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Prediction of tree and shrub leaf chemistry and digestibility by the use of Near Infrared Reflectance Spectroscopy

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Key Words: Fodder trees / Leaf chemistry / Herbivory / Digestibility / NIRS / PLS

Introduction

In the Mediterranean area, farmers are graze their herds on a diversity of pastures, including wooded rangelands. At certain periods, some of them expect the rangeland diet to meet up to 3/4 of total energy for high requirement ruminants such as lactating goats1,2. The sheperds therefore design their grazing route by combining native and cultivated pastures, and fenced paddocks often include a wide heterogeneity of fodder resources3. To upgrade pasturing management recommendations, one needs to assess the nutritive value of native foliages including their changes over time and spatial diversity4. As an exemple, one can see on figure 1 the wide range in fodder resources quality in a Provence goat farmland (Meuret, unpublished). In such diverse environments, assessing the nutritive value of fodder resources, including native and cultivated tree and shrub foliages, by the conventional wet chemical analysis of samples is time-consuming and too expensive, as very large samplings are required. In addition, some results are declared uncertain due to the particular composition of woody foliages as compared with cultivated forages for which standard analytical methods were developed5,6,7,8. Fiber assay is disturbed by the possible insolubilization of proteins caused by their interaction with phenolic compounds9. In the last ten years, simultaneously with studies that tried to improve wet chemical analysis for ligneous products, the near-infrared reflectance spectroscopy (NIRS) has been tested as a tool to describe diverse pastoral resources including woody foliages10,11,12. Within the same period, remote sensing and ecological studies have used this technique to predict leaf canopy chemistry13,14,15,16,17. Using a wide range of native and cultivated Mediterranean tree and shrub foliages, our objective was to evaluate the potential of NIRS to determine foliage chemistry and in vitro digestibility for ruminants.

Material and Methods

Samples were collected from typical wooded rangeland and fodder tree plantations in the French Mediterranean area. The data base comprises 25 species, representing the diversity of regional ligneous fodder resources (botanical names9,10: Arbutus unedo L., Amorpha fruticosa, Buxus sempervirens L., Calicotome spinosa L., Cistus albidus L., Cistus monspeliensis L., Cistus salvifolius L., Cytisus villosus Pourr., Cotula arborescens L., Coronilla emerus L., Erica arborea L., Erica scoparia L., Hedera helix L., Juniperus communis L., Juniperus oxycedrus L., Morus alba L., Philyrea angustifolia L., Phillyrea latifolia L., Pistacia lentiscus L., Pistacia terebinthus L., Quercus ilex L., Quercus pubescens Willd., Rhamnus alaternus L., Robinia pseudoacacia L., Ruscus aculeatus L. Most species were sampled at different periods in the year, when they were actually being browsed by animals. The samples were taken from plant parts selected within the different eating bites19. The date base comprises 222 samples, including leaves and stems only, divided before analysis into the successive growing parts. All samples were placed directly after cutting in a refrigerated container at +10°C before being frozen at -20°C. They were then air dried in a ventilated oven at 60°C. Drying kinetics were monitored for each sample, and the drying times were calculated to obtain 93% dry materials.
Results and Discussion

The foliage base is very heterogeneous. The standard deviation spectra of the raw spectra of the foliage are twice wider than the standard deviation of a reference herbaceous forage base. The 222 foliage samples data base is characterized by an extremely wide range of chemical components concentration and in vitro digestibility (Table I). The lowest standard errors of calibration (SEC) and cross validation (SECV) are comparable to the literature data for nitrogen (SEC slightly up to 0.1) and are better for lignin (SECV is 1.48 compared to SEC 2.5 - 2.9 in previous studies with foliages). Calibration Rsquares ranged from 0.96 to 0.99. Concerning IVDMD, SECV is close to 2.0 and appears satisfying because quite similar to usual standard errors concerning in vitro digestibility predictions determined on narrower sets than the current one. Graphic comparisons between wet chemistry values and NIR predicted values for N, ADL and IVDMD are shown in figure 2. One can see that the prediction equations are all effective.

The broad-base equation for IVDMD was applied to the 46 collected Quercus pubescens Wild. plant parts. Since oak species are well represented in the calibration data base, all the samples are predictable whereas the distances of these samples vs the calibration set remain less than the conventional limit of 3. As maturing progress, leaf IVDMD decreases from 65 to 15 % dry matter with a +15 % difference with the last stem value until October (figure 3). The two older growth stems have a regular and very similar variation around 30 % IVDMD. This type of information, with a high frequency of sampling on individualized edible plant parts, should be linked with the intake models of small ruminant browsing on oak foliages. From these models, one can estimate that the nutritive value of this oak during the summer period (mid-June to September) varies from 55 to 52% OM digestibility.
Conclusion

The NIRS is a performing technique to predict constituent contents for nutritive value estimations of Mediterranean foliages from trees and shrubs. The NIR analysis could point out which samples have been deteriorated during the conditioning process. It is a highly valuable tool for international networks that conduct woody fodder surveys and have to compare samples from various origins. This study shows that broad-based calibrations could be made on extremely diverse sets of data, including high nutritive leguminous shrubs such as Cistus and Robinia and very coarse Ericacea species, grouping leaves and stems within the same database. The calibration for fiber lignified fractions appears quite satisfactory. That confirms the relevance of our specific oven-drying technique for woody foliages. Prediction of pepsin-cellulase in vitro digestibility could be reliably used for these foliages, as is the case with more conventional green forages and herbage, to determine the effect of maturation on nutritive value of plant parts.

References

3. B. Hubert, Comment raisonner de manière systémique l'utilisation du territoire pastoral ? in Proc. IVth International Rangeland Congress, Montpellier (France) : (1992).
8. J. D. Reed, JD, Relationship among soluble phenolics, insoluble proanthocyanidins and fiber in East African browse species. J. Range Manage., 39, 5-7 (1986).

Table I
Wet chemical range (%) for each constituent within the calibration sample set.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Mean</th>
<th>STD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM</td>
<td>222</td>
<td>93.8</td>
<td>3.2</td>
<td>82.6 - 98.3</td>
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<tr>
<td>N</td>
<td>222</td>
<td>1.84</td>
<td>0.86</td>
<td>0.39 - 4.17</td>
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<tr>
<td>NDF</td>
<td>98</td>
<td>52</td>
<td>13</td>
<td>85.0 - 23.8</td>
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<tr>
<td>ADF</td>
<td>122</td>
<td>31.5</td>
<td>10.7</td>
<td>12.7 - 54.1</td>
</tr>
<tr>
<td>ADL</td>
<td>122</td>
<td>13.9</td>
<td>6.2</td>
<td>3.0 - 26.9</td>
</tr>
<tr>
<td>IVDMD</td>
<td>83</td>
<td>64</td>
<td>19.8</td>
<td>28.2 - 94.0</td>
</tr>
</tbody>
</table>

Table II
Modified partial least squares regression
Equation calibration statistics for OM, N, NDF, ADF, ADL and IVDMD without outliers and with scatter correction

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>SEC</th>
<th>$R^2$</th>
<th>SECV</th>
<th>Math treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM</td>
<td>204</td>
<td>0.54</td>
<td>0.97</td>
<td>0.63</td>
<td>1 5 5</td>
</tr>
<tr>
<td>N</td>
<td>206</td>
<td>0.11</td>
<td>0.98</td>
<td>0.14</td>
<td>1 5 5</td>
</tr>
<tr>
<td>NDF</td>
<td>90</td>
<td>1.36</td>
<td>0.99</td>
<td>2.06</td>
<td>1 5 5</td>
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<tr>
<td>ADF</td>
<td>110</td>
<td>1.85</td>
<td>0.97</td>
<td>2.36</td>
<td>1 10 5</td>
</tr>
<tr>
<td>ADL</td>
<td>108</td>
<td>1.04</td>
<td>0.97</td>
<td>1.46</td>
<td>2 5 5</td>
</tr>
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<td>IVDMD</td>
<td>75</td>
<td>1.51</td>
<td>0.99</td>
<td>2.09</td>
<td>2 20 5</td>
</tr>
</tbody>
</table>

* Math treatment indicates the mathematical transformation of spectral data: the first number is the order of the derivative function, the second is the length in data points over which the derivative was taken and the third the segment length over which the function was smoothed.
Figure 1
Range of fodder resources quality within a diversified goat farmland in Provence (Meuret, unpublished)

Figure 3
Variation over time in the in vitro pepsine-cellulase digestibility for the edible plant parts of Quercus pubescens Willd. $L_0/S_0$ is the current year's growth leave to stem ration (% dry matter).
Figure 2

Relationship between NIR predicted value for independent samples set and wet chemistry value (% dry matter) for nitrogen, lignin and in vitro digestibility.