

## Rumen degradability of dehydrated beet pulp and dehydrated citrus pulp

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(Received 6 May 2003; accepted 10 February 2004)

**Abstract** – The rumen degradation of dry matter (DM) and crude protein (CP) of 10 samples of dehydrated beet pulp (DBP) and 2 samples of dehydrated citrus pulp (DCP) were studied in three rumen cannulated wethers using nylon bag and rumen outflow rate techniques. The animals were fed with a mixed diet of prairie hay and concentrate (2:1 on DM) at an intake level of 40 g DM·kg BW<sup>-0.75</sup>. The effective degradability (ED) values of all feeds of each group were estimated from the rumen outflow rate determined on a sample of each kind of pulp; no significant differences ( $P > 0.05$ ) were observed between these values (4.66 and 3.52%·h<sup>-1</sup>, for DBP and DCP, respectively). The samples of DBP showed a great variability for the chemical composition as well as for both DM and CP degradation. Thus, the ED values of DM ranged from 41.0 to 70.8% and those of CP from 34.3 to 73.1%. Both values were correlated ( $r = 0.874$ ;  $P < 0.001$ ). A good prediction of the ED of DM ( $R^2 = 0.933$ ) was obtained from the contents of neutral detergent fibre and acid detergent fibre as the first and second predictive variables. In the same manner, the best prediction ( $R^2 = 0.954$ ) of the ED of CP was derived from the concentrations of CP and neutral detergent fibre. For DCP samples, mean values of ED of DM and CP were 81.0 and 74.2%, respectively. The equation obtained from DBP to predict the ED of DM also allowed a close prediction in these last samples, which seems to indicate that DM degradation is conditioned by the same factors in both kinds of pulps. On the contrary, this fact was not observed for CP degradation.

**dehydrated beet pulp / dehydrated citrus pulp / chemical composition / rumen degradability**

**Résumé** – Dégradabilité ruminale des pulpes déshydratées de betterave et d'agrumes. La dégradation dans le rumen de la matière sèche (MS) et des matières azotées totales (MAT) de 10 échantillons de pulpe de betterave déshydratée (PBD) et de 2 échantillons de pulpe d'agrumes déshydratée (PAD) a été mesurée sur trois béliers, porteurs de canules du rumen, par la méthode des sachets de nylon couplée à la technique de passage des particules hors du rumen. Les animaux ont été nourris avec une ration mixte de foin de prairie et concentré (2:1 sur MS) distribuée à 40 g MS·kg P<sup>-0.75</sup>. La dégradabilité théorique (DT) pour tous les échantillons de chaque groupe a été calculée avec les taux de sortie du rumen déterminés pour un échantillon de chaque genre de pulpe. Ces valeurs n'ont pas été différentes (4,66 et 3,52 %·h<sup>-1</sup>, pour PBD et PAD, respectivement ;  $P > 0,05$ ). Les

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échantillons de PBD ont montré une importante variabilité, tant pour la composition chimique que pour la dégradation de la MS ou des MAT. Les valeurs de DT ont varié de 41,0 à 70,8 % pour la MS et de 34,3 à 73,1 % pour les MAT. Par ailleurs, les deux valeurs ont été étroitement corrélées ( $r = 0,874$  ;  $P < 0,001$ ). La meilleure prédiction de la DT de la MS ( $R^2 = 0,933$ ) a été obtenue à partir des teneurs en parois (NDF) et lignocellulose (ADF), respectivement première et seconde variables indépendantes. De la même façon, la meilleure prédiction de la DT des MAT ( $R^2 = 0,954$ ) a été obtenue avec les teneurs en MAT et en NDF. Pour la PAD, les valeurs moyennes de la DT de la MS et des MAT ont été : 81,0 et 74,2 %, respectivement. L'équation obtenue avec la PBD pour la DT de la MS permet une prédiction précise pour ces pulpes, ce qui indique que ce sont les mêmes facteurs qui contrôlent la dégradation dans les deux groupes de pulpes ; alors que ce fait n'a pas été observé pour la dégradation des MAT.

## **pulpe de betterave déshydratée / pulpe d'agrumes déshydratée / composition chimique / dégradabilité ruminale**

### **1. INTRODUCTION**

The estimations of protein degradability and the microbial protein synthesis in the rumen associated with each specific feed are essential for the suitable application of the new systems that assess protein nutrition in ruminants. Nevertheless, the variability existing within a given feed type for both parameters, and specially for the former, is not usually considered in these systems [1, 11, 19]. This variability may be important for the foodstuffs resulting from industrial processes or those resulting from a mix of different raw materials. Both conditions coincide with dehydrated sugar beet pulp (DBP) as a consequence of the differences in the conditions of the drying method employed and with the amount of molasses (or other soluble materials) added back to the pulp. Therefore, there is an important variability in the values assumed for the protein degradability of this by-product [9, 11, 17]. Studies focused on determining the factors affecting degradability have a special interest in this type of feed. DBP as well as dehydrated citrus pulp (DCP), are good sources of digestible fibre as a consequence of their respective high and low contents in pectins and lignin [4]. Therefore, they have a high energy value and are usually used in diets for productive ruminants (especially for dairy cows) to diminish the inclusion of cereal grains and, therefore, to reduce the digestive problems derived from an excess

of starch. The objectives of this study were: (i) to obtain information on the variation of the rumen degradability of both pulp types and (ii) to study the possible relationships between their physical and chemical characteristics and their rumen degradation.

### **2. MATERIALS AND METHODS**

#### **2.1. Feed samples**

A total of ten samples of DBP (DBP<sub>1</sub> to DBP<sub>10</sub>) and two samples of DCP (DCP<sub>1</sub> and DCP<sub>2</sub>) from different industrial origins were examined to determine their rumen degradation characteristics using the nylon bag and rumen outflow rate techniques. All these samples were pelleted except DBP<sub>10</sub>.

#### **2.2. Animals and feeding**

Three Manchega wethers (live weight (LW)  $68 \pm 6.4$  kg) fitted with permanent ruminal cannulas (50 mm internal diameter) were employed. The animals were housed in individual pens and had free access to water and mineral blocks. Each animal was offered a diet consisting of prairie hay and concentrate in the ratio of 2:1 (DM basis) at a rate of  $40 \text{ g DM} \cdot \text{kg LW}^{-0.75}$  from 15 days before starting the experimental period. The diet was offered in two equal meals at 9.00 and 17.00 hours. The chemical composition of the diet ( $\text{g} \cdot \text{kg}^{-1}$  DM) was

the following: 896 organic matter (OM), 162 crude protein (CP), 417 neutral detergent fibre (NDF) and 268 acid detergent fibre (ADF).

### 2.3. Ruminant degradation

Feed samples were incubated in nylon bags (pore size 46  $\mu\text{m}$ ) of 7  $\times$  11 cm (inner dimensions) made by heat-sealing. The bags were filled with approximately 3 g (air dry basis) of feed samples ground through a 2 mm sieve and incubated in the rumen of each animal for periods of 2, 4, 8, 16, 24 and 48 h. Two series of incubations were conducted for each feed in two different periods, in order to have two bags per sheep and incubation time. All bags of each incubation series of each feed were placed simultaneously in the rumen at the morning feeding time. After being removed from the rumen, the bags were washed thoroughly under tap water and deep frozen ( $-20\text{ }^{\circ}\text{C}$ ). Once defrosted for analysis, the bags were washed three times with cold water for 5 min in a turbine washing machine, dried at  $80\text{ }^{\circ}\text{C}$  for 48 h, weighed for DM determination, and the residues were homogenised and analysed for N.

The disappearance of DM and CP from the nylon bags was calculated from their respective amounts remaining after incubation in the rumen. Disappearance data of DM and CP of DCP samples as well as those of DM of DBP fitted well to a simple exponential curve and were described for each animal using the model proposed by Ørskov and McDonald [12]:  $y = a + b(1 - e^{-kdt})$ . Conversely, the disappearance of CP of most DBP samples showed a sigmoidal sharp and were described in all cases using the logistic model of growth of France and Thornley [5], which is also well adapted to describe rumen degradation:  $y = a(a + b)/(a + b e^{-kdt})$ . For both models, the constant  $a$  represents the soluble or very fast degradable fraction and  $b$  represents the non-soluble degradable component. In the model of Ørskov and McDonald [12]  $k_d$  represents the constant fractional degradation rate of

the  $b$  fraction. Conversely, in the model of France and Thornley [5] the rate of degradation of the  $b$  fraction is not constant through time.

The effective degradability (ED) of DM and CP was estimated by using the above equations and the rumen particulate outflow rate ( $k_p$ ) (see later) according to the integration method proposed by Ørskov and McDonald [12]. Thus, when degradation was described with the exponential model, ED was calculated as:  $\text{ED} = a + (b \times k_d / (k_d + k_p))$ . The application of this method to the logistic equation of France and Thornley [5] leads to the equation:

$$\text{ED} = k_p \int_0^{\infty} [a(a + b) / (a + b e^{-k_d t})] e^{-k_p t} dt.$$

The primitive function of this integral has not been obtained and therefore the ED values were determined by mathematical approximation using mathematical calculation software (Derive 2; Soft Warehouse Inc., Honolulu, USA).

### 2.4. Rumen particulate outflow rate

One sample of DBP and one of DCP were washed with a commercial detergent in an automatic washing machine to eliminate the soluble components and marked by soaking in solutions containing ytterbium (Yb) and europium (Eu), respectively, as described by González et al. [6]. To determine the  $k_p$  values, a pulse dose of each marked feed (50 g) was offered to each animal 15 min before the morning feeding, which was readily ingested within 15 min. A total of 20 samples of faeces were obtained from the rectum of each animal, the first before supplying the marker feed and the rest between 24 and 148 h afterwards. The samples of the faeces were dried, milled and analysed for Yb and Eu. The pattern of Yb and Eu concentrations in the faeces over time was described for each

animal by fitting the model proposed by Grovum and Willians [7], and rate constants derived from the decreasing phase of concentrations were used as  $k_p$  values for all samples of each feed class.

## 2.5. Analytical methods

All samples were ground to pass a 1 mm sieve before analysis. Dry matter, ash and CP ( $N \times 6.25$ ) were determined following AOAC methods [2]. NDF, ADF and acid detergent lignin (ADL) were determined as described by Robertson and Van Soest [14]. Insoluble N in neutral detergent (NDIN) and in acid detergent (ADIN) solutions were determined by Kjeldahl analysis of the NDF and ADF residues, respectively. The solubility of CP (CPS) was determined in triplicate in McDougall buffer for 6 h as previously described by Pereira et al. [13]. The samples of faeces were thawed, dried, ashed (600 °C for 6 h) and then wet-digested with a solution of 1.5 M  $HNO_3$  and KCl (3.81 g·L<sup>-1</sup>) for the determination of concentrations of Yb and Eu using, respectively, atomic absorption spectrometry and atomic emission spectrometry (Smith Hieftje 22, thermo Jarrell Ash, MA, USA). Predosed samples of faeces were used to prepare common-matrix standards.

## 2.6. Statistical analysis

The transit and degradation kinetics were obtained by an iterative least squares procedure and best fit values were chosen using the Marquart procedure of the Statistical Analysis Systems (SAS) Institute [18]. The analyses of variance for degradation parameters and ED within each kind of feed were performed with a simple model examining the effect allocated to the feed and animal. Uni- and multi-variate regression analyses of data were used to establish prediction equations for feed evaluations. All these analyses were also performed using the SAS statistical programme.

## 3. RESULTS

### 3.1. Chemical characteristics of the tested feeds

The chemical composition of the experimental feeds ranked by increased cell wall contents is given in Table I. The samples of DBP showed a large variation for all fractions. However, an important part of these variations was associated with the large deviations observed for DBP<sub>1</sub> and DBP<sub>2</sub> samples. The range of variation of the CPS was also very large (from 8.55 to 47.2%), although the main part of this variation was also due to DBP<sub>1</sub> and DBP<sub>2</sub> samples. On the other hand, the variations of chemical composition were intercorrelated (Tab. II). Thus, ash and CP were positively related ( $r = 0.824$ ;  $P < 0.01$ ), with both fractions showing negative correlations with the fibre traits, specially with NDF, ADF and NDIN. In the same manner, CPS was correlated positively with the contents of ash ( $r = 0.963$ ;  $P < 0.001$ ) and CP ( $r = 0.775$ ;  $P < 0.01$ ) and negatively with the contents of NDF and ADF ( $r = -0.850$  and  $0.898$ ;  $P < 0.01$ , respectively). The proportion of NDIN was mainly related to the concentrations of CP ( $r = -0.867$ ;  $P < 0.01$ ) and NDF ( $r = 0.823$ ;  $P < 0.01$ ) and at a lower level with the CPS ( $r = -0.687$ ;  $P < 0.05$ ). On the contrary, the proportion of ADIN showed the closest correlation with ADL ( $r = 0.668$ ;  $P < 0.05$ ). However, no correlation was observed between NDIN and ADIN. The variation in chemical composition between both samples of DCP was low. These samples presented a lower content of cell wall but more lignin than the usual values observed in DBP samples, because seeds are not usually separated from the citrus pulp in the Spanish industry. Proportions of NDIN and ADIN were in the range observed for DBP samples.

### 3.2. Ruminal degradation

The parameters of the degradation kinetics and the ED in the rumen of DM and CP

**Table I.** Chemical composition (g·kg<sup>-1</sup>DM) and buffer crude protein solubility (CPS) of dehydrated beet pulp (DBP) and dehydrated citrus pulp (DCP) samples.

Sample	Ash	CP	NDF	ADF	ADL	NDIN <sup>1</sup>	ADIN <sup>1</sup>	CPS <sup>2</sup>
DBP <sub>1</sub>	116	132	340	162	21.1	14.0	3.43	47.2
DBP <sub>2</sub>	88.4	117	448	198	19.5	22.9	5.73	32.6
DBP <sub>3</sub>	65.8	118	483	254	22.6	12.2	1.84	11.4
DBP <sub>4</sub>	63.9	88.8	497	238	62.0	49.3	12.4	17.7
DBP <sub>5</sub>	60.5	75.0	503	258	39.0	47.1	11.9	11.5
DBP <sub>6</sub>	63.6	82.0	506	242	24.8	52.9	8.86	9.5
DBP <sub>7</sub>	57.7	96.7	529	245	23.9	48.1	2.07	15.8
DBP <sub>8</sub>	48.5	88.4	567	265	28.4	63.0	2.02	8.55
DBP <sub>9</sub>	47.7	83.0	570	210	26.3	60.3	10.3	11.8
DBP <sub>10</sub>	48.6	93.3	640	269	31.6	62.6	8.61	8.93
DCP <sub>1</sub>	74.6	65.4	221	161	40.4	33.9	8.10	29.2
DCP <sub>2</sub>	67.0	85.7	259	185	30.8	34.1	5.40	32.3

<sup>1</sup> % of total N.

<sup>2</sup> % of total CP.

CP: crude protein, NDF: neutral detergent fibre, ADF: acid detergent fibre, ADL: acid detergent lignin, NDIN: neutral-detergent insoluble nitrogen, ADIN: acid-detergent insoluble nitrogen, CPS: crude protein solubility.

**Table II.** Simple correlation coefficients among chemical composition and crude protein solubility (CPS) of dehydrated beet pulp samples.

	CPS	ADIN	NDIN	ADL	ADF	NDF	CP	Ash
Ash	0.963***	-0.317	-0.789**	-0.329	-0.835**	-0.911***	0.824**	1
CP	0.775**	-0.632*	-0.867**	-0.470	-0.623*	-0.683*	1	
NDF	-0.850**	0.231	0.823**	0.162	0.761*	1		
ADF	-0.898**	0.098	0.557	0.314	1			
ADL	-0.244	0.668*	0.353	1				
NDIN	-0.687*	0.437	1					
ADIN	-0.243	1						
CPS	1							

\*:  $P < 0.05$ , \*\*:  $P < 0.01$ , \*\*\*:  $P < 0.001$ .

For abbreviations see Table I.

are shown in Table III, with an indication of the differences between feeds. As previously indicated in the materials and methods, all these kinetics were fitted with a single exponential function except those of CP of all DBP samples which were fitted using a logistic function. The estimates of

ED were established based on the individual values of the rumen fractional outflow rates measured for a sample of DBP and another of DCP. The mean values (%·h<sup>-1</sup>) were respectively 4.66 and 3.52. No significant difference was observed between both samples (mean standard error = 0.625).

**Table III.** Rumen degradation characteristics of dry matter (DM) and crude protein (CP) for dehydrated beet pulp (DBP) and dehydrated citrus pulp (DCP) samples.

Feed sample	Dry matter				Crude protein			
	<i>a</i>	<i>b</i>	<i>k<sub>d</sub></i>	ED	<i>a</i>	<i>b</i>	<i>k<sub>d</sub></i>	ED
	(%)	(%)	(% h <sup>-1</sup> )	(%)	(%)	(%)	(% h <sup>-1</sup> )	(%)
DBP <sub>1</sub>	41.3	51.2	6.21	70.8	49.9	45.6	7.07	73.1
DBP <sub>2</sub>	32.9	59.8	5.37	63.9	42.3	51.0	6.41	65.8
DBP <sub>3</sub>	19.8	71.3	4.40	54.8	32.8	59.9	5.55	55.8
DBP <sub>4</sub>	20.0	71.8	4.67	56.4	22.1	69.3	6.65	48.1
DBP <sub>5</sub>	12.3	79.2	4.50	51.6	7.14	80.7	10.5	36.9
DBP <sub>6</sub>	10.6	79.0	4.59	50.2	12.1	77.6	7.95	39.3
DBP <sub>7</sub>	18.6	68.7	5.28	55.4	20.5	68.5	7.85	49.2
DBP <sub>8</sub>	5.60	79.3	4.40	44.2	11.6	79.9	7.81	38.5
DBP <sub>9</sub>	11.7	78.7	4.31	49.9	11.9	74.8	6.57	34.3
DBP <sub>10</sub>	1.53	88.9	3.71	41.0	11.5	76.7	7.80	37.4
L.S.D.	3.75	2.73	0.91	6.05	3.02	3.02	1.84	4.68
DCP <sub>1</sub>	45.7	52.8	7.50	82.4	39.1	55.5	5.96	74.8
DCP <sub>2</sub>	43.6	54.2	6.42	79.6	47.9	46.5	4.03	73.6
L.S.D.	7.84	6.22	0.74	2.53	3.15	3.17	2.27	6.98

*a* and *b* represent soluble and non-soluble degradable fractions, respectively; *k<sub>d</sub>* is the fractional degradation rate of the *b* fraction for DM and also for CP in DCP samples and it is not assigned to any biological significance for CP degradation in the DBP samples; L.S.D.: least significant difference at  $P < 0.05$ .

The DM degradation showed important and significant differences between DBP samples, as for the degradation parameters and for the ED. In general, the soluble fraction (*a*) was low and the insoluble but degradable fraction (*b*) was high, except for DBP<sub>1</sub> and DBP<sub>2</sub> samples. Since the potential extent of DM degradation (*a* + *b*) was high and relatively similar in all the samples (between 84.9 and 92.8%), the *a* and *b* fractions were markedly complementary. The variation of the fractional degradation rate was large (from 3.71 to 6.21%·h<sup>-1</sup>), although most samples ranged between 4 and 5%·h<sup>-1</sup>. The range of variation of the ED of DM was also large (from 41.0 to 70.8%). However, most samples showed values between 50 and 56%. The DBP<sub>1</sub> and DBP<sub>2</sub> samples showed the highest values (70.8 and 63.9%,

respectively), which were significantly ( $P < 0.05$ ) different from the other samples and between them, whereas the minimum value was recorded for DBP<sub>10</sub>. The ED of DM was significantly ( $P < 0.001$ ) correlated with the *a*, *b* and *k<sub>d</sub>* parameters ( $r = 0.993, -0.973$  and  $0.874$ , respectively). The ED of DM was also correlated with all chemical fractions, except ADL and ADIN, however the closest correlations were recorded with NDF (negative) and ash (positive). Both fractions also showed the closest correlations with *a*, *b* and *k<sub>d</sub>* parameters.

The CP degradation of the DBP samples (Tab. III) showed similar trends to those observed for DM. There were marked differences between samples for all the degradation kinetic parameters and for the ED values, with the largest deviations (except

**Table IV.** Simple correlation coefficients between rumen dry matter or crude protein degradation characteristics and chemical composition of dehydrated beet pulp samples.

	<i>a</i>	<i>b</i>	$k_d$	$u^1$	ED
<i>Dry matter degradation</i>					
Ash	0.938***	-0.920***	0.850**	-0.540	0.920***
CP	0.800**	-0.801**	0.556	-0.386	0.735*
NDF	-0.929***	0.914***	-0.822**	0.524	-0.945***
ADF	-0.854**	0.828**	-0.802**	0.523	-0.846**
ADL	-0.227	0.283	-0.248	-0.138	-0.185
NDIN	-0.837**	0.800**	-0.518	0.576	-0.814**
ADIN	-0.287	0.416	-0.205	-0.430	-0.228
<i>Crude protein degradation</i>					
Ash	0.917***	-0.906***	-0.227	-0.826**	0.914***
CP	0.951***	-0.943***	-0.596	-0.845**	0.931***
NDF	-0.823**	0.803**	0.200	0.787**	-0.852**
ADF	-0.761**	0.785**	0.367	0.540	-0.724*
ADL	-0.344	0.364	0.185	0.201	-0.315
NDIN	-0.888***	0.883***	0.439	0.776**	-0.887***
ADEN	-0.470	0.439	0.347	0.536	-0.482
CPS	0.885***	-0.886***	-0.261	-0.746*	0.894***

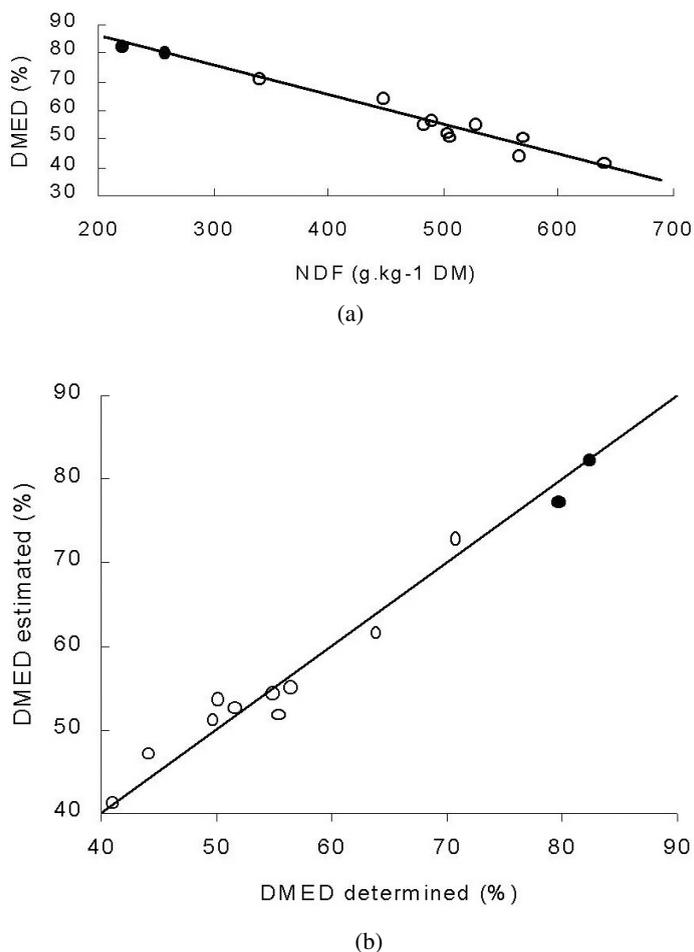
<sup>1</sup> Undegradable fraction, estimated as  $1 - (a + b)$ .  
 For other abbreviations, see Tables I and III.  
 \*:  $P < 0.05$ , \*\*:  $P < 0.01$ , \*\*\*:  $P < 0.001$ .

for  $k_d$ ) recorded for the DBP<sub>1</sub> and DBP<sub>2</sub> samples. In the same manner, the values of *a* and *b* for CP were also closely complementary, since the potential extent of CP degradation was relatively similar (from 86.7 to 95.5%). Consequently, both fractions were closely correlated ( $r = -0.994$ ;  $P < 0.001$ ). Therefore, the ED of CP was closely correlated with both fractions ( $r = 0.988$  and  $-0.978$ ;  $P < 0.001$ , respectively). The ED of CP showed close and direct correlations (Tab. IV) with the CPS ( $r = 0.894$ ;  $P < 0.001$ ) and with the contents of CP and ash ( $r = 0.931$  and  $0.914$ , respectively;  $P < 0.001$ ). The closest correlations with kinetic parameters were also recorded with the CP content. On the contrary, the ED of CP showed inverse correlations (Tab. IV) with the proportion of NDIN ( $r = -0.887$ ;  $P < 0.001$ ) and the NDF and ADF contents

( $r = -0.852$ ;  $P < 0.001$  and  $r = -0.724$ ;  $P < 0.05$ , respectively).

The ED values of DM and CP were also correlated ( $r = 0.874$ ;  $P < 0.001$ ). The best prediction of the ED of DM of DBP was derived from the NDF content (Fig. 1a), which explained 89.4% of the total variation. This percentage was increased up to 93.3%, using the content of ADF as a second predictive variable (Fig. 1b). For the prediction of the ED of CP, the use of the CP content allowed to explain 87.8% of the recorded variation (Fig. 2a), and its combined use together with the NDF content, 95.4% of the recorded variation (Fig. 2b).

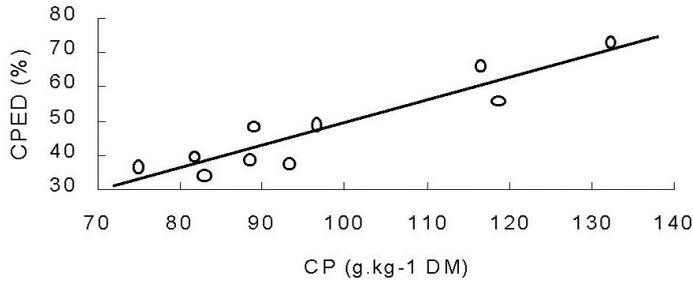
The degradation of DM of dehydrated citrus pulp was extensive (Tab. III), with high values for the *a* and  $k_d$  parameters. The differences ( $P < 0.05$ ) between both samples were only observed for  $k_d$  and ED, but



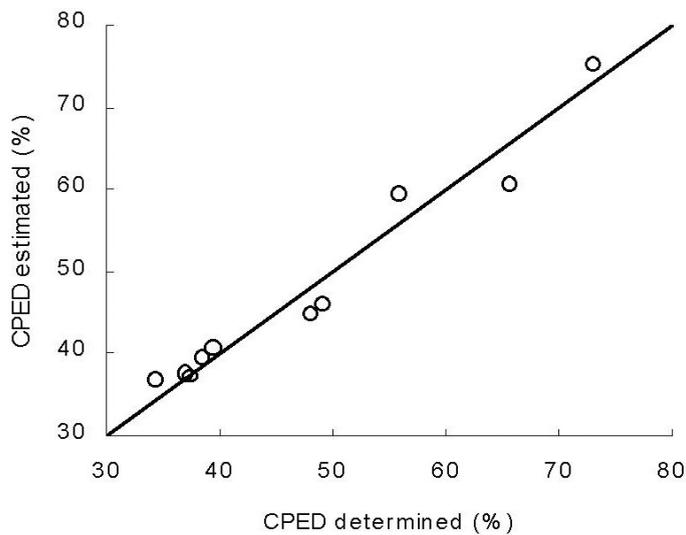
**Figure 1.** Relationship between (a) the neutral detergent fibre concentration (NDF;  $\text{g}\cdot\text{kg}^{-1}$  DM) and the effective degradability of dry matter (DMED) or (b) determined and predicted values of DMED using the acid detergent fibre concentration (ADF;  $\text{g}\cdot\text{kg}^{-1}$  DM) as the second predictive variable in dehydrated beet pulps (o). The regression equations were: (a)  $\text{DMED} = 106.4 - 0.103 \text{ NDF}$ ;  $n = 10$ ;  $\text{RSD} = 3.02$ ;  $\text{R}^2 = 0.894$ ;  $P < 0.001$ ; and (b)  $\text{DMED} = 111.8 - 0.078 \text{ NDF} - 0.077 \text{ ADF}$ ;  $n = 10$ ;  $\text{RSD} = 2.58$ ;  $\text{R}^2 = 0.933$ ;  $P < 0.001$ . The fitting of dehydrated citrus pulp samples (•) to the equations obtained from dehydrated beet pulps is also represented.

this last difference was small. The ED values of DM in the DCP samples were up to the range observed for DBP. The CP degradation of both samples of DCP were similar, except for the distribution of degradable CP in its *a* and *b* fractions. The ED values were in the upper range observed in

the DBP samples. The values of ED of DM fitted well with the equations obtained with the DBP samples (see Figs. 1a and 1b). On the contrary, the equations obtained with the DBP samples for the ED of CP were not useful in predicting these values in the DCP samples.



(a)



(b)

**Figure 2.** Relationship between (a) the crude protein concentration (CP;  $\text{g}\cdot\text{kg}^{-1}$  DM) and the effective degradability of CP (CPED; %) or (b) determined and predicted values of CPED using the neutral detergent fibre concentration (NDF;  $\text{g}\cdot\text{kg}^{-1}$  DM) as the second predictive variable in dehydrated beet pulps. The regression equations were: (a)  $\text{CPED} = -16.6 + 0.66 \text{ CP}$ ;  $n = 10$ ;  $\text{RSD} = 5.15$ ;  $\text{R}^2 = 0.868$ ;  $P < 0.001$ ; and (b)  $\text{CPED} = 36.7 + 0.46 \text{ CP} - 0.067 \text{ NDF}$ ;  $n = 10$ ;  $\text{RSD} = 3.22$ ;  $\text{R}^2 = 0.954$ ;  $P < 0.001$ .

#### 4. DISCUSSION

Products marketed with added molasses and/or vinasses also figure under the name of dehydrated beet pulp. These two raw materials have a higher content of ash and CP than the beet pulp and a negligible proportion of fibre [4, 8, 17]. The use of some of these additions at a high level is therefore

evident in the  $\text{DBP}_1$  and  $\text{DBP}_2$  samples, which showed the minimum values of fibre and the maximum values of ash and CP as well as of CPS. The high soluble fraction recorded in both DM and CP degradation gave additional evidence of the addition of soluble materials to these samples. Some of these characteristics were also observed in other samples ( $\text{DBP}_3$ ,  $\text{DBP}_4$  and  $\text{DBP}_7$ ) but

at lower levels. In addition to the inclusion of these or other soluble additives, the differences in the efficiency of the molasses extraction by the industrial procedure employed should also be considered. In this manner, both facts easily explain the positive correlations observed between ash, CP and CPS as well as the negative relations of all these parameters with fibre traits (Tab. II). The chemical composition of the beets employed by the industry should also be taken into account to explain the variation of DBP composition. The highest variability was, however, recorded for the proportions of NDIN and ADIN. This may be a consequence of the heterogeneity of the collection sample studied, with enriched pulps (molasses, vinasses, ...) which showed low values for these parameters, specially for NDIN, and some others which showed the effects of thermal treatments (dehydration and pelleting) with a condensation of protein and carbohydrates. Thus, the high values of ADL recorded for some samples (DBP<sub>4</sub> and DBP<sub>5</sub>) that also displayed the highest proportion of ADIN (Tab. I), may be explained by the generation of artificial lignin. In this same line, the closest correlation of ADIN was observed with ADL (Tab. II).

The important variation of the ED values observed for both DM and CP were mainly caused by the variation of their respective soluble fractions. Therefore, these values are mainly conditioned by the addition of soluble raw materials and by the cell wall content in DBP, which in turn also depends on the original content of soluble materials in fresh beets and on the efficiency of the extraction process. These facts explain the close correlations observed between the ED values and those of ash and NDF for the DM degradation or ash, CP, CPS and NDIN for CP degradation. The appearance of multiple correlations between ED values and CPS or many chemical parameters is logical, because most of these factors are inter-correlated (Tab. II). It is interesting to remark the close and negative correlation observed between the degradation rate of

DM and NDF and the lack of correlation between this rate and ADL. Therefore, the low degree of lignification of this by-product does not seem to be an important barrier to the degradative actions of microorganisms. An increased content of NDF may also indicate a lower content of pectins, whose decrease in the cell walls should decelerate the progression of the degradation.

As indicated in the materials and methods, the CP degradation kinetics of most DBP samples showed a sigmoidal trend and, consequently, the single exponential model does not allow the accurate fitting of all these kinetics. On the contrary, the logistic model employed allowed all these fittings with higher determination coefficients. These same facts were also observed by Rodríguez [15]. The ED values of CP showed a high variability (range from 34.3 to 73.1%). Therefore, the use of a mean constant value can lead to major errors. This high variability is also observed in the literature, as shown by the data of different works [9, 10, 19] which vary from 38 to 61%, or by the estimations indicated in several national feed tables such as those of the National Research Council [11] or those of Sauvant et al. [17]: 33.8 and 52%, respectively. The values of ED of CP are apparent since microbial contamination was not taken into account. Using <sup>15</sup>N as microbial marker, Bernard et al. [3] and Rodríguez et al. [16] showed that the underestimation of the ED of CP derived from the microbial contamination was high. However, there were important differences between both works for this value: 25.8 and 13.1%, respectively. The application of a corrective equation, obtained under similar experimental conditions by Rodríguez et al. [16], produced values for this underevaluation of 6.93 and 8.50% for DBP<sub>1</sub> and DBP<sub>2</sub>, respectively, and from 10.3 to 13.1% for the remaining samples. These values are moderate, because the main factor that influences this error, according to these authors, is the cellulose content, whereas the main structural carbohydrates of the fibre of this

by-product are hemicelluloses. The respective corrected values of ED of CP ranged from 39.3 to 78.5%, averaging 53.4%.

Our results also showed that the ED of both DM and CP are closely correlated. Considering the moderate CP content of the DBP, it is clear that the improvement on the protein value derived from the increased microbial protein synthesis promoted by the addition of soluble raw materials should be higher than the reduction of the proportion of by-pass protein. Nevertheless, the addition of soluble raw materials removes the most interesting characteristics of this feed: its moderate fermentation rate and its low degradable CP content. These characteristics are interesting to counteract the low rumen pH produced by an excess of starch in the diets, or an excess of degradable CP, usual in the diets with a high proportion of green or ensiled forages, especially legumes.

The contents of ash, CP and NDF allow to identify the pulp samples added back with high doses of molasses or vinasses. However, the use of ash as a reference seems to be less advisable for the prediction of ED values, since this content may be influenced by contamination or included by manipulation to simulate a higher level of rumen availability. In addition, some soluble additives are treated to reduce their mineral content, which can affect the accuracy of the predictions based on the content of ash. The use of the predictive equations shown in Figures 1 and 2 should allow for a higher accuracy in the valorisation of the protein value of DBP and a more rational use of this pulp in accordance with the diet characteristics.

DCP is usually considered to be similar to DBP. However, DCP has a higher content of sugars and pectins and a lower content of fibre than DBP [4, 17]. The accurate prediction of the values of ED of DM using the equations developed from the DBP samples may be expected, since the cell walls of both by-products are rarely lignified. In contrast, the characteristics of CP

degradation were not similar between both kinds of pulps, and consequently, the equations obtained for DBP cannot be used to predict their values of ED of CP. The present values were higher than those recorded by V $\acute{e}$ rite et al. [19] averaging 66%, but they were close to the estimation of the National Research Council [11]: 75.8%. The application of the above-cited correction for microbial contamination [16] leads to corrected ED values for CP of 80.9 and 79.8%, for DCP<sub>1</sub> and DCP<sub>2</sub>, respectively.

## 5. CONCLUSIONS

The ED of both DM and CP of dehydrated beet pulp showed a large variability. However, the use of CP and fibre contents provides a good prediction of these values and, therefore, a more accurate protein evaluation. The factors conditioning the ED of DM seems to be similar in both kinds of pulps, because the equations derived from dehydrated beet pulp provide close estimations for dehydrated citrus pulp samples.

## ACKNOWLEDGMENTS

This work has been supported by the CICYT funded Project 89-0126.

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