Nutritive Value of Several Tropical Legume Shrubs in Hainan Province of China

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Abstract: The aim of this experiment was to evaluate the nutritive value of tropical legume shrub species *Crotalaria argentea*, *Leucaena leucocephala*, *Flemingia macrophylla*, *Cajanus cajan*, *Dendrolobium triangular*, *Cassia didymobotrya*, *Cassia bicapsularis* and *Acacia farnesiana* in Hainan province, China based on their chemical compositions and in vitro Gas Production (GP). The Crude Protein (CP) contents of legume shrubs ranged from 13.43% (*D. triangular*) to 18.44% (*C. argentea*). The Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) contents varied between 20.73% (*S. didymobotrya*) to 48.61% (*D. triangular*) and 21.11% (*S. didymobotrya*) to 55.27% (*D. triangular*), respectively. The Total Tannins (TT) ranged from 0.78% (*C. argentea*) to 2.67% (*A. farnesiana*). The Relative Feed Values (RFV) of tropical legume shrubs ranged from 85.99% (*D. triangular*) to 321% (*C. didymobotrya*). GP of tropical legume shrubs was determined 0, 3, 6, 12, 24, 48, 72 and 96 h after incubation and their kinetics were described using the equation $y = a + b(1 - e^{-kt})$. The calculated *in vitro* Dry Matter Degradability (IVDMD), Organic Matter Digestibility (OMD) and Metabolizable Energy (ME) ranged from 36.91% (*D. triangular*) to 79.30% (*C. bicapsularis*), 40.70% (*F. macrophylla*) to 72.70% (*C. bicapsularis*), 5.41 MJ kg$^{-1}$ (*D. triangular*) to 11.26 MJ kg$^{-1}$ (*C. bicapsularis*), respectively.

Key words: Chemical composition, relative feed value, in vitro gas production, in vitro dry matter degradability, organic matter digestibility, metabolizable energy

INTRODUCTION

Hainan province situated at the Southernmost tip of China is the 2nd largest island of China. It covers a land with area of 35.4 km$^2$ and has a tropical monsoon climate with very clear rainy and dry seasons each year. The rainy season runs from May to October and the dry season from November to April. There are calculated 9-10$^4$ Hainan black goats (Capra hircus) in the island. Most of them belong to different smallholder farmers.

These goats live largely on the natural pasture and crop residues and are often short of feeds during the long dry season. Thus, the major constraint of goat productivity in this area is inadequate nutrition. Most tropical legume shrubs are evergreen plants, which contain high protein content and Gross Energy (GE) (Blair, 1990; Leng, 1997; Rubanza et al., 2003; Salem et al., 2006; Mahlapa et al., 2009) and play an important role in ruminant feeding systems in many tropical areas around the world. The *in vitro* Gas Production (GP) technique which provides empirical equations to estimate the digestibility and Metabolizable Energy (ME) content of animal feeds (Menke and Steingass, 1988) has been widely used to evaluate the nutritive value of animal feeds such as forage, straws, byproducts and tropical feeds (Getachew et al., 1998a, b; Makkar et al., 1999; Mould, 2003; Negesse et al., 2009; Camacho et al., 2010). Feeding legume shrubs could improve the nutritional status of goats during the dry season. But the chemical compositions and feeding values of legume shrubs in Hainan are largely unknown. Therefore, the present study was aimed to evaluate the nutritive value of legume shrubs through measurement of their chemical compositions, *in vitro* GP kinetics and some estimated parameters such as ME and Organic Matter Digestibility (OMD).

MATERIALS AND METHODS

Sample preparation: The foliage of *Crotalaria argentea*, *Leucaena leucocephala*, *Flemingia macrophylla*, *Cajanus cajan*, *Dendrolobium triangular*, *Cassia didymobotrya*, *Cassia bicapsularis* and *Acacia farnesiana* were procured from the legume shrubs grown...
at the Tropical Pasture Research Center (TPRC) of Chinese Academy of Tropical Agricultural Sciences (CATAS). TPRC is located in Dazhou city, Hainan, China and has latitude of 19°30'N, longitude of 109°30'E and altitude of 149 m. The legume shrub species were selected based on ease of collection and their wide occurrence in Hainan province, China. Samples were oven dried at 65°C for 48 h and milled through a 1.0 mm screen for in vitro studies and chemical analysis.

**Chemical analysis:** Dry Matter (DM), Ash contents (XA) and Nitrogen (N) content were measured by the Kjeldahl method (AOAC, 1990). Crude Protein (CP) was calculated as N×6.25. Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) were determined by the method of Van Soest et al. (1991). Gross Energy (GE) content was determined by PARR6300. Total Tannin (TT) content was determined by the method of Makkar (2003). All chemical analyses were carried out in triplicate.

**Relative feed value:** Relative Feed Value (RFV) developed by the Hay Marketing Task Force of American Forage and Grassland Council (Rohweder et al., 1978) (Table 1) is the most widely used index for forage quality in the marketing of hays (Rohweder et al., 1978). RFV of legume shrubs was calculated from the estimates of Dry Matter Digestibility (DMD) and Dry Matter Intake (DMI). Following are the used equations:

\[
ADF = \text{Acid Detergent Fiber (DM\%)}
\]

\[
DMI = \text{Dry Matter Intake (BW\%)}
\]

\[
DMD (\%) = 88.9 - (0.779 	imes ADF\%)
\]

\[
DMI (BW\%) = 120/\text{NDF}\%
\]

\[
RFV = (DMD\% - DMI\%) / 1.29
\]

where, BW is the body weight.

**In vitro gas production:** The rumen fluid was collected from three healthy mature Hainan black goats using with permanent rumen cannulae (O = 50 mm) for measurement of In vitro Dry Matter Digestibility (IVDMD) and GP. Rumen fluid was strained through gauze and mixed with buffer solution as described by Menke and Steingass (1988). About 200 mg samples were placed in polyester/polyethylene bags (size 5×3 cm, pore size 25 μm), incubated at 39°C with 35 mL rumen liquor-buffer mixture in 100 mL glass syringes and measured after 0, 3, 6, 12, 24, 48, 72 and 96 h incubation. After finishing the in vitro digestion trials, bags were gently rinsed with cold tap water and dried at 65°C for 48 h to determine IVDMD. The residues were analyzed for Organic Matter (OM) and Organic Matter Digestibility (OMD). Each measurement was performed in triplicate. GE of feeds was obtained using the method described previously (ARC, 1965) and Metabolizable Energy content (ME) value was calculated using the following equation:

\[
ME = \text{GE} \times \text{IVDMD} \times 0.815
\]

The exponential Eq:

\[
y = a + b (1 - \text{exp}^{-c})
\]

Where:

- \(y\) = The gas production at time \(t\)
- \(a\) = The gas production from the immediately soluble fraction (mL)
- \(b\) = The gas production from the insoluble fraction (mL)
- \(c\) = The gas production rate constant
- \(a+b\) = The potential gas production (mL)
- \(t\) = The incubation time (h)

proposed by Orskov and McDonald (1979) was used to determine characteristics of gas production.

**Predictive methods:** The ME (MJ kg⁻¹ DM) and OMD of samples were calculated using equations of Menke et al. (1979) as follows:

\[
\text{ME (MJ kg}^-1\text{DM)} = 2.20 + 0.136 \text{GP} + 0.057 \text{CP}
\]

\[
\text{OMD (\%)} = 14.88 + 0.889 \text{GP} + 0.45 \text{CP} + 0.0651 \text{XA}
\]

Where, ME (24 h GP) and OMD (24 h GP) were calculated by using 24 h net Gas Production (GP) (mL/200 mg), CP(%) and XA(%). Similarly, the ME (48 h GP) and OMD (48 h GP) as well as ME (96 h GP) and OMD (96 h GP) were calculated using GP, CP and XA measured 48 and 96 h after incubation, respectively.
Statistical analysis: Chemical composition and in vitro GP were analyzed using the General Linear Models (GLM) procedure of SAS (1996) in a completely randomized design to test differences among plant species. Differences of the means within species of grass or legume and between grass and legume were compared using probability of difference. The means were compared for statistical significance by using Duncan’s multiple range test (Duncan, 1955). Mean differences were considered significant at p<0.05. Standard errors of means were calculated from the residual mean square in the analysis of variance. As there were great differences in the chemical composition and in vitro kinetics among the Legume shrub species, Pearson correlation coefficients (r) between chemical composition and GP and between some estimated parameters within legume shrubs were estimated.

RESULTS

Chemical composition: The chemical composition and TT contents of the shrub species are shown in Table 2. The DM contents of shrubs ranged between 25.02 (S. bispinularis) to 37.12% (A. farnesiana). CP contents ranged between 13.43% (D. triangulate) to 18.44% (C. argentea). EE contents varied between 2.36 (F. macrophylla) to 5.06% (C. bispinularis). ADF and NDF contents varied between 20.73% (C. didymobotrya) to 48.61% (D. triangulate) and 21.11% (C. didymobotrya) to 55.27% (D. triangulate), respectively. GP contents varied between 17.37 MJ kg⁻¹ (C. argentea) to 19.57 MJ kg⁻¹ (A. farnesiana). TT ranged from 0.78% (C. argentea) to 2.67% (A. farnesiana).

Relative Feed Value (RFV): DMD, DMI and RFV of the shrub species are shown in Table 3. DMD of shrubs ranged from 51.03% (D. triangulate) to 72.75% (C. didymobotrya). DMI ranged from 2.17 (D. triangulate) to 5.68% (C. didymobotrya). RFV ranged from 85.9% (D. triangulate) to 321% (C. didymobotrya). The grades of C. argentea, L. leuconeophila, F. macrophylla, C. cajan, D. triangulate, C. didymobotrya, C. bispinularis, and A. farnesiana were 2, prime, 2, 1, 4, prime, prime and prime, respectively. In another word, the grade of shrubs ranged from 4 to prime according to the standard assigned by Hay Market Task Force of American Forage and Grassland Council given in Table 1.

The order of shrub species containing RFV from high to low was C. didymobotrya, C. bispinularis, A. farnesiana, L. leuconeophila, F. macrophylla, C. cajan, C. argentea, F. macrophylla and D. triangulate. Except D. triangulate, all the observed legume shrubs are high grade fed for ruminants.

Gas production: The GP profiles for the shrub species examined are shown in Fig. 1. There were differences

<table>
<thead>
<tr>
<th>Species</th>
<th>DM (%)</th>
<th>CP</th>
<th>EE</th>
<th>ADF</th>
<th>NDF</th>
<th>Ash</th>
<th>GE</th>
<th>TT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. argentea</td>
<td>25.98</td>
<td>18.44</td>
<td>2.59</td>
<td>30.69</td>
<td>49.19</td>
<td>9.25</td>
<td>17.3</td>
<td>0.78</td>
</tr>
<tr>
<td>L. leuconeophila</td>
<td>31.25</td>
<td>19.18</td>
<td>4.13</td>
<td>27.19</td>
<td>37.66</td>
<td>8.25</td>
<td>17.88</td>
<td>2.34</td>
</tr>
<tr>
<td>F. macrophylla</td>
<td>33.67</td>
<td>14.22</td>
<td>2.36</td>
<td>30.43</td>
<td>45.27</td>
<td>5.40</td>
<td>17.98</td>
<td>1.91</td>
</tr>
<tr>
<td>C. cajan</td>
<td>36.26</td>
<td>15.29</td>
<td>4.43</td>
<td>34.29</td>
<td>43.52</td>
<td>4.80</td>
<td>19.16</td>
<td>1.29</td>
</tr>
<tr>
<td>D. triangulate</td>
<td>35.98</td>
<td>13.43</td>
<td>3.31</td>
<td>48.61</td>
<td>55.27</td>
<td>5.85</td>
<td>18.05</td>
<td>1.16</td>
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<tr>
<td>C. didymobotrya</td>
<td>26.69</td>
<td>15.49</td>
<td>4.73</td>
<td>20.73</td>
<td>21.11</td>
<td>7.19</td>
<td>17.59</td>
<td>1.82</td>
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<tr>
<td>C. bispinularis</td>
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<td>17.19</td>
<td>5.06</td>
<td>21.94</td>
<td>23.75</td>
<td>8.32</td>
<td>17.42</td>
<td>1.38</td>
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<tr>
<td>A. farnesiana</td>
<td>37.12</td>
<td>18.05</td>
<td>4.60</td>
<td>21.87</td>
<td>31.27</td>
<td>4.22</td>
<td>19.57</td>
<td>2.67</td>
</tr>
<tr>
<td>Mean</td>
<td>31.49</td>
<td>16.29</td>
<td>3.66</td>
<td>30.59</td>
<td>38.38</td>
<td>6.66</td>
<td>18.12</td>
<td>1.45</td>
</tr>
<tr>
<td>SE</td>
<td>4.99</td>
<td>1.94</td>
<td>0.96</td>
<td>9.83</td>
<td>12.19</td>
<td>1.85</td>
<td>0.81</td>
<td>0.59</td>
</tr>
</tbody>
</table>

DM: Dry Matter (%), CP: Crude Protein (%), EE: Neutral Detergent Fiber (%), ADF: Acid Detergent Fiber (%), GE: Gross Energy (MJ kg⁻¹), TT: Total Tannin (%). Means within the same column with different letters are significantly different (p<0.05). SE: Standard Error

<table>
<thead>
<tr>
<th>Species</th>
<th>DMD (%)</th>
<th>DMI (%)</th>
<th>RFV</th>
<th>Quality standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. argentea</td>
<td>64.99</td>
<td>2.44</td>
<td>123.0</td>
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<tr>
<td>L. leuconeophila</td>
<td>67.72</td>
<td>3.10</td>
<td>167.0</td>
<td>Prime</td>
</tr>
<tr>
<td>F. macrophylla</td>
<td>58.18</td>
<td>2.65</td>
<td>119.0</td>
<td>2</td>
</tr>
<tr>
<td>C. cajan</td>
<td>62.18</td>
<td>2.76</td>
<td>133.0</td>
<td>1</td>
</tr>
<tr>
<td>D. triangulate</td>
<td>51.03</td>
<td>2.17</td>
<td>85.9</td>
<td>4</td>
</tr>
<tr>
<td>C. didymobotrya</td>
<td>72.79</td>
<td>5.68</td>
<td>321.0</td>
<td>Prime</td>
</tr>
<tr>
<td>C. bispinularis</td>
<td>71.81</td>
<td>5.05</td>
<td>281.0</td>
<td>Prime</td>
</tr>
<tr>
<td>A. farnesiana</td>
<td>71.86</td>
<td>3.84</td>
<td>214.0</td>
<td>Prime</td>
</tr>
<tr>
<td>Mean</td>
<td>65.07</td>
<td>3.47</td>
<td>181.0</td>
<td>-</td>
</tr>
<tr>
<td>SE</td>
<td>7.66</td>
<td>1.29</td>
<td>84.0</td>
<td>-</td>
</tr>
</tbody>
</table>

DMD: Dry Matter Digestibility (%), DMI: Dry Matter Intake (%), RFV: Relative Feed Value. Means within the same column with different letters are significantly different (p<0.05). SE: Standard Error

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among species in the gas volume produced from digestion throughout the incubation period: gas volume produced from A. farnesiana was the lowest and from C. bicapularis was the highest. The GP kinetics and some estimated parameters are shown in Table 4. GP parameters a, b, a+b, and c of shrubs ranged from -4.57% (A. argentea) to 0.21% (A. farnesiana), 12.01% (A. farnesiana) to 37.04% (C. didymobotrya), 12.22% (A. farnesiana) to 38.31% (C. bicapularis), 0.04% (F. macrophylla) and 0.05% (D. triangulare) to 0.08% (C. bicapularis), respectively. The GP at 96 h incubation ranged from 12.29 mL (A. farnesiana) and 40.07 mL (C. bicapularis). The IVMD of the shrub species ranged from 36.91-79.30%. The order of shrub species which had GP parameters a+b, GP 96 h and IVMD from high to low was Cassia bicapularis, Cassia didymobotrya, Cratylia argentea, Leucaena leucocephala, Cajanus cajan, Flemingia macrophylla, Dendrolobium triangulare and Acacia farnesiana.

Metabolizable energy and organic matter digestibility:
The observed and calculated values of ME and OMD are shown in Table 5. The ME values of shrubs ranged from 5.41 (D. triangulare) to 11.26 MJ kg⁻¹ (C. bicapularis) in in vitro observation from 3.23% (A. farnesiana) to 6.34% (C. bicapularis) at 24 h incubation, from 3.54% (A. farnesiana) to 7.07% (S. bicapularis) at 48 h and from 3.78% (A. farnesiana) to 7.64% (C. bicapularis) at 96 h, respectively. The OMD values of shrubs ranged from 4.70% (F. macrophylla) to 72.70% (C. bicapularis) in in vitro observation, from 21.66% (A. farnesiana) to 41.96% (C. bicapularis) at 24 h, 23.68% (A. farnesiana) to 46.72% (C. bicapularis) at 48 h, 25.21% (A. farnesiana) to 50.48% (C. bicapularis) at 96 h, respectively. The observed values of ME and OMD were higher than the predicted and the predicted increase with the incubation time. The wide variation in the predicted values of ME and OMD is evident when compared to those observed in vitro.

Correlations among gas production, some estimated parameters and chemical composition: The correlation coefficients among chemical composition, GP and some estimated parameters of legume shrub species are shown in Table 6. There were strong positive correlations among GP, ME, IVMD and OMD contents (data not presented). CP and EE contents were positively correlated with GP, ME, IVMD and OMD (p<0.05). XA were positively correlated with GP (p<0.05), ME (p<0.05), IVMD (p<0.05) and OMD (p<0.05). ADF and NDF contents were negatively correlated with GP (p<0.05), ME (p<0.05), IVMD (p<0.05) and OMD (p<0.05). GE and TT contents were negatively correlated with GP, ME, IVMD and OMD (p<0.05). ADF/CP and NDF/CP contents were negatively correlated with GP (p<0.05), ME (p<0.05), IVMD (p<0.05) and OMD (p<0.05).

Predictive equations of ME, IVMD and OMD for tropical legume shrubs: Predictive equations were screened with multiple linear regression analysis of several chemical compositions and GP at 96 h of incubation which is significantly correlated with ME,

![Graph showing cumulative gas production profiles](image)

**Table 4: Gas production kinetics and some estimated parameters**

<table>
<thead>
<tr>
<th>Species</th>
<th>a</th>
<th>b</th>
<th>a+b</th>
<th>c</th>
<th>GP</th>
<th>IVMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cratylia argentea</td>
<td>-4.5a</td>
<td>35.83a</td>
<td>31.29a</td>
<td>0.06a</td>
<td>31.68a</td>
<td>66.22a</td>
</tr>
<tr>
<td>Leucaena leucocephala</td>
<td>-0.87a</td>
<td>30.77a</td>
<td>29.90a</td>
<td>0.05a</td>
<td>30.19a</td>
<td>60.67a</td>
</tr>
<tr>
<td>Flemingia macrophylla</td>
<td>0.01a</td>
<td>21.90a</td>
<td>21.50a</td>
<td>0.04a</td>
<td>21.46a</td>
<td>43.06a</td>
</tr>
<tr>
<td>Cajanus cajan</td>
<td>-0.24a</td>
<td>27.71a</td>
<td>27.47a</td>
<td>0.05a</td>
<td>27.78a</td>
<td>59.36a</td>
</tr>
<tr>
<td>Dendrolobium triangulare</td>
<td>-0.61a</td>
<td>20.73a</td>
<td>20.11a</td>
<td>0.04a</td>
<td>19.31a</td>
<td>36.91a</td>
</tr>
<tr>
<td>Cassia didymobotrya</td>
<td>-2.85a</td>
<td>37.04a</td>
<td>34.19a</td>
<td>0.06a</td>
<td>35.08a</td>
<td>76.16a</td>
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<tr>
<td>Cassia bicapularis</td>
<td>-3.66a</td>
<td>41.97a</td>
<td>38.31a</td>
<td>0.08a</td>
<td>40.07a</td>
<td>79.30a</td>
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<tr>
<td>Acacia farnesiana</td>
<td>0.21a</td>
<td>12.01a</td>
<td>12.22a</td>
<td>0.05a</td>
<td>12.29a</td>
<td>46.49a</td>
</tr>
<tr>
<td>Mean</td>
<td>-1.57</td>
<td>28.49</td>
<td>26.92</td>
<td>0.05</td>
<td>27.23</td>
<td>57.39</td>
</tr>
</tbody>
</table>

SE | 1.85 | 9.93 | 8.44 | 0.01  | 9.06  | 15.66 |

Means within the same column with different letters are significantly different (p<0.05). SE: Standard Error

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Table 5: Metabolizable Energy (ME, MJ kg⁻¹ DM) and Organic Matter Digestibility (OMD) (DM%) for the shrub species evaluated by different methods

<table>
<thead>
<tr>
<th>Species</th>
<th>ME in vitro</th>
<th>24 h GP</th>
<th>48 h GP</th>
<th>96h GP</th>
<th>OMD in vitro</th>
<th>24 h GP</th>
<th>48 h GP</th>
<th>96h GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crotalaria argentea</td>
<td>9.39</td>
<td>5.03</td>
<td>5.79</td>
<td>6.36</td>
<td>60.10</td>
<td>33.37</td>
<td>38.37</td>
<td>42.06</td>
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<td>Leucaena leucocephala</td>
<td>8.83</td>
<td>4.95</td>
<td>5.79</td>
<td>6.31</td>
<td>55.65</td>
<td>33.17</td>
<td>38.38</td>
<td>41.76</td>
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<tr>
<td>Flemingia macrophylla</td>
<td>6.30</td>
<td>3.97</td>
<td>4.05</td>
<td>5.15</td>
<td>40.70</td>
<td>26.48</td>
<td>30.91</td>
<td>34.19</td>
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<td>Cajanus cajan</td>
<td>7.85</td>
<td>4.50</td>
<td>5.27</td>
<td>5.77</td>
<td>47.94</td>
<td>29.93</td>
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<td>5.41</td>
<td>3.77</td>
<td>4.40</td>
<td>4.78</td>
<td>34.75</td>
<td>25.15</td>
<td>26.29</td>
<td>31.73</td>
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<tr>
<td>Cassia didymobotrya</td>
<td>10.89</td>
<td>4.62</td>
<td>5.77</td>
<td>6.73</td>
<td>70.68</td>
<td>30.73</td>
<td>38.25</td>
<td>44.49</td>
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<tr>
<td>Cassia bicapsularis</td>
<td>11.26</td>
<td>6.34</td>
<td>7.07</td>
<td>7.64</td>
<td>72.70</td>
<td>41.96</td>
<td>46.62</td>
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<tr>
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<td>3.23</td>
<td>3.54</td>
<td>3.78</td>
<td>44.53</td>
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<td>4.56</td>
<td>5.29</td>
<td>5.82</td>
<td>53.38</td>
<td>30.31</td>
<td>35.67</td>
<td>38.52</td>
</tr>
<tr>
<td>SE</td>
<td>2.08</td>
<td>0.95</td>
<td>1.08</td>
<td>1.22</td>
<td>13.83</td>
<td>6.21</td>
<td>7.05</td>
<td>7.96</td>
</tr>
</tbody>
</table>

Means within the same column with different letters are significantly different (p<0.05). SE: Standard error

Table 6: The correlation coefficients between GP, ME, IVDMD and OMD and chemical composition of Legume shrubs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GP</th>
<th>ME</th>
<th>IVDMD</th>
<th>OMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>0.23</td>
<td>0.54</td>
<td>0.50</td>
<td>0.49</td>
</tr>
<tr>
<td>EE</td>
<td>0.54</td>
<td>0.61</td>
<td>0.53</td>
<td>0.56</td>
</tr>
<tr>
<td>ADF</td>
<td>-0.41</td>
<td>-0.81*</td>
<td>-0.75*</td>
<td>-0.77*</td>
</tr>
<tr>
<td>NDF</td>
<td>-0.44</td>
<td>-0.76*</td>
<td>-0.72*</td>
<td>-0.74*</td>
</tr>
<tr>
<td>Ash</td>
<td>0.77*</td>
<td>0.66</td>
<td>0.74*</td>
<td>0.69</td>
</tr>
<tr>
<td>GE</td>
<td>-0.18</td>
<td>-0.42</td>
<td>-0.47</td>
<td>-0.45</td>
</tr>
<tr>
<td>TT</td>
<td>-0.57</td>
<td>-0.14</td>
<td>-0.23</td>
<td>-0.19</td>
</tr>
<tr>
<td>ADF/CP</td>
<td>-0.42**</td>
<td>-0.80**</td>
<td>-0.74**</td>
<td>-0.75**</td>
</tr>
<tr>
<td>NDF/CP</td>
<td>-0.47**</td>
<td>-0.84**</td>
<td>-0.78**</td>
<td>-0.80**</td>
</tr>
</tbody>
</table>

*Significance at 5% level; **significance at 1% level

IVDMD and OMD. About three approaches were developed to predict ME, IVDMD and OMD for tropical Legume shrubs as:

\[
ME = 9.52 - 0.94 \times ADF + 0.41 \times NDF + 0.16 \times GP + 10.06 \times (ADF/CP) - 5.17 \times (NDF/CP) \quad (R^2 = 0.9973; p<0.01) \tag{1}
\]

\[
IVDMD = 5.31 + 0.10 \times ADF + 7.07 \times NDF - 0.04 \times XA + 1.28 \times GP + 151.63 \times (ADF/CP) + 113.26 \times (NDF/CP) \quad (R^2 = 0.9975; p<0.01) \tag{2}
\]

\[
OMD = 55.12 - 8.60 \times ADF + 5.09 \times NDF + 1.12 \times GP + 114.54 \times (ADF/CP) - 77.60 \times (NDF/CP) \quad (R^2 = 0.9978; p<0.01) \tag{3}
\]

Where, the units of ME and GP were MJ kg⁻¹ DM and mL/200 mg DM at 96 h of incubation, respectively the unit of IVDMD and OMD was %; the unit of CP, ADF, NDF and XA was DM%.

**DISCUSSION**

**Chemical composition:** Chemical compositions of some tropical legume shrubs have been reported previously. Kexian et al. (1998) reported that in Colombia, N (CP), ADF and NDF contents were 3.37, 36.73 and 58.87 % for C. argentea and 2.86, 36.80 and 48.56 % for **F. macrophylla**, respectively. Tiemann et al. (2008) reported that in the same region of Colombia, N (CP), ADF and NDF contents were 41.3, 232 and 423 g kg⁻¹ DM for **C. argentea** and 38.1, 167 and 431 g kg⁻¹ DM for **L. leucocephala**, respectively. However, their results of N contents (CP) (3.37% and 41.3 g kg⁻¹ DM, respectively) for **C. argentea** were higher than that of 18.44% in this study.

The ADF and NDF contents for **C. argentea** in the study were lower than that reported by Kexian et al. (1998) and higher than that by Tiemann et al. (2008). Compared to the present study, Kexian et al. (1998) reported lower N (CP) and comparable NDF and ADF contents for **F. macrophylla** and Tiemann et al. (2008) reported higher N (CP), higher NDF and lower ADF contents for **L. leucocephala**. Getachew et al. (2002) analyzed leaf samples of tropical browse species collected from the International Livestock Research Institute (ILRI) Forage Seed Multiplication Centre, Zway (Ethiopia) and reported higher CP contents, 194.7, 171.8 and 265.5 g kg⁻¹ DM for **L. leucocephala**, **F. macrophylla** and **C. cajan**, respectively, compared to the present study. Fondevila et al. (2002) reported in Brazil, N (CP), ADF and NDF contents of 33.7, 198 and 390, respectively for **L. leucocephala** and 30.2, 328 and 523 g kg⁻¹ DM, respectively for **C. cajan**.

Compared to the present results, their results of N and NDF contents are higher and of ADF contents are lower. Ramirez et al. (2000) and Ramirez and Lara (1998) reported higher level of CP, ADF and NDF contents (20.2, 23.4 and 39.5%) for **A. farnesiana** in Mexico than the results. Interestingly, **D. triangulare** has been reportedly used as tropical forage legumes in marginal smallholder farming systems of the sub humid and humid tropical regions (Schultze-Kraft et al., 1989; Van der Maesen, 1996; Kretschmer Jr. and Fitman, 2001). **C. bicepsularis** and **C. didymobotrya** has also been reportedly used as medicine in Africa because their extracts have diseases or parasites-resistant activity (Deogracious and Innocent,
The minimum CP in diet required for lactation and growth of ruminants are 12% and 11.3%, respectively (ARC, 1984). L. leucocephala, C. argentea and A. farnesiana showed comparable CP content with Medicago sativa (NRC, 2007). Overall, the mean CP content in the legume shrub species was 16.29%, obviously higher than the threshold CP requirement, indicating these eight legume shrub species could be considered as potential CP source to supplement poor quality basal diets. TT of legume shrubs has been reported. For example, Kexian et al. (1998) reported that the total condensed tannin content were 0% for C. argentea and 5.13% for F. macrophylla which is higher than that in the present study.

Tiemann et al. (2008) reported a higher TT level for C. argentea and L. leucocephala compared with that of the current study. Getachew et al. (2002) reported TT were 44.8, 85.3 and 11.4 g kg\(^{-1}\) DM for L. leucocephala, F. macrophylla and C. cajan, respectively; only C. cajan had lower TT compared to the present study. Fondevila et al. (2002) reported that L. leucocephala and C. cajan had higher total condensed tannins than the present study. Ramirez and Lara (1998) reported lower TT (1.8%) in A. farnesiana compared to the present study. Barry et al. (1986) suggested the level of tannins in forages for ruminants should be 30-40 g kg\(^{-1}\) DM in order to improve the efficiency of nitrogen digestion. Low level of tannins could protect protein from microbial degradation, thus increasing the amount of undegraded proteins in the small intestine.

TT contents of all legume shrub species in the current experiment were lower than the suggested level. However, variations in the chemical composition of legume shrub species in current study have been observed in other studies on the same shrubs which are largely affected by plant species, planting location, plant morphological fraction, environmental factors, part of plants and maturity stage (Chikagwa-Malunga et al., 2009; Camacho et al., 2010). Overall, legume shrubs in the current study are potential high quality feed resource for goats because of its higher CP content and lower tannin contents in tropical area in China.

Gas production and estimated parameters IVDMD, OMD and ME: Kexian et al. (1998) reported that IVDMD were 48.42% for C. argentea and 22.87% for F. macrophylla. Bakshi and Wadhwa (2007) reported higher net GP (132.4 mL g\(^{-1}\) DM/24 h) and OMD (70.1%) for L. leucocephala compared to the present study. Fondevila et al. (2002) reported high GP (3 mL g\(^{-1}\) DM/24 h) and OMD and low DMD for L. leucocephala (163, 47.3, 55.6%, respectively) and C. cajan (146, 41.2, 55%, respectively). Ramirez et al. (2000) and Ramirez and Lara (1998) reported the DMD of A. farnesiana in \textit{in situ} study with sheep and in \textit{in vitro} study using effective DMD at solid outflow rates as 2, 5 and 8% h\(^{-1}\) were 56.3, 47.7 and 43.4%, respectively as well as 55.5, 46.7, 41.5%, respectively.

Krishnamoorthy et al. (1995) reported ME for L. leucocephala K8 and L. leucocephala K72 were 8.2 and 7.9 MJ kg\(^{-1}\), respectively. The means of their results were comparable to the present study. GP and estimated parameters IVMD, OMD and ME of the legume shrub species in this study were different from those reported in the literature for other tropical shrubs. The wide variations of GP and estimated parameters were mostly caused by their variable nutrient contents.

Overall, the mean ME content of the legume shrub species was 8.41 MJ kg\(^{-1}\) which is sufficient to meet the maintenance ME requirement (8.42 MJ kg\(^{-1}\) DM) for goats fattening in China (Yang, 2003). Moreover, C. argentea, C. diaphylosa and C. ficus-indica were relatively adequate to the ME requirements of growing goats with 30 kg body weight (NRC, 2007). In addition, the legume shrubs studied were high in ME, thus they except F. macrophylla and D. triangulare would be able to support animal production as a sole diet.

Correlations among gas production, some estimated parameters and chemical composition: Kexian et al. (1998) reported IVMD was positively correlated with N and negatively with ADF, NDF and CT for three tropical shrub legumes. Among them, the correlation between IVMD with N, ADF and CT were significant. Other researchers have reported negative relationships between the \textit{in vitro} fermentation parameters such as IVMD, OMD, ME, shrub fiber fraction and TT (Rubanzu et al., 2003; Salem et al., 2007; Salem, 2005; Casler and Jung, 2006; Camacho et al., 2010).

Mahipala et al. (2009) reported that AX was positively correlated with GP, OMD and ME and TT was significantly negatively correlated with GP, OMD and ME in leguminous browse species. Consistent relationships occurred between the contents of CP, NDF, ADF, AX, TT, \textit{in vitro} GP and some estimated parameters in the present study. Cono reported incutation of casein produced 32% GP compared to carbohydrates. Tan reported the dietary ratio of structural and nonstructural carbohydrates could affect rumen degradability.

Tang et al. (2005) reported that characteristic of \textit{in vitro} GP and its positive correlation with NDS/CP (p<0.001) depended upon the balance of non-structural carbohydrate and CP. In present study, NDF/CP and ADF/CP were negatively correlated (p<0.01) with GP, IVMD, OMD and ME. This could be explained as
follows; the carbohydrates in substrate was the energy source for microorganisms in rumen in which gas was largely produced from GP and utilization efficiency of structural and nonstructural carbohydrate was different. CP in substrate provided nitrogen for the microorganisms and was only used to produce small part of GP. Substrate balance between carbohydrates and protein was the key factor for in vitro fermentation. However, further researches on the optimal ratio of carbohydrates to protein and the ratio of structural and nonstructural carbohydrates in the diet for ruminant are necessary.

Predictive equations: Menke et al. (1979) suggested ME values of feeds can be predicted from GP by in vitro incubating samples with rumen fluid in combination with a few chemical components. In addition, a strong correlation between ME values measured in vivo and predicted by GP. Robinson et al. (2004) reported six unified single equations to predict in vivo ME values of feeds such as forages, grains, protein meals and other by 0.99 products in sheep. These results suggested that no equation was able to consistently discriminate ME value of individual feed. The goodness of fit ($r^2$) for the two NRC approaches and UC Davis approach were 0.61, 0.72 and 0.84, respectively.

Therefore, the precision of these prediction approaches is lower than the ME prediction equation in present study ($r^2 = 0.9973$). Magalhaes et al. (2010) evaluated several methods for ME estimation of some tropical forages and compared with that measured in in vivo digestion. Their results indicated that in vitro systems underestimated ME values of most tropical forages and suggested that the accurate estimate systems for predicting ME of tropical feeds should base upon chemical composition such as NRC (2001), DeJong and 2.

Overall, the predicted ME values with different prediction equations were mostly inconsistent with those determined in vivo. On the other hand, predictive equations should vary dependent upon local conditions, specific objectives and feedstuffs. The equations proposed in the present study to predict the values of ME, IVMD and OMD have high accuracy and precision and should be recommended to evaluate the nutritive value of tropical legume shrubs.

The tropical legume shrubs studied except D. triangulare have high contents of RFV, CP, ME, IVMD and OMD and moderate content of TT, most of which meet the nutrition requirements for small ruminants (NRC, 2007). Thus, legume shrubs have higher potential nutritive values for goats in Hainan province of China. The predictive equations proposed in the present study for ME, IVMD and OMD based on the in vitro gas production technique and some chemical composition are suitable for tropical legume shrubs in China.

CONCLUSION

These results indicate that the above nutrition indices of the tropical legume shrubs studied except D. triangulare meet the requirement proposed by Hay Market Task Force of American Forage and Grassland Council and are potential high nutrition feeds for goats in Hainan province of China.

In addition, this study found that ADF, NDF, ash content, ADF/CP and NDF/CP were significantly correlated with IVMD, OMD and ME and proposed new, more accurate and precise predictive equations for ME, IVMD and OMD.

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REFERENCES


