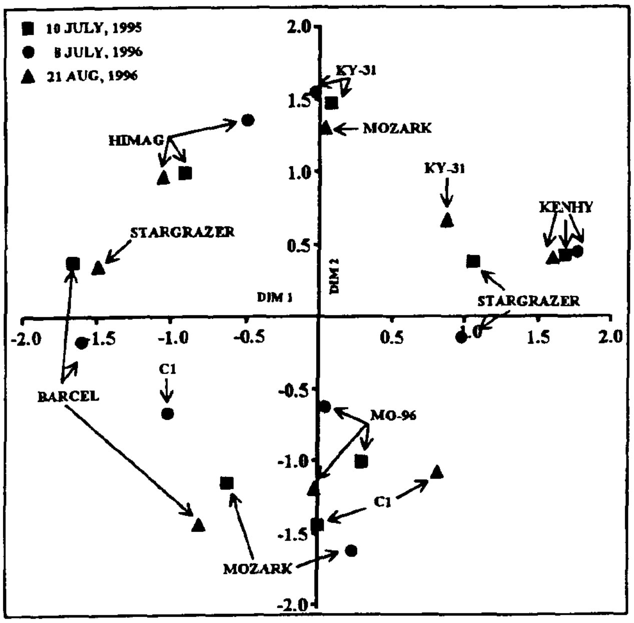

Figure 1. Multidimensional scaling of the mean preference shown by ewes for hays of eight tall fescue cultivars (KY-31 = KENTUCKY 31; MO-96 = MISSOURI 96; DIMI = dimension 1, and DIM2 = dimension 2) in Exp. 1 (harvested July 10, 1995), Exp. 2 (harvested July 8, 1996), and Exp. 3 (harvested August 21, 1996).

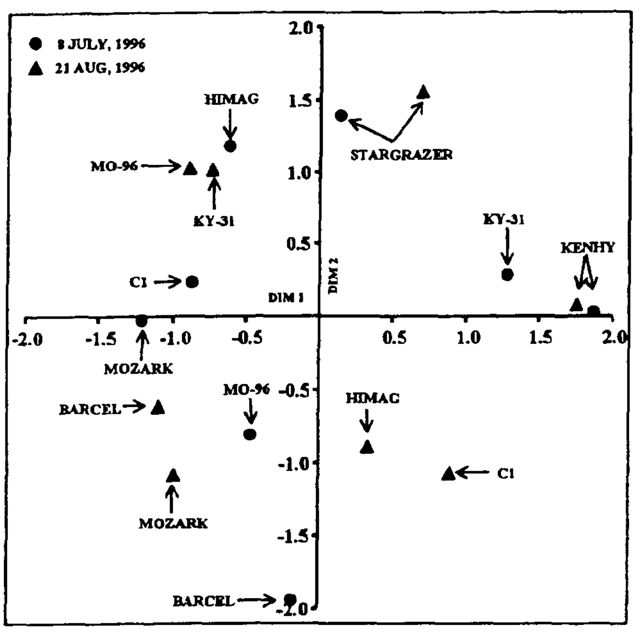

Figure 2. Multidimensional scaling of the mean preference shown by doe goats for hays of eight tall fescue cultivars (KY-31 = KENTUCKY 31; MO-96 = MISSOURI 96; DIM1 = dimension 1 and DIM2 = dimension 2) in Exp. 4 (harvested July 8, 1996) and Exp. 5 (harvested August 21, 1996).

occurrences. The negative sector shows BARCEL was avoided four of the five times and MOZARK three of the five times evaluated. The other hays had one negative dimension and were generally of intermediate preference.

The sheep and goats preferred hays of the same cultivars that were most preferred by heifers when grazing the same cultivars (plots) in a previous study (Shewmaker et al., 1997). Ranking by grazing heifers was KENHY > KY-31 > HIMAG = BARCEL = C1 = STARGRAZER > MO-96 = MOZARK. The major discrepancy in rank was the stronger avoidance in our study of BARCEL. Such general agreement between studies indicates that the cues that cattle used for preference were apparently perceived similarly by sheep and goats. Further, the cues were not greatly altered by different weather conditions or lost through harvesting and drying and were detected by different methodologies. The cues were apparently compositional, as suggested by Krueger et al. (1974), because the morphological differences among cultivars were minimized by chopping prior to feeding.

Nutritive Value and Preference

No attempt was made by Shewmaker et al. (1997) to determine why heifers chose one cultivar over another. In previous preference studies analyzed by MDS, composition of the hays fed were found associated in several dimensions with short-term dry matter intake (Buntinx et al., 1997; Fisher et al., 1999) and was also observed in this study.

Examination of the mean compositional values of hays fed sheep (Table 2) and goats (Table 3) shows the fiber fractions to be fairly consistent, whereas CP, carbohydrate fractions, and TNC changed considerably. For example, in the sheep experiments, which evaluated hay from all three harvests, CP averaged 89 g/kg in Exp. 1 and increased to 131 g/kg in Exp. 2 and to 230 g/kg in Exp. 3 (Table 2). On the other hand, TNC averaged 168 g/kg in Exp. 1, declined to 125 g/kg in Exp. 2, and declined further to 80 g/kg in Exp. 3. Within experiments, however, the range among cultivars was generally small. For example, the range in NDF was only 24 g/kg in Exp. 3 with a maximum of 44 g/kg in Exp. 2. The range for TNC within experiments was only 13 g/kg in Exp. 3 with a maximum of 34 g/kg in Exp. 2. The range of such compositional differences influences the magnitude of the relationship with DMI and preference and how definitive animals can be in selecting one hay over another (Fisher et al., 1999).

Regression analysis of dimension one in the sheep experiments identified three variables that explained 96% of the variation in preference in Exp. 1 (Table 4), one variable for 56% of the variation in preference in Exp. 2, and none in Exp. 3. Dimension 2 was associated with three variables in Exp. 1 accounting for 92% of the variation in preference, one variable in Exp. 2 accounting for 65% of the variation in preference, and one

Table 2. Dry matter intake and composition of tall fescue hays fed to sheep in Exp. 1, 2, and 3 (oven-dry basis)

	Intake[a]				Cell wall fractions[c]						Nonstructural carbohydrates[d]				
Cultivar	Meal, g	Rate, g/min	IVTDMD[b], g/kg	CP, g/kg	NDF	ADF	HEMI	CELL	Lignin	AIA	MONO	DI	Fructans	Starch	Total
					g/kg						g/kg				
Exp. 1 (harvested July 10, 1995)															
BARCEL	139[e]	2.5	818	92	543 (−2)[f]	287	255	251	15.5	20.7	50.7	15.5	71.2	11.7	149
Cl	206	3.5	814	90	529 (+11)	276	253	246	13.9	15.6	53.8	14.7	87.4	12.4	168
HIMAG	197	3.5	787	89	528 (+11)	278	250	244	15.0	19.0	50.9	19.3	83.9	12.6	167
KENHY	295	5.8	826	94	520 (+6)	266	254	237	13.6	14.9	51.2	19.4	81.2	13.8	166
KY-31	215	3.7	824	90	517 (+6)	266	251	235	14.3	16.1	55.9	17.9	94.0	11.9	180
MO-96	219	4.0	785	86	530 (+5)	275	254	246	12.9	16.1	60.5	16.8	86.6	13.8	177
MOZARK	171	2.7	789	89	537 (+1)	280	258	246	12.7	20.4	58.6	18.9	68.9	13.0	159
STARGRAZER	199	3.8	803	82	532 (+6)	274	258	245	13.9	14.9	50.5	23.3	90.3	13.4	177
Mean	205	3.7	806	89	529 (+6)	275	254	244	14.0	17.2	54.0	18.2	82.9	12.8	168
MSD[g]	43	0.9	—	—	—	—	—	—	—	—	—	—	—	—	—
SE	—	—	0.60	0.14	0.29	0.25	0.10	0.18	0.03	0.09	0.14	0.09	0.31	0.03	0.37
CV, %	18.6	21.6	—	—	—	—	—	—	—	—	—	—	—	—	—
Exp. 2 (harvested July 8, 1996)															
BARCEL	112	1.3	818	130	549 (+1)	283	267	249	13.2	18.4	14.3	42.1	41.2	13.3	111
Cl	203	3.0	810	134	540 (+6)	279	261	246	13.5	18.0	15.3	45.1	44.8	12.7	118
HIMAG	251	4.6	818	131	528 (+7)	269	259	238	13.3	17.0	13.5	51.7	52.5	13.2	131
KENHY	325	7.9	847	138	505 (+25)	253	253	224	11.4	15.2	11.6	59.5	58.6	14.7	144
KY-31	332	5.7	817	134	522 (−6)	266	255	234	12.2	17.4	10.4	54.7	56.2	12.1	133
MO-96	239	4.2	810	129	538 (+6)	278	260	245	12.9	18.6	11.5	54.1	44.5	12.3	122
MOZARK	209	3.5	803	133	549 (+4)	284	265	249	14.6	18.7	12.5	49.0	36.2	12.1	110
STARGRAZER	265	4.6	818	125	530 (+3)	268	262	237	12.3	16.6	16.1	47.5	54.0	12.5	130
Mean	242	4.3	817	131	533 (+5)	273	260	240	13.9	17.5	13.1	50.5	48.5	12.9	125
MSD	55	1.3	5	3	5	3	4	3	0.5	0.8	2.8	2.9	3.5	1.5	5
CV, %	20.8	27.9	0.5	2.3	1.0	1.1	1.4	1.2	3.9	4.1	17.6	5.4	6.7	9.1	4.0
Exp. 3 (harvested August 21, 1996)															
BARCEL	203	2.5	853	238	526 (+3)	257	269	233	12.6	10.1	25.0	31.2	14.3	5.9	76
Cl	284	4.0	825	231	531 (+5)	256	274	231	12.6	10.3	27.1	28.6	16.6	6.0	78
HIMAG	259	3.4	830	227	522 (+8)	253	270	229	12.5	10.3	26.7	28.8	18.9	6.3	81
KENHY	297	4.8	854	230	519 (+12)	248	271	225	11.4	10.0	26.4	29.4	23.0	6.7	85
KY-31	307	4.6	835	227	528 (+10)	253	275	228	12.4	10.8	23.7	33.0	22.9	5.3	85
MO-96	326	4.8	830	232	530 (+10)	255	275	231	13.0	10.8	25.7	27.6	16.8	6.2	76
MOZARK	282	4.2	821	228	543 (+4)	261	282	236	13.7	10.9	26.8	27.0	13.9	4.7	72
STARGRAZER	287	4.3	844	229	523 (+5)	253	270	229	11.9	9.6	26.6	30.8	21.8	5.5	85
Mean	281	4.1	837	230	528 (+7)	255	273	230	12.5	10.3	26.0	29.6	18.5	5.8	80
MSD	63	1.4	5	4	6	3	5	3	0.6	1	NS	4.9	1.8	1.5	5
CV, %	17.6	26.9	0.6	1.5	1.0	1.1	1.6	1.1	4.5	7.1	11.9	11.3	9.1	17.4	5.5

[a]Mean = 4-h exposure in Exp. 1 and 2.5-h exposure in rest and rate based on first 30 min.
[b]IVTDMD = in vitro true dry matter disappearance.
[c]HEMI = hemicellulose and CELL = cellulose.
[d]MONO = monsaccharides and DI = disaccharides.
[e]Each value is the mean of six animals.
[f]Values in parentheses are weigh-back NDF − hay fed NDF [the calculation for BARCEL, Exp. 1 is weigh-back NDF (541 g/kg) − hay fed NDF (543 g/kg) = −2].
[g]MSD = minimum significant difference, based on the Waller-Duncan k-ratio (k = 100) *t*-test.

Table 3. Dry matter intake and composition of tall fescue hays fed to goats in Exp. 4 and 5 (oven-dry basis)

Cultivar	Intake[a] Meal, g	Rate, g/min	IVTDMD[b], g/kg	CP, g/kg	Cell wall fractions[c] NDF	ADF	HEMI	CELL	Lignin	AIA	Nonstructural carbohydrates[d] MONO	DI	Fructans	Starch	Total
					g/kg						g/kg				
Exp. 4 (harvested July 8, 1996)															
BARCEL	100[e]	1.1	822	129	547 (+5)[f]	281	266	249	13.0	17.1	13.6	41.4	44.2	12.3	111
Cl	168	2.2	810	131	547 (−2)	278	269	245	13.4	17.1	15.0	46.3	47.8	13.5	123
HIMAG	210	3.3	812	131	531 (+3)	269	262	237	12.9	16.3	13.6	50.5	51.8	12.8	129
KENHY	307	6.2	840	136	507 (+14)	254	253	226	11.5	15.4	14.2	55.4	59.9	14.4	144
KY-31	301	4.7	818	129	524 (+7)	265	259	233	12.5	16.7	11.3	53.5	56.5	13.0	134
MO-96	201	3.3	808	128	539 (+5)	276	263	244	13.6	17.8	11.0	50.1	45.7	12.1	119
MOZARK	171	2.6	798	132	548 (+5)	287	262	251	14.7	18.3	14.8	47.1	38.9	12.2	113
STARGRAZER	222	3.7	822	123	532 (+8)	270	262	239	13.0	16.3	15.5	48.2	57.5	12.1	133
Mean	210	3.4	816	130	534 (+5)	272	262	241	13.1	16.9	13.6	49.1	50.3	12.8	126
MSD[g]	43	0.9	5	3	5	3	4	3	0.6	1	3	5	3	2	6
CV, %	19.2	24.7	0.6	2.3	0.9	1.2	1.4	1.3	4.3	5.2	18.8	9.1	6.6	10.5	4.5
Exp. 5 (harvested August 21, 1996)															
BARCEL	169	2.6	848	239	526 (+2)	256	270	232	12.7	9.6	28.7	26.2	15.7	4.3	75
Cl	232	3.8	827	230	529 (+7)	254	275	229	12.5	10.2	24.9	26.6	15.5	4.9	72
HIMAG	212	3.3	830	227	527 (+4)	249	278	225	12.9	9.9	25.8	29.5	19.1	4.9	79
KENHY	289	5.3	858	228	519 (+8)	247	273	225	11.7	9.0	24.6	26.9	23.1	5.5	80
KY-31	240	3.4	834	224	531 (−1)	251	280	227	12.9	10.2	24.2	30.0	21.7	4.2	80
MO-96	194	2.7	829	233	533 (+3)	253	280	229	13.2	10.4	25.1	26.6	15.0	5.0	72
MOZARK	182	2.2	822	228	542 (+5)	260	282	233	13.8	10.5	23.9	25.1	13.1	4.7	67
STARGRAZER	287	4.7	841	225	528 (0)	254	274	230	12.9	9.3	27.9	28.5	19.8	4.2	80
Mean	226	3.5	837	230	529 (+4)	253	277	228	12.7	9.9	25.7	27.4	17.9	4.7	76
MSD	37	0.8	7	3	5	3	5	3	0.7	1	3	NS	3	0.8	5
CV, %	15.0	21.1	0.8	1.1	0.9	1.2	1.6	1.2	4.8	7.8	10.0	16.2	13.2	13.2	5.7

[a]Meal = 2.5-h exposure and rate based on first 30 min.
[b]IVTDMD = in vitro true dry matter disappearance.
[c]HEMI = hemicellulose and CELL = cellulose.
[d]MONO = monosaccharides and DI = disaccharides.
[e]Each value is the mean of six animals.
[f]Values in parentheses are weigh-back NDF − hay fed NDF [the calculation for BARCEL, Exp. 1 is weigh-back NDF (552 g/kg) − hay fed NDF (549) = +5].
[g]MSD = minimum significant difference, based on the Waller-Duncan k-ratio (k = 100) *t*-test.

Table 4. Stepwise regression analysis of the stimuli coordinates from the eight tall fescue hays estimated with multidimensional scaling in each of the two dimensions for hay preference among sheep in Exp. 1, 2, and 3 and among goats in Exp. 4 and 5

Dimension 1					Dimension 2				
Intercept	Coefficient	Variable[a]	$P > F$	R^2	Intercept	Coefficient	Variable[a]	$P > F$	R^2
Sheep									
Exp. 1 (harvested July 10, 1995)									
−24.788	+0.218	IVTDMD	0.061		13.380	−1.136	CELL	0.022	
	−2.002	AIA	0.033			+8.389	Lignin	0.006	
	+8.324	Starch	0.012	0.96		+1.432	DI	0.072	0.92
Exp. 2 (harvested July 8, 1996)									
21.819	−0.908	CELL	0.033	0.56	−5.246	+1.081	Fructans	0.016	0.65
Exp. 3 (harvested August 21, 1996)									
—	—	—	—	—	54.409	−2.363	CP	0.008	0.72
Goats									
Exp. 4 (harvested July 8, 1996)									
35.808	−0.670	NDF	0.003	0.80	−20.265	+22.112	Lignin	0.006	
						−13.062	AIA	0.047	
						+1.071	TNC	0.014	0.93
Exp. 5 (harvested August 21, 1996)									
65.415	−0.519	IVTDMD	0.121	—	—	—	—	—	—
	−20.172	Lignin	0.016						
	+7.704	Starch	0.139	0.88					

[a]IVTDMD = in vitro true dry matter disappearance; CELL = cellulose; DI = disaccharides; and TNC = total nonstructural carbohydrates.

variable in Exp. 3 accounting for 72% of the variation in preference.

In the goat experiments (Table 4), dimension one was associated with one variable in Exp. 4 accounting for 80% of the variation and three variables in Exp. 5 accounting for 88% of the variation. In dimension 2, three variables in Exp. 4 accounted for 93% of the variation but none of the variables analyzed was associated with dimension two in Exp. 5.

In all five experiments the regression coefficients were positive for available carbohydrate fractions but negative for constituents that define the fiber fractions. An exception was noted for dimension two in Exp. 1 and 4, in which lignin had a positive coefficient in models with other variables. Further, the relationship of AIA to preference in some models (dimension 1, Exp. 1 and dimension 2, Exp. 4) is not clear. It should be noted that other constituents not analyzed could have influenced the selection of one cultivar over another through correlation with the constituents selected for analyses.

Dry Matter Intake

Correlation analysis between preference when expressed as DMI (g/meal) and nutritive value of the hay generally showed a negative relationship with fiber fractions (NDF, ADF, Cellulose, and lignin), but these were not always significant (Table 5). Further, the association with the carbohydrate fractions (except monosaccharides) and TNC were positive but not always significant. This same pattern was also reported for sheep and goats by Fisher et al. (1999) when determining the preference between afternoon and morning harvests of tall fescue.

According to the MSD, dry matter intake (g/meal) for sheep (Table 2) was highest for KENHY in Exp. 1 and lowest for BARCEL and MOZARK, which were similar. Intake rate showed the same patterns. In Exp. 2, KENHY and KY-31 had high and similar DMI and BARCEL was lowest. Intake rate was highest for KENHY followed by KY-31 with BARCEL lowest. Differences were less evident in Exp. 3; all hays gave similar DMI except BARCEL, which was lowest. These differences are reflected in MDS analyses (Figure 1).

In the goat experiments (Table 3), the MSD showed DMI of KENHY in Exp. 4 to be highest and similar to KY-31 and BARCEL the lowest (same hay as Exp. 2). Intake rates showed the same differences. Goats differentiated between KENHY and KY-31 in Exp. 5, which sheep did not do when fed the same hay (Exp. 3), but both ranked intake rate for KENHY as highest. In Exp. 5, DMI for KENHY was highest but similar to DMI for STARGRAZER. Intake rate was highest for KENHY, followed by STARGRAZER, which was similar, and BARCEL and MOZARK had the lowest intake rates.

Table 5. Correlations[a] between composition of tall fescue hays offered and dry matter intake by sheep or goats

	Sheep						Goats			
	Exp. 1		Exp. 2		Exp. 3		Exp. 1		Exp. 2	
Item[b]	r	$P > F$	r	$P > F$	r	$P > F$	r	$P > F$	r	$P > F$
IVTDMD	0.312	0.45	0.474	0.23	−0.370	0.37	0.482	0.23	0.518	0.19
CP	0.253	0.55	0.354	0.39	−0.568	0.14	0.273	0.51	−0.505	0.20
NDF	−0.809	0.01	−0.872	<0.01	0.119	0.78	−0.899	<0.01	−0.591	0.12
ADF	−0.856	<0.01	−0.831	0.01	−0.222	0.60	−0.858	<0.01	−0.786	0.02
HEMI	−0.291	0.49	−0.902	<0.01	0.423	0.30	−0.833	0.01	−0.138	0.75
CELL	−0.733	0.04	−0.852	<0.01	−0.295	0.48	−0.892	<0.01	−0.765	0.03
Lignin	−0.376	0.36	−0.649	0.08	−0.054	0.90	−0.645	0.09	−0.790	0.02
AIA	−0.758	0.03	−0.678	0.07	0.384	0.35	−0.602	0.11	0.679	0.06
MONO	−0.035	0.93	−0.514	0.19	0.012	0.98	−0.256	0.54	−0.069	0.87
DI	0.231	0.58	0.859	<0.01	−0.213	0.61	0.964	<0.01	0.430	0.29
Fructans	0.441	0.27	0.813	0.01	0.460	0.25	0.800	0.02	0.794	0.02
Starch	0.628	0.09	0.149	0.73	0.026	0.95	0.548	0.16	0.147	0.73
TNC	0.469	0.24	0.873	<0.01	0.271	0.52	0.896	<0.01	0.685	0.06

[a]Probabilities of r based on n = 8.
[b]IVTDMD = in vitro true dry matter disappearance; HEMI = hemicellulose; CELL = cellulose; MONO = monosaccharides; DI = disaccharides; and TNC = total nonstructural carbohydrates.

The degree of selectivity that animals showed when eating each hay was estimated in all five experiments by comparing the NDF concentration in the residue left after feeding with the NDF of the "as fed" hays. This difference is noted in the parentheses following the NDF of the "as-fed" hays (Tables 2 and 3). Although there was some selection, the differences were generally similar among cultivars within each experiment. The major exception was KENHY in Exp. 2 and 4, in which the residual forage had apparently higher NDF concentrations, indicating more selective consumption relative to the other hays. The hays in Exp. 2 and 4 were

Table 6. Stepwise regression analysis of the nutritive value estimates from eight tall fescue hays on dry matter intake and intake rate (30 min) based on meals giving hay preference among sheep in Exp. 1, 2, and 3 and among goats in Exp. 4 and 5

	Dry matter intake				Intake rate				
Intercept	Coefficient	Variable[a]	$P > F$	R^2	Intercept	Coefficient	Variable[a]	$P > F$	R^2
Sheep									
Exp. 1 (harvested July 10, 1995)									
−1,421.406	+89.005	CP	0.001		11.620	−0.988	ADF	0.021	
	+32.571	Fructans	0.001			+5.236	Lignin	0.109	
	+439.159	Starch	<0.001	0.98		+9.325	Starch	0.038	0.89
Exp. 2 (harvested July 8, 1996)									
4,036.783	−6.473	CELL	0.031		36.469	−0.749	NDF	0.015	
	−69.196	HEMI	0.094			+1.545	DI	0.035	0.96
	−421.010	Starch	0.009	0.97					
Exp. 3 (harvested August 21, 1996)									
1,538.727	−54.648	CP	0.142	0.32	—	—	—	—	—
Goats									
Exp. 4 (harvested July 8, 1996)									
−518.663	+124.121	DI	0.001		−95.221	+0.849	IVTDMD	0.004	
	+23.855	Fructans	0.085	0.96		+9.011	Lignin	0.017	
						+3.574	DI	<0.001	0.99
Exp. 5 (harvested August 21, 1996)									
45.641	+100.584	Fructans	0.019	0.63	−8.843	−21.067	Lignin	<0.001	
						+1.413	HEMI	0.002	0.98

[a]CELL = cellulose; HEMI = hemicellulose; DI = disaccharides; and IVTDMD = in vitro true dry matter disappearance.

Table 7. Median particle size and nutritive value of whole masticate and three particle size classes of the whole masticate collected from esophogeally fistulated steers fed tall fescue hays harvested July 8 and August 21, 1996 (oven-dry basis)

Cultivar	Whole masticate				Large (> 1.7 mm)				Medium (< 1.7 and > 0.5 mm)				Small (< 0.5 mm)			
	Median, mm	IVTDMD[a]	CP	NDF	Prop.[b] %	IVTDMD	CP	NDF	Prop., %	IVTDMD	CP	NDF	Prop., %	IVTDMD	CP	NDF
		g/kg				g/kg				g/kg				g/kg		
Harvested July 8																
BARCEL	2.14[c]	865	131	522	61.1	865	126	527	35.0	866	139	519	3.9	864	134	480
Cl	1.67	850	127	518	51.2	848	121	529	41.5	850	134	513	7.3	860	131	466
HIMAG	1.81	855	127	501	57.0	854	123	511	36.3	856	133	495	6.7	865	132	454
KENHY	1.75	875	132	481	49.4	875	127	494	41.6	875	137	475	9.0	883	139	436
KY-31	1.79	853	124	500	51.4	851	119	513	41.0	852	128	497	7.6	867	127	433
MO-96	1.72	847	129	517	50.9	846	123	526	43.1	847	135	513	6.0	854	135	472
MOZARK	1.72	844	127	526	50.3	842	121	537	42.1	844	133	524	7.6	852	134	477
STARGRAZER	2.01	859	122	512	58.9	857	117	519	34.7	858	129	511	6.4	868	126	454
Mean	1.8	856	127	510	53.8	855	122	519	39.4	856	133	506	6.8	864	132	459
MSD[d]	0.45	3	3	7	11.4	4	4	9	NS	4	5	8	3	8	5	14
CV, %	16.2	0.4	2.4	1.3	14.3	0.4	3.0	1.6	15.5	0.4	3.2	1.5	32.4	0.8	3.5	2.8
Harvested August 21																
BARCEL	1.83	892	212	485	54.2	892	209	485	41.3	893	217	487	4.5	886	206	458
Cl	1.90	870	209	487	57.9	869	205	489	37.8	871	216	486	4.3	871	205	463
HIMAG	2.03	876	212	481	63.1	877	211	485	32.8	877	215	475	4.1	882	205	443
KENHY	2.15	884	205	477	65.1	884	202	483	30.9	885	212	471	4.0	884	202	441
KY-31	1.89	874	203	486	57.9	873	200	490	36.8	875	208	484	5.3	869	195	447
MO-96	1.88	876	218	484	56.2	875	215	488	38.5	877	223	480	5.3	878	210	454
MOZARK	1.81	872	214	499	53.9	873	212	505	40.1	870	217	498	6.0	875	209	469
STARGRAZER	2.15	874	205	478	63.4	875	203	482	32.3	873	209	476	4.3	879	205	445
Mean	1.96	877	210	484	59.0	877	207	488	36.3	877	215	482	4.7	878	205	45.3
MSD	NS	4	7	8	8.3	5	9	11	7	4	6	8	1.9	7	6	20
CV, %	13.1	0.4	2.7	1.5	10.6	0.5	3.5	1.8	14.8	0.5	2.5	1.5	26.7	0.7	2.6	3.3

[a]IVTDMD = in vitro true dry matter disappearance.
[b]Prop. = proportion of dry matter.
[c]Each value is the mean of six steers.
[d]MSD = minimum significant difference, based on the Waller-Duncan k-ratio (k = 100) *t*-test.

from the same source and both sheep and goats responded similarly.

Nutritive Value and Intake

Regression analysis showed that three variables in Exp. 1 accounted for 98% of the variation in sheep DMI and 89% of the variation for intake rate (Table 6). The variables differed, however, between DMI and intake rate; CP, fructan, and starch were important in the former and ADF was most important in the latter. In Exp. 2, three variables accounted for 97% of the variation for intake. In this case, the fiber fractions, cellulose and hemicellulose, were important, as was starch. The most important variables associated with intake rate in Exp. 2 were NDF and disaccharides. In Exp. 3, only one variable was found to be associated with DMI and accounted for only 32% of the variation, whereas none was identified for intake rate.

In experiments with goats, disaccharides and fructans accounted for 96% of the variation in DMI in Exp. 4, and fructan accounted for 63% of the variation in Exp. 5 (Table 6). Intake rate was more complex, with three variables accounting for 99% of the variation in Exp. 4 and two variables accounting for 98% of the variation in Exp. 5. Higher IVTDMD was most important for intake rate in Exp. 4, and lignin concentration was most important in Exp. 5. In general, DMI was associated with CP or a constituent(s) of available carbohydrate, or both, whereas a fiber constituent(s) was most important in describing intake rate. These general responses are consistent with the ruminant's apparent preference for higher carbohydrate concentration in forage (Orr et al., 1997; Fisher et al., 1999) and against those forages requiring increased chewing time because of elevated fiber constituents (Dulphy et al., 1980; McLeod and Smith, 1989). The positive coefficients for lignin when associated with intake rate in Exp. 1 and 4 are not easily explained but are consistent for July-harvested hays in dimension 2 (Table 2) of the MDS analyses. It should be noted, however, that lignin entered the model with a positive coefficient only with a fiber fraction having a negative coefficient or with an estimate of digestibility having a positive coefficient.

Mastication

In the absence of esophageally fistulated sheep or goats, steers were used to assess potential differences in the physical breakdown during mastication of the eight cultivars harvested July 12 (sheep Exp. 2 and goat Exp. 4) and August 21, 1996 (sheep Exp. 3 and goat Exp. 5). Our major interest was in differences between cultivars highly preferred or avoided. Steers offered the hays harvested July 8 consumed diets with little difference in median particle size among cultivars (Table 7). BARCEL, however, had a larger median particle size than C1. The nutritive value of the whole masticate was generally high for all cultivars, averaging 856 g/kg IVTDMD, 127 g/kg CP, and 510 g/kg NDF. KENHY had the highest IVTDMD (875 g/kg) and lowest NDF (481 g/kg), and BARCEL and MOZARK had the highest NDF. The proportion of particles differed in the large and small classes; KENHY had the lowest proportion of large particles (49.4%) and the highest proportion of small particles (9.0%) compared with BARCEL. Conversely, BARCEL had the highest proportion of large particles (61.1%) and the lowest proportion of small particles (3.9%). A consistent pattern is evident of higher IVTDMD and lower NDF in KENHY particles, regardless of particle class, than noted either for BARCEL or MOZARK.

The diet selected from the hays harvested August 21 appeared different (not tested for significance) from the July 8 harvest; whole masticate IVTDMD was higher (877 vs 856 g/kg), as was CP (210 vs 127 g/kg), and NDF was lower (484 vs 510 g/kg). Median particle size of the whole masticate was similar among all cultivars. In contrast to the July harvest, KENHY had the highest proportion of large particles (65.1%) in the whole masticate compared with BARCEL (54.2%) and MOZARK (53.9%). Further, KENHY had the smallest proportion of medium particles (30.9%) compared with BARCEL (41.3%) and MOZARK (40.1%) and the lowest proportion of small particles (4.0%) compared with MOZARK (6.0%) but was similar to BARCEL (4.5%). Variation in NDF was less evident compared with the July 8 harvest. No cultivar had lower NDF than KENHY in any particle class, but only KENHY medium particles had lower NDF than BARCEL.

Implications

Preference expressed by sheep and goats in confinement was similar to preference expressed by cattle when grazing the same eight tall fescue cultivars. The drying of forage for hay and the processing to minimize the impact of plant morphology did not greatly alter the preference rank. Ruminants can cue on subtle differences that seem associated, in part, with soluble carbohydrates and fiber fractions. Selection of agronomically acceptable tall fescue cultivars that are also preferred by ruminants can improve the production efficiency of ruminants with essentially no added production cost.

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Appendix Table 1. Hay stimulus coordinates and dimension weights by animal for the two-dimensional solution to the preference among sheep in Exp. 1, 2, and 3 and among goats in Exp. 4 and 5

	Sheep						Goats			
	Exp. 1		Exp. 2		Exp. 3		Exp. 4		Exp. 5	
Item	Dim 1[a]	Dim 2[a]	Dim 1	Dim 2	Dim 1	Dim 2	Dim 1	Dim 2	Dim 1	Dim 2
	Coordinates									
Cultivar										
BARCEL	−1.6495	0.3733	−1.5813	−0.2470	−0.8061	−1.4361	−0.1705	−1.9444	−1.0930	−0.6196
CI	0.0090	−1.4462	−1.0063	−0.6725	0.8278	−1.0740	−0.8638	0.2309	0.8955	−1.0713
HIMAG	−0.9016	0.9000	−0.4803	1.3518	−1.0563	0.9689	−0.6123	1.1755	0.3433	−0.8894
KENHY	1.6943	0.4144	1.7803	0.4374	1.6080	0.4043	1.8792	0.0271	1.7612	0.0739
KY-31	0.0912	1.4593	−0.0195	1.5433	0.8799	0.6683	1.2845	0.2846	−0.7349	1.0139
MO-96	0.3030	−1.0109	0.0549	−0.6312	−0.0177	−1.1862	−0.4563	−0.8187	−0.8902	1.0262
MOZARK	−1.6075	−1.1521	0.2391	−1.6327	0.0433	1.3063	−1.2004	−0.0339	−0.9810	−1.0864
STARGRAZER	1.0612	0.3721	1.0131	−0.1492	−1.4789	0.3481	0.1396	1.3846	0.6992	1.5527
Animal (dimension weights)										
1	0.9408	1.0559	0.9315	1.0641	0.9499	1.0477	1.0869	0.9048	0.9535	1.0445
2	1.0977	0.8916	1.2260	0.7049	0.9735	1.0258	1.0674	0.9277	1.0906	0.9003
3	1.1545	0.8167	0.9909	1.0090	0.9283	1.0669	0.9362	1.0600	1.0301	0.9690
4	0.9680	1.0310	1.0816	0.9111	1.0459	0.9519	1.3164	0.5167	1.2889	0.5819
5	0.9426	1.0543	0.9335	1.0623	0.9433	1.0537	1.1049	0.8827	1.0319	0.9670
6	1.1174	0.8669	1.2184	0.7179	1.1025	0.8857	0.7088	1.2240	0.9268	1.0682
Rel. imp.[b]	100	26	100	17	100	26	100	19	100	20
R^2	0.844		0.849		0.808		0.875		0.848	

[a]Dim 1 and Dim 2 = dimension one and dimension two.

[b]Rel. imp. = relative importance and is based on the model sums of squares for each dimension.