

Fuzzy comprehensive evaluation of five forage shrubs in Mu Us sandland, China

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ABSTRACT

Chemical compositions during different growing periods, preference and *in vitro* digestibility at the post-fruiting period of five psammophyte shrubs, which include *Caragana intermedia*, *Caragana korshinskii*, *Hedysarum scoparium*, *Hedysarum laeve*, *Salix psammophylla* were determined. The nutritive values were synthetically evaluated in terms of chemical composition, preference and *in vitro* digestibility through fuzzy multifactorial model. The crude protein (CP) concentrations of the five shrubs had the tendency to decrease with growing stage, the peak values of *C. intermedia*, *C. korshinskii* and *S. psammophylla* appeared at blooming period and those of *H. scoparium* and *H. laeve* appeared at vegetative period. The neutral-detergent fiber (NDF), acid-detergent fiber (ADF) and lignin concentrations of *C. intermedia*, *C. korshinskii* and *S. psammophylla* were all decreased before post-fruiting period and then increased significantly; while the variation tendency of those of *H. scoparium* and *H. laeve* were alike, and the lowest NDF, ADF and lignin concentrations were at vegetative period or post-fruiting period. The five shrubs can be used as feedstuffs, the synthetical nutritive value at the post-fruiting period were high in order of *C. intermedia*, *H. scoparium*, *H. laeve*, *C. korshinskii* and *S. psammophylla*. Considering the characteristics of growth and nutritive value, the optimum time to use these shrubs as feedstuffs is the post-fruiting period in autumn. Among the five shrubs, *C. intermedia* is the best as feedstuff for raising the production of livestock.

Keywords: Chemical Composition; Fuzzy Multifactorial Model; Vitro Digestibility; Preference;

Psammophyte Shrubs

1. INTRODUCTION

The Mu Us sandy land, an ecotone comprised of steppe, desert-steppe and steppe-desert, is located in the Ordos plateau, covers an area of approximately 40000 km², and is one of the twelve well-known sandy deserts in China [1]. It is characterized by sparse precipitation, frequent drought and poor soil nutrients [2-4]. The local herbaceous coverage is especially low usually [4]. Provision of adequate quantities of inexpensive high-quality forage is a major challenge in the development of livestock production systems in this region.

Psammophyte shrubs are tolerant to drought, barren ground, and wind erosion, grow rapidly and have well developed root systems. These shrubs have become the dominant species by ecological restoration and play an important role in the control of land degradation and desertification, as well as in grassland construction [5].

With the advance of sand fixation, large areas of sandy grassland mainly with psammophyte shrubs have been established in Mu Us sandy land based on their roles in reducing wind speed and soil erosion and improving ecological environments [6]. Since psammophyte shrubs have high biomass production [7] and also have been widely used as feedstuffs [8], they can play an important role in the nutrition of grazing animals during a withered season and a droughty year. The ultimate aim is effective utilization of sandy land resources to acquire optimum balance of ecological and economic benefits, to realize the sustainability of ley farming and to raise the production of livestock simultaneously. Evaluations of the feeding value of psammophyte shrubs provide a sound basis for determining nutritional feasibility of utilizing them. Some existing reports have indicated that psammophyte shrubs are promising feedstuffs based on their biomass and chemical composition [9-11]. Several researchers have investigated the dynamics of nutrient

contents of psammophyte shrubs [8,12-13]. However, these shrubs have not been fully evaluated in terms of concurrent estimation of chemical composition, preference and digestibility.

The objective of this paper is to determine the dynamics of nutrient content of different growth periods for several psammophyte shrubs in Mu Us sandy land, and to evaluate synthetically the nutritive value at the post-fruiting period in terms of chemical composition, preference and *in vitro* digestibility.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is located at the southwest edge of Mu Us sandy land in Yanchi, Ningxia, China (37°52'30" - 37°57'30"N and 107°26'15" - 107°33'45"E) with an elevation of 1300 m - 1360 m. Mean annual temperature is 8.1°C, the coldest and warmest monthly mean temperatures are -9.3°C in January and 22.0°C in July respectively. Wind season is mainly in April and May, average wind speed reaches 3 - 4 m/s. Mean annual precipitation is 295 mm and about 70 percent concentrated from June to September. Mean annual potential evaporation is about 2710 mm, frost-free period is 148 days. This area is a transition zone between semiarid and arid climate. Rainfall is irregular and characterized by extreme seasonal and annual variability (From Weather Bureau in Yanchi County). Frequent drought is a major limiting factor for growth of sandy land vegetation (The environmental conditions for the experimental year and the long term are shown in **Figure 1**). The regional vegetation cover belongs to desert-steppe type. The major plant species in this area are *Artemisia sphaerocephala*, *Caragana intermedia*, *Psammochloa villosa*, *Salix psammophylla*, *Corispermum tylocarpum*, *Hedysarum scoparium*, *H. laeve*, *Artemisia ordosica*, *Sophora alopecuroides*, *Cynanchum komarovii*, *Pennisetum centrasiatricum*, *Setaria viridis*, *Oxytropis aciphylla*, *Leymus secalinus*, *Nitraria tangutorum*, *Kalidium gracile*, *Achnatherum splendens*. In the past few years, with the development of sand fixation, large areas of artificial and semi-natural grassland mainly included psammophyte shrubs have been established.

2.2. Sample Collection and Preparation

We selected five species of shrubs *Caragana intermedia*, *Caragana korshinskii*, *Hedysarum scoparium*, *Hedysarum laeve* and *Salix psammophylla* which are abundant and widespread in Mu Us sandy land at the same location. In Mu Us sandyland, these shrubs provide essential food especially in autumn and winter for grazing animals, and also can be made into haycube to be used as

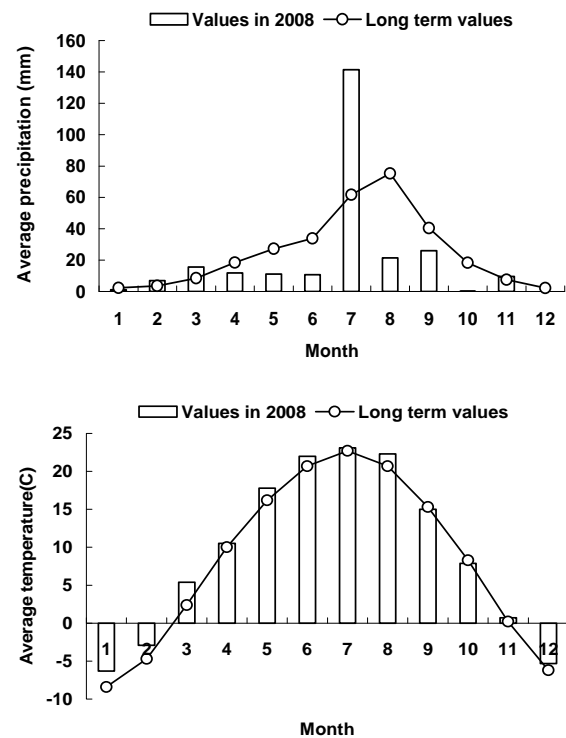


Figure 1. Mean monthly rainfall and temperature for the long-term and for 2008.

supplemental feed in winter. The shrubs were established with five replications of each species in a random block design and grew under natural conditions. We randomly selected 15 5-year-old individuals about 2 m height of each species in each replication, and determined the phenological periods and harvesting dates of the shrubs by field observing. One fourth of the total shoots of less than 3 mm diameter with leaves (it was revealed by investigation that they are the parts of plants most likely to be chosen by sheep and goats [14]) of the 15 assigned plants from each plot replication for each species were harvested by hand at vegetative period (Apr. 20, 2008 for *C. intermedia* and *C. korshinskii*, May 20, 2008 for *H. scoparium* and *H. laeve* and Mar. 20, 2008 for *S. psammophylla*), blooming period (May 20, 2008 for *C. intermedia* and *C. korshinskii*, Jul. 20, 2008 for *H. scoparium* and *H. laeve* and Apr. 20, 2008 for *S. psammophylla*), fruiting period (Jun. 20, 2008 for *C. intermedia* and *C. korshinskii*, Aug. 20, 2008 for *H. scoparium* and *H. laeve* and May 20, 2008 for *S. psammophylla*), post-fruiting period (Sep. 20, 2008) and withering period (Dec. 20, 2008 and Feb. 20, 2009, respectively). The 15 samples obtained per species from the same plot replication for the same period were cut short, mixed to give a single compound sample, and the analytical sample of 1000 g were took out by using quartation. The analytical samples were dried in an oven at 60°C to constant weight and ground to pass through 1-mm screen using a laboratory

mill prior to laboratory analysis [15].

For comparison, samples of *Medicago sativa*, *Achnatherum splendens* and stalks of *Zea mays* which present respectively high, moderate and low quality of local forages were subjected to the same range of analyses as the five species of shrubs at the post-fruiting period.

2.3. Chemical Analyses

Kjeldahl nitrogen (N) was analyzed according to standard procedures, crude protein (CP) concentration was computed as N concentration \times 6.25 [15]. Neutral-detergent fiber (NDF), acid-detergent fiber (ADF) and lignin were determined by the methods of Van Soest [16].

2.4. Determination of *in Vitro* Digestibility

In vitro dry matter digestibility (IVDMD) and *in vitro* organic matter digestibility (IVOMD) of the five shrubs for the post-fruiting period were determined by the two-stage technique of Tilley and Terry [17] using rumen fluid of Tan sheep. Eight female Tan sheep, each with a permanent rumen cannula, belonging to the flocks of the research farm of Ningxia University were used. The sheep were 2 years of age and the mean body weight was 32.6 ± 1.4 kg. They were housed in individual pens (3 m \times 2.5 m), fed with alfalfa hay and concentrate supplement and had free access to water for a 11 day period before collection of the rumen fluid for the *in vitro* incubations. On day 12 of the feeding period a 200 ml rumen fluid sample was extracted from each animal via the cannula. We mixed the fluid contents from different sheep for determining *in vitro* digestibility

2.5. Determination of Preference

For determining preference at the post-fruiting period, five Tan-sheep (average 35.2 ± 1.6 kg of body weight and grazing on grasslands before the experiment) were housed in small individual pens (250 cm \times 200 cm) and fed twice daily (in the morning and in the afternoon) with 4 kg/head of fresh twigs less than 3 diameter and leaves of each species (including *M. sativa*, *A. splendens* and *Z. Mays*) put separately into different lattice of the trough at the same time. An hour later, the intake of each plant was recorded. This was conducted every other day for 2 consecutive days, and repeated five times per animal and varied the positions of the different plants in the troughs each time. Preference index (P_i) was calculated according to the equation [18]:

$$P_i = \frac{\sum_{k=1}^n \frac{D_i k}{RA_i k}}{n}$$

where D_i is the weight percentage of i plant in ingested plants, RA_i is the weight percentage of i plant in provided

plants, k is the time of experimental.

2.6. Statistical Analyses

The mean and standard error values for each parameter were analyzed by 1-way analysis of variance (ANOVA) following Tukey's multiple range test obtained using SPSS12.0 (SPSS, Chicago, IL, USA) software to determine the statistical differences among species and among growth periods.

2.7. Estimation of Feeding Value

We selected the post-fruiting period and evaluated the feeding value of the five shrubs through fuzzy multi-factorial model. The reason for selecting this period was because of the restriction of shrubs to withstand grazing. Forestry scholars suggested that it was feasible in late autumn to use shrubs as feedstuffs when they stopped growing gradually, at this time, the five shrubs were all at post-fruiting period [14]. Moreover, it was convenient for comparison of each other simultaneously.

Considering that it's not comprehensive to evaluate the feeding value of a kind of plant by using single factor or isolated multiple factors, we applied fuzzy transformation principle and maximum subordination principle, choosing those factors related to feeding value of forages and making a comprehensive evaluation.

2.7.1. Model of Fuzzy Comprehensive Evaluation System

Fuzzy comprehensive evaluation refers to the overall evaluation of a thing or a phenomenon affected by multiple factors, and then gives the evaluated thing or phenomenon a nonnegative evaluation value [19].

This model defines a grading level set of $v = \{\text{grading level } 1, 2, \dots, m\}$ and a factor set of $U = \{\text{factor } 1, 2, \dots, n\}$. A membership vector $R_i = (r_{i1}, r_{i2}, \dots, r_{im})$, developed to evaluate the contribution of factor i to the various grading levels can be considered as a fuzzy subset on the grading level set v . According to this model, if r_{ij} represents the membership $\mu_R(U_i, V_j)$ of the contribution of factor i on quality level j , then for n factors and m grading levels, the fuzzy transformation matrix R can be written as:

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

The membership μ is not defined arbitrarily, but by the expertise, knowledge, experience, experimental results, etc., available about the system [20].

To make an acceptable fuzzy evaluation, we may as-

sign each element in the factor set U , a weighting factor based on the expertise of judges or experimental results.

The weighting factor vector A then is a fuzzy subject of factor set U .

$$A = (a_1, a_2, \dots, a_n), a_i \geq 0, \sum_{i=1}^n a_i = 1$$

The fuzzy comprehensive evaluation process is a fuzzy transformation process from a weighting factor vector to a comprehensive grading vector B as given below:

$$B = A \cdot R = (a_1, a_2, \dots, a_n) \cdot \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} = (b_1, b_2, \dots, b_m)$$

2.7.2. Selection of Assessment Factors for Fuzzy Comprehensive Evaluation

According to the characters of shrubs and the contribution of each factors to feeding value, we selected CP, ADF at the post-fruiting period, preference index, grazing seasons and IVOMD as assessment factors. Because each assessment factors has its own level of importance in feeding function, weighting coefficient and quantitative grade standards for each assessment factor (**Figure 2**, **Table 1**) were determined by the expertise.

2.7.3. Fuzzy Comprehensive Evaluation of the Nutritive Value for the Shrubs

Based on the traits of the appraisal for feeding value of forages, we took the following set of grading level:

$$v = \{\text{lowest, lower, low, moderate, high, higher, highest}\} = \{\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7\}$$

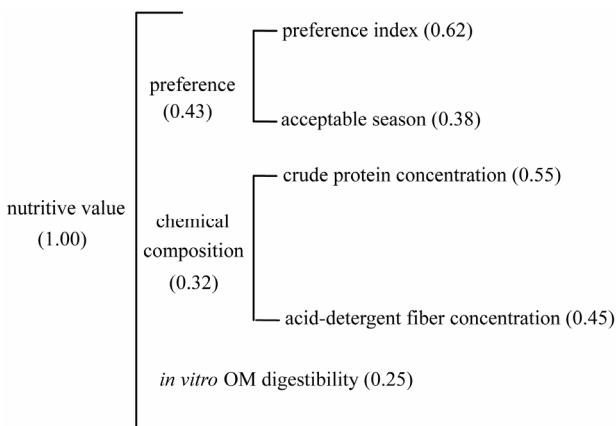


Figure 2. Factorial relationships and their weighting coefficients (numbers in the brackets) for the fuzzy multifactorial model.

where

$$\Phi_i(x) = \begin{cases} \max \left\{ 0, 1 - 12 \left(x - \frac{i-1}{6} \right) \right\}, & x \in (0, 1) \\ 0, & x \in (0, 1) \end{cases} \quad (i = 1, 2, \dots, 7)$$

$\Phi_1, \Phi_2, \dots, \Phi_7$ are truth values of standard language. Appraisal grades of the shrubs can be determined using results of comprehensive judgment values. To simplify the calculation of peak values, we suggested the following method [21]:

$$\Phi = \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \\ \phi_5 \\ \phi_6 \\ \phi_7 \end{bmatrix} = \begin{bmatrix} 0.65 & 0.35 & 0 & 0 & 0 & 0 & 0 \\ 0.35 & 0.40 & 0.25 & 0 & 0 & 0 & 0 \\ 0 & 0.35 & 0.40 & 0.25 & 0 & 0 & 0 \\ 0 & 0 & 0.30 & 0.40 & 0.30 & 0 & 0 \\ 0 & 0 & 0 & 0.27 & 0.40 & 0.33 & 0 \\ 0 & 0 & 0 & 0 & 0.25 & 0.40 & 0.35 \\ 0 & 0 & 0 & 0 & 0 & 0.35 & 0.65 \end{bmatrix}$$

Then result of comprehensive evaluation on feeding value of a certain species of shrub was:

$$B = A \cdot R = A \cdot \Phi = (b_1, b_2, \dots, b_7)$$

According to maximum subordination principle, we chose v_i which corresponded to the largest b_i as the evaluating result.

The comprehensive evaluation value (EV) was:

$$EV = A \cdot R \cdot \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \end{bmatrix} = A \cdot \Phi \cdot \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \end{bmatrix}$$

EV value shows that the comprehensive judgment value corresponding to comprehensive grading vector B . Thus, we may make an objective grade evaluation for different species of the shrubs.

3. RESULTS AND DISCUSSION

3.1. Dynamics of Nutrient Concentration of the Five Shrubs

Chemical compositions of the five shrubs at different growth periods are presented in **Figure 3**. The CP concentrations of the 5 shrubs declined gradually from the blooming period to withered period. *S. psammophylla*, *C.*

Table 1. Quantitative grade standard for comprehensive evaluation (except upper limit).

Φ i	Preference Index	Acceptable Seasons	CP Concentration	ADF Concentration	IVOMD
Φ 7	>1.50	four seasons	>200	<300	>740
Φ 6	1.25 - 1.50	four seasons	150 - 200	300 - 340	650 - 740
Φ 5	1.00 - 1.25	growing seasons	100 - 150	340 - 380	570 - 650
Φ 4	0.75 - 1.00	growing seasons	60 - 100	380 - 420	480 - 570
Φ 3	0.50 - 0.75	autumn, winter	40 - 60	420 - 460	390 - 480
Φ 2	0.25 - 0.50	autumn	30 - 40	460 - 500	310 - 390
Φ 1	<0.25	less than two months	<30	>500	<300

†Units of CP, ADF concentrations and IVOMD were $\text{g}\cdot\text{kg}^{-1}$ DM.

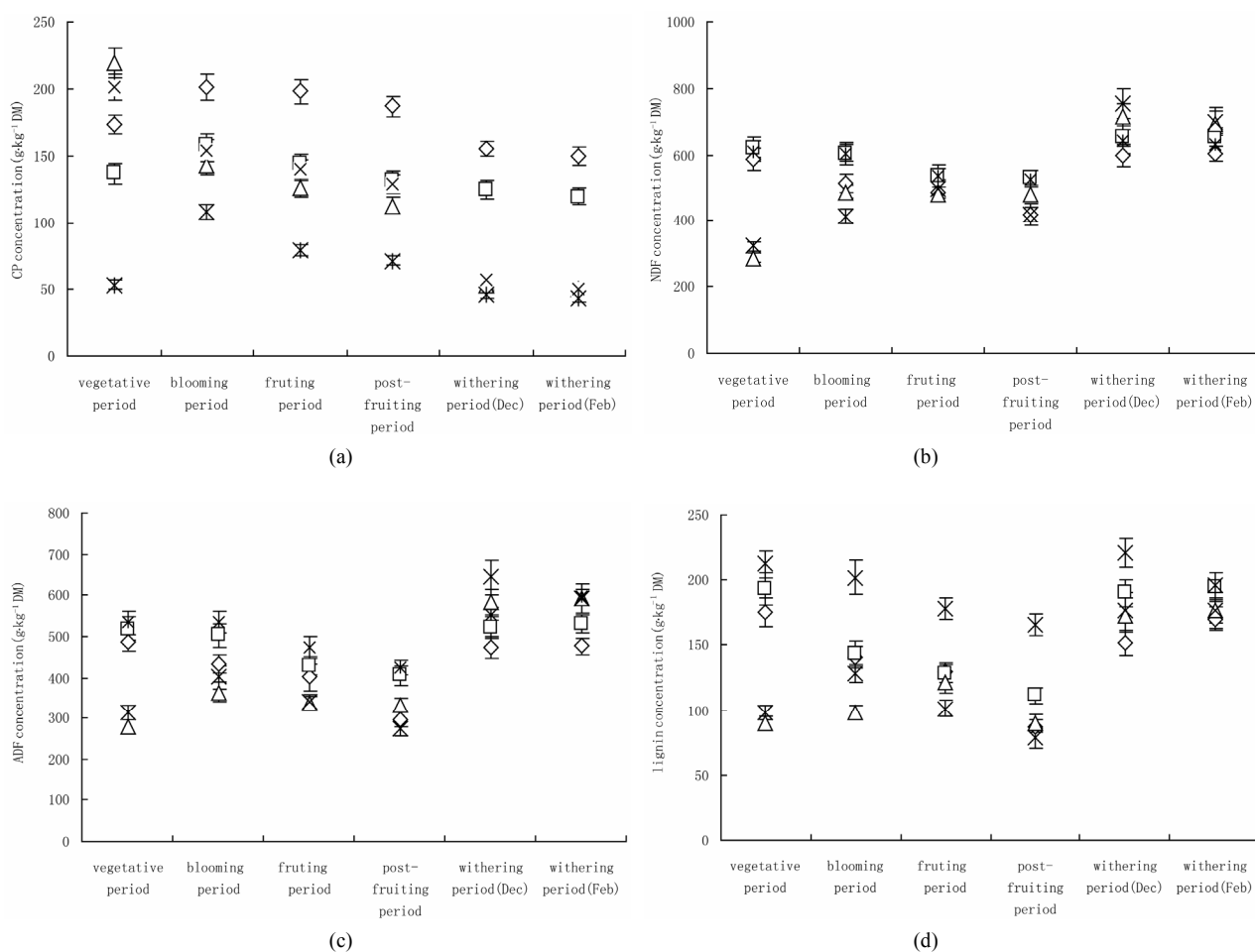


Figure 3. Dynamics of CP (a), NDF (b), ADF (c) and lignin (d) concentration of the five shrubs. \diamond , *Caragana intermedia*; \square , *Caragana korshinskii*; \triangle , *Hedysarum scoparium*; \times , *Hedysarum laeve*; $*$, *Salix psammophylla*.

intermedia and *C. korshinskii* had similar trends, the greatest CP concentrations were at blooming period; for *H. scoparium* and *H. laeve*, the greatest CP concentrations were at vegetative period. Among the five shrubs, CP concentration of *C. intermedia* was the highest and *S. psammophylla* was the lowest. The NDF, ADF and lignin

concentrations for *C. intermedia*, *C. korshinskii* and *S. psammophylla* all decreased from vegetative period to the post-fruiting period, thereafter they increased significantly and reached the highest values at the withering period. The NDF, ADF and lignin concentrations of *H. scoparium* were the lowest at vegetative period and in-

creased with growth period; for *H. laeve*, the lowest NDF concentration was at vegetative period, whereas the lowest ADF and lignin concentration were at post-fruiting period. According to CP and fibrous portion, the nutritive values of the five shrubs at the post-fruiting period were much higher over the whole growing period.

The decrease in CP concentrations with growth period of the five shrubs in the present study agreed with the earlier findings [8,12-13]. Neutral-detergent fiber, acid-detergent fiber and lignin concentrations of *H. scoparium* and *H. laeve* increased gradually and were consistent with the general variation law of forages [22]. In contrast, for *C. intermedia*, *C. korshinskii* and *S. psammophylla*, Neutral-detergent fiber, acid-detergent fiber and lignin concentrations decreased before the post-fruiting period and were reversed to general variation law of forages. This could be explained in terms of a lower leaf to shoot ratio at the early growing stage. At the beginning of growing stage, their leaves were very few and small, for *S. psammophylla*, it even bloomed before leaves emerged; for *C. intermedia* and *C. korshinskii*, they began budding while leaves emerged. In addition, most shoots are old at the early stage. With growing, the ratio of current annual young shoots and leaves increased and resulted in decreasing trends of NDF, ADF and lignin concentrations before the post-fruiting period.

3.2. The Comprehensive Evaluation of Feeding Value of the Five Shrubs at the Post-Fruiting Period

The results of chemical composition at the post-fruit-

ing period, preference, *in vitro* DM and OM digestibility and comprehensive evaluation value (EV) are presented in **Table 2**. Chemical composition of the five shrubs were significantly different ($p < 0.05$). The CP concentration of *C. intermedia* was the highest and only 0.89% lower than that of *M. Sativa*; the CP concentration of *S. psammophylla* was the lowest, but significantly higher than that of cornstalk. The NDF, ADF and lignin concentrations of *H. laeve* and *C. intermedia* were much lower, those of *H. scoparium* were moderate and those of *C. korshinskii* and *S. psammophylla* were much higher. Fibrous matter concentrations of the 5 shrubs were significantly higher than those of *M. sativa*, NDF, ADF concentrations were obviously lower than those of cornstalk and *A. splendens* and lignin concentrations were significantly higher than those of cornstalk and *A. splendens*.

The order of preference indices at the post-fruiting period was high in order *C. intermedia*, *H. scoparium*, *S. psammophylla*, *H. Laeve*, and *C. korshinskii*. It was revealed by investigation that sheep and goats all like eating the five shrubs when they were at the post-fruiting period in late autumn. At this time, *C. intermedia* and *H. scoparium* were eaten best by sheep, *H. laeve* and *S. psammophylla* were better, but *C. Korshinskii* was much worse. Preference indices of the five shrubs were all significantly lower than that of *M. sativa* and higher than that of cornstalk ($p < 0.05$).

In vitro dry matter digestibility and *in vitro* organic matter digestibility of *C. intermedia* were the highest with the value of $682.0 \text{ g}\cdot\text{kg}^{-1}$ and $681.3 \text{ g}\cdot\text{kg}^{-1}$ respectively, and only exceeded by those of *M. Sativa*. Those of

Table 2. Chemical composition, preference, *in vitro* digestibility and Evaluation value of the five shrubs at the post-fruiting period.

parameter	<i>Caragana intermedia</i>	<i>Caragana korshinskii</i>	<i>Hedysarum scoparium</i>	<i>Hedysarum laeve</i>	<i>Salix psammophylla</i>	<i>Medicago sativa</i>	<i>Achnatherum splendens</i>	Stalks of <i>Zea mays</i>
CP (g·kg ⁻¹ DM)	187.0 ± 4.9 ^a	132.5 ± 3.2 ^b	113.0 ± 3.9 ^c	128.8 ± 6.3 ^b	71.4 ± 3.4 ^d	195.9 ± 4.8 ^a	104.8 ± 3.9 ^c	34.5 ± 1.0 ^e
NDF (g·kg ⁻¹ DM)	418.9 ± 14.0 ^d	528.9 ± 15.8 ^c	481.7 ± 14.9 ^{cd}	417.8 ± 18.5 ^d	527.7 ± 13.6 ^c	324.3 ± 10.2 ^f	697.3 ± 14.9 ^b	809.0 ± 21.9 ^a
ADF (g·kg ⁻¹ DM)	296.1 ± 9.6 ^{cd}	406.0 ± 13.4 ^b	331.5 ± 10.3 ^c	272.9 ± 9.5 ^d	423.4 ± 11.4 ^b	216.7 ± 10.8 ^e	433.5 ± 11.4 ^b	523.4 ± 18.0 ^a
Lignin (g·kg ⁻¹ DM)	87.7 ± 2.9 ^c	111.4 ± 4.0 ^b	90.4 ± 3.7 ^c	78.2 ± 4.5 ^{cd}	165.7 ± 5.4 ^a	77.2 ± 4.8 ^{cd}	58.4 ± 2.6 ^e	66.9 ± 4.4 ^d
Acceptable season	autumn, winter	autumn, winter	autumn, winter	autumn, winter	autumn, winter	four season	growing season	autumn, winter
Preference index	1.3 ± 0.1 ^b	0.6 ± 0.1 ^e	1.2 ± 0.1 ^{bc}	0.9 ± 0.1 ^d	1.1 ± 0.1 ^c	1.6 ± 0.1 ^a	0.8 ± 0.1 ^d	0.3 ± 0.0 ^f
IVDMD (g·kg ⁻¹ DM)	682.0 ± 6.0 ^b	614.1 ± 6.3 ^c	601.2 ± 7.3 ^c	551.7 ± 6.0 ^d	492.7 ± 5.5 ^e	757.6 ± 8.3 ^a	449.7 ± 6.0 ^f	437.4 ± 6.7 ^f
IVOMD (g·kg ⁻¹ DM)	681.3 ± 6.0 ^b	621.6 ± 5.4 ^c	600.0 ± 4.3 ^d	546.6 ± 5.7 ^e	504.7 ± 5.6 ^f	755.9 ± 6.5 ^a	473.0 ± 5.7 ^e	425.1 ± 5.2 ^h
Evaluation value (EV)	5.5 ± 0.1 ^b	4.0 ± 0.1 ^{de}	4.8 ± 0.1 ^c	4.4 ± 0.1 ^d	3.9 ± 0.1 ^{de}	6.6 ± 0.1 ^a	3.8 ± 0.1 ^c	2.2 ± 0.1 ^f

†Means followed by different letters within a row are significantly different at $p < 0.05$.

C. korshinskii, *H. scoparium* and *H. laeve* were moderate, while those of *S. psammophylla* were the lowest ($p < 0.05$), but they were all significantly higher than those of *A. splendens* and cornstalk ($p < 0.05$).

In the past, the nutritional qualities of psammophyte shrubs have usually been evaluated by adopting single factor or isolated multiple factors [8-12], but these methods were confined greatly in practice. The feeding value of shrubs could not be reflected comprehensively and some important information was probably lost by using these methods. In this paper, we applied fuzzy multifactorial model to evaluate the nutritive values of the five shrubs at the post-fruiting period. Compared with the methods using single or isolated multiple factors, our method emphasized the application of mathematical model, that was, a strictly quantitative approach to the evaluation of the forage shrubs. This model has also been proved to be an efficient tool for the comprehensive evaluation of forages by Wang and Zhu [21].

The evaluation values of the five shrubs from high to low were *C. intermedia*, *H. scoparium*, *H. laeve*, *C. Korshinskii*, and *S. psammophylla* in sequence. The comprehensive evaluation values for the five shrubs were all lower than that of *M. sativa*. As feedstuffs, the five shrubs were all better than *A. splendens* and cornstalk. According to maximum subordination principle, the feeding value of *C. intermedia* was the highest, that of *H. scoparium* was high and those of *H. laeve*, *C. korshinskii* and *S. psammophylla* were moderate.

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