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Ruminal Kinetics of Nutrients Degradation, Hydration, and Functional Specific Gravity of Three Types of Beet Pulp

Research Article

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ABSTRACT

Two experiments were conducted to evaluate the relationships between nutrients degradability, kinetics of hydration, functional specific gravity (FSG) of the three types of beet pulp (BP) including fine (FBP), normal (NBP) and pelleted (PBP) BP. In experiment 1, about 3 g of samples was weighed in sealed nylon bags (6 cm×7.5 cm, 40±5 µm pore size), incubated in rumen of two cannulated Holstein steers at 0, 3, 6, 12, 18, 24, 36 and 48 h. The dry matter (DM) degradation was different among the treatments for soluble, slowly and potentially degradable fractions, rate of degradation, and effective degradability. In experiment 2, after ruminal incubation of two bags at 0, 0.5, 1, 1.5, 3, 6, 12, 18, 24, 36 and 48 h, the bags were removed without and with washing, the kinetic of hydration, functional specific gravity (FSG) measured with pycnometer. Hydration rate and water holding capacity (WHC) were different. Grinding and pelleting decreased hydration rate and WHC of BP, but increased initial and final FSG over incubation time. Soluble, slowly degradable, and indigestible fraction of DM explained 82.4, 94.8, 2.7, 54.2, 87.3 and 79.7%; 34.1, 50.0, 2.2, 31.4, 62.2 and 63.4%; and 89.1, 12.2, 68.0, 84.7 and 92.9% of the total variation of the fractional rate of degradation, effective degradability, hydration rate, WHC, initial and final FSG, respectively. In addition, the correlations between digestion and hydration parameters were high. As BP has lower than critical size, can easily pass from the reticulorumen orifice, therefore, its FSG is more important to control ruminal retention time and degradation.

KEY WORDS beet pulp, physical property, physically effective fiber, ruminant feed.

INTRODUCTION

Particle size and functional specific gravity (FSG) are feed characteristics that influenced ruminal mean retention time and ruminal nutrients digestibility. Beet pulp (BP) is economical sources of nutrients in ruminant rations because of initial higher specific gravity (SG) than dried forages and smaller size than the critical size of particles that can retain in the rumen. In addition, BP has high digestible neutral detergent fiber (NDF) and is often used to reduce the content of non-fiber carbohydrate (NFC) in dairy cattle diets. Much of the NFC in BP is pectin. Pectins are the main components of the primary cell walls of dicotyledons where they play a major role in the physico-chemical properties (Ben-Ghedalia *et al.* 1989). They are complex polysaccharides; their backbone, characterized by a high proportion of galacturonic acid and presence of rhamnose, presents two distinct structures: homogalacturonan or rhamnogalacturonan which has a propensity for acetate versus propionate production in the rumen (Catherine *et al.* 1999). In addition, the NDF in BP is highly fermentable in the rumen, and it can be used to supply fermentable fiber in the diet. The two processes in the rumen that increase the functional specific gravity (FSG) of particles are liquid uptake and particle size

reduction. Therefore, both particle size and specific gravity should be used to define escapable and nonescapable rumen fiber fractions (Allen and Mertens, 1988). The inescapable fraction consists of particles that have an FSG less than the rumen fluid (Allen and Mertens, 1988) and size greater than the critical size (Poppi *et al*. 1980). The escapable fraction consists of particles that are denser than the rumen fluid and are below the threshold size for retention. In addition, digestibility is directly proportional to the digestible fraction of fiber and rate of fiber digestion, but inversely related to the rate of release of particles from nonescapable to an escapable fiber pool and rate of escape. The rate of release from fiber fractions is a function of the rate of change in FSG and the rate of particle size breakdown (Allen and Mertens, 1988). Particle size reduction increases the release rate from the nonescapable fraction, which results in reduced digestibility. Ruminal particulate matters are mostly below the threshold size for escape; therefore, particle size reduction may not be the rate-limiting step in clearance from the reticulorumen (Kaske and Engelhardt, 1990; Kaske and Engelhardt, 1992). High FSG of feeds seems to reduce the amount of fiber in ruminal mat and affects escapable particle retention (Allen and Mertens, 1988). For stimulation of chewing activity and ruminal mat formation and maintenance of mat consistency, particles must be retained in the rumen (Teimouri Yansari *et al*. 2004). However, Kaske and Engelhardt (1990), Kaske and Engelhardt (1992) and Teimouri Yansari *et al*. (2004) found that FSG is a better indicator of retention than particle size. On the otherwise, feed DM can be divided into soluble and insoluble fractions. Soluble DM is easily degraded and, in any case, its rumen passage rate is that of the liquid phase, which is easily measurable. Insoluble DM can be degraded at different rates, and its passage rate can vary widely, depending on physico-chemical properties of feed particles (Ehle and Stern, 1986). The objectives of the current study were to evaluate kinetics of hydration and FSG of different types of BP over time of incubation with ruminal inoculum and to relate these data to kinetics of nutrients degradability *in situ.*

MATERIALS AND METHODS

Sample preparation and composition

Two types including normal beet pulp (NBP) and pelleted beet pulp (PBP) were used in this experiment were prepared from feed manufacture of Khorasan province, Iran. The FBP was prepared by milling NBP, using 1 mm screen pore size of miller. Feeding dried BP chips into the pelleting machine produced pellets. Pellets were obtained from dried by grinding and hardening into a cylindrical shape, about 5 cm long and about 0.5 cm in diameter and are uniform in appearance and texture. Samples were dried at 55 ˚C, ground through a Wiley mill (1 mm screen), analyzed for dry and organic matter, Kjeldahl N, ether extract (EE), Ca, P, Cl, Na and K (AOAC, 2002), NDF, acid detergent fiber (ADF; Van Soest *et al*. 1991; using heat stable amylase and sodium sulfite) and ash at 605 ˚C at 3 h. NFC was calculated by 100 - (% crude protein (CP)+% NDF + % Ash + % EE) (Table 1).

Digestion kinetics

The ruminal nutrients degradation was determined *in situ*, using two cannulated Holstein steers (approximately 1 year old, body weight= 335.2 ± 10.3 kg). Steers were given access to water at all times and were housed in an open front shed. The steers were fed corn silage and concentrates in a ratio of about 65:35 (DM basis) according to their requirements. The diet was fed in two equal meals at 08:00 and 20:00 h. About 3 g of DM equivalent were weighed in each sealed nylon bag (6 cm×7.5 cm, polyamide, 26% porosity, 40±5 µm pore size) that was closed using a heat sealer. Three bags were incubated in the rumen for each of the following periods 0, 3, 6, 12, 18, 24, 36 and 48 h. All incubations started after the morning feeding. Bags were attached to a plastic tube (5 mm diameter) that was fixed to the outside of the fistula with a string. The bags and the tubes had free movement inside the rumen and reticulum. On removal, bags were washed using cold water until the effluent ran clear. The bags were dried in an oven at 60 ˚C for 48 h, and weighed. Following the weighing, bags were opened and residues from the three bags for each period were homogenized and placed in tightly capped plastic bottles. Samples were ground through a 1 mm sieve, analyzed for Kjeldahl N and NDF (Van Soest *et al*. 1991). All analyses were made on combined residues of the three bags. The analyses were run in duplicate and rerun when differences were greater than 3% and sufficient residue was available. The potentially degradable fraction was calculated as 100 minus the 0-h fraction. Kinetics of DM degradation *in situ* was estimated by the nonlinear regression procedure of SAS (1998). For each TMR and period, the following model was fitted to the percentage of degradation of DM (Ørskov and MacDonald, 1979):

$$P= a + b(1-\exp^{(-Kdt)})$$

Where:
P: degradability (%).
a: soluble fraction (%).
b: slowly digestible fraction (%).
Kd: fractional rate of degradation (%/h).
t: time of incubation (h).

The effective degradability (ED) was calculated, assuming a passage rate (Kp) of 0.04, 0.05 and 0.06/h. The equation ED= [a + b × Kd / (Kd+Kp)] was used to calculate ED.

In this equation, the Kp represents the flow rate of particles out of the rumen.

Kinetic of hydration and functional specific gravity

The ruminal kinetic of hydration, FSG and changes of FSG of samples were measured *in situ*, using two cannulated Holstein steers that fed as described before. The two bags were incubated in the rumen for each of the following periods 0, 0.5, 1, 1.5, 3, 6, 12, 18, 24, 36 and 48 h. After incubation in rumen and removal of bags, the kinetic of hydration, FSG, and changes of FSG of samples measured with 100 mL pycnometer (Wattiaux, 1990), without washing. All the measurements were made in a separate oven that was maintained at 39 ± 0.15 ˚C. All of solution, distiller water, sample, small magnet and pycnometer put 5 h before the starting of FSG in the oven at 39 ˚C. The McDougall's buffer (artificial saliva solution, 1984) was used as hydration solution (McDougall, 1948). The earliest reading of the total weight of pycnometers was taken after 6 min of initial soaking was the shortest interval necessary to eliminate all gas bubbles that considered as FSG. The data obtained during hydration were used to determine the hydration rate and water uptake using NLIN procedures of SAS, (2002); Wattiaux, (1990). A biexponential models could be described by the function below:

$$Y_t = Ae^{-k_a t} + Be^{-k_b t}$$

Where:

Y: water uptake over time (g/g of insoluble DM).

A and B: represent pool sizes of hydration.

k_a and k_b: represent respective fractional hydration rate (min^{-1}).

Some data were fit best to single (i.e., the B component was removed) rather than double exponential models. Total water holding capacity (WHC; g/g of insoluble DM) was calculated as the sum of total solution uptake (sum of A+B) and initial moisture content of the samples. A mean for hydration rate that was weighted for pool sizes from biexponential models was calculated: $[(A\times k_a) + (B\times k_b)] / (A+B)$ (Bhatti and Firkins, 1995). Data were analyzed as a complete randomized design by ANOVA using Proc GLM of SAS (2002). Means were separated using Duncan's multiple range test at an alpha level of 0.05.

Statistical analysis

The data were analyzed by a complete randomize block design as three types of BP and steers were considered as treatment and block, respectively. Data were analyzed by using the GLM procedure of SAS (2002). Pearson correlation analyses of the physical and chemical properties of feed were done with CORR procedure of SAS (2002). In addition, regression analyses of the physical and chemical properties of feed were done with REG procedure of SAS (2002). Means were separated using Duncan's multiple range test with an alpha level of 0.05.

RESULTS AND DISCUSSION

Ruminal degradation

The DM degradation parameters and ED showed important and significant differences among three types of BP (Table 1). The soluble fraction of DM for FBP was higher than in NBP and PBP. However, there was no significant difference of soluble fraction of DM between NBP and PBP. In addition, the slowly degradable fraction in FBP was higher and NBP than PBP (59.00 and 57.00 *vs*. 55.66% of DM, respectively). The potential extent of DM degradation was high and ranged between 78.33 and 90.00% and was significantly different among the samples (P<0.0001). In contrast, indigestible DM fraction was relatively low and had significantly different among the samples (P<0.0001). The DM fractional rate of degradation was relatively large (11.2, 10.3 and 10.1 %/h, respectively) and significantly different (P=0.0007). Regardless the value of Kp, the values of the ED of DM was also significantly different (P<0.0001). The FBP and PBP samples had the highest and lowest values of ED, respectively. Similar to DM, the NDF degradation showed significant differences between three types of BP as for the degradation parameters and for the ED (Table 1). FBP and PBP had the highest and lowest soluble fraction of NDF, respectively. The slowly digestible fraction of FBP was significantly higher than NBP and PBP. However, there was no significant difference between NBP and PBP. The potential extent of NDF degradation was high and was significantly different among the samples (P<0.0001; 86.00, 79.00 and 75.00 for FBP, NBP and PBP, respectively). The indigestible NDF fraction had significant differences among three types of BP (P<0.0001). The NDF fractional rate of degradation was relatively large (9.80, 8.80 and 8.30 %/h, for FBP, NBP and PBP, respectively) and significantly different (P=0.0002). The ED of NDF was also significantly different (P<0.0001). The FBP and PBP samples had the highest and lowest values of ED for NDF, respectively.Degradation of CP for the degradation parameters and for the ED, similar to DM and NDF, had significant differences among three types of BP. FBP and PBP had the highest and lowest soluble protein, respectively. There were no significant difference on the slowly digestible protein between FBP and NBP, but the slowly digestible protein for PBP was significantly lower than FBP and NBP. The potential extent of CP degradation was high and significantly different among the samples (P<0.0001;

87.00, 83.00 and 77.00 for FBP, NBP and PBP, respectively). The indigestible CP fraction was different among three types of BP (P<0.0001). The CP fractional rate of degradation was relatively large (10.80, 10.00 and 9.70 %/h, for FBP, NBP and PBP, respectively) and significantly different (P<0.0001). Regardless the value of Kp, the values of the ED of CP was also significantly different (P<0.0001). The FBP and PBP samples had the highest and lowest values of ED for CP, respectively.

The DM and NDF (DePeters *et al*. 1997) or DM and CP (Pereira and Gonzalez, 2004) degradation of the BP samples showed similar trends. Torrent *et al*. (1994) reported that apparent digestibilities of BP were 78.0, 81.5, 81.3 and 78.9% for DM, OM, NDF and ADF, respectively. Using *in situ* method, Torrent *et al*. (1994) found that rates of degradation, potentially digestible fractions, and lag time of NDF and ADF fractions of BP were 11.6%/h, 94.1% of NDF, and 0.8 h; and 14.3%/h, 92.6% of ADF, and 1.9 h, respectively. DePeters *et al*. (1997) found while the NDF content of BP ranged from 33.22 to 42.18%, the rates of NDF digestion ranged from 7.3 to 9.0%/h (with mean K_d=8.3%/h) for BP. In addition, Bhatti and Firkins (1995) reported a much larger range in NDF digestion for BP, 5.5 to 11.6%/h. Richardson *et al*. (2003) found that proportion of soluble, slowly degradable, and the rate of degradation of the potentially degradable OM and N of unmolassed BP were 6.50%, 87.20% and 7.70%/h; and 0.00%, 92.30%, and 3.20%/h, respectively. These results clearly showed that BP did not contain a rapidly degradable N fraction and had a slower rate of degradation of the potentially degradable fraction than winter barley. BP is commonly added with molasses or vinasses, which had an important effect on DM and protein solubility. However, the most experiments confirmed that rates of degradation for DM, NDF and CP were high and had similar trend. Gonzalez *et al*. (2001) found that in a BP sample with 49.1, 42.7, and 11.0 (% of DM) NDF, ADF, and CP content the soluble CP, insoluble degradable fraction and potential degradable fraction were 17.7, 65.4 and 83.1% of CP content, respectively. Pereira and Gonzalez (2004) tested 10 samples of dried beet pulp observed a range of variation of the soluble, slowly degradable fraction and fractional degradation rate of DM and CP from 1.53 to 41.3%, 7 to 50%, 3.71 to 6.21%/h; 11.5 to 50.0%, 51.0 to 80.7% and 5.55 to 10.5%/h, respectively. Pereira and Gonzalez (2004) reported that the ED values of DM ranged from 41.0 to 70.8% and those of CP from 34.3 to 73.1% and both values were correlated (r=0.874). Gonzaleze *et al*. (2001) tested the effects of degradation of soluble or insoluble proteins measured by rumen incubations at 0 h (washout value) and 16 h, respectively. Washing effects on essential amino acid proportions of DBP were limited. However, the DBP sample employed by Pereira and Gonzalez (2004) and Gonzaleze *et al*. (2001) included an important addition of molasses and therefore, its DM, NDF and protein solubility was high. In the present experiment, grounding and pelleting significantly increased and decreased soluble fraction of DM, NDF, and CP (Table 1), therefore, the significant difference on potential degradable fraction and fractional rate of degradation may be result of differences in soluble fraction of DM, NDF, and CP. In addition, the lag time of DM, NDF, and CP of three types of BP were not detected. The most experiments also, have confirmed the current results. However, using *in vitro* method, Bhatti and Firkins (1995) found that extent, fractional rate and lag time of DM for FBP samples were 67.4%, 8.41%/h and 3.9 h, respectively. In addition, Pereira and Gonzalez (2004) showed the ED values of CP had a high variability (range from 34.3 to 73.1%), therefore, using a mean constant value may lead to major errors to estimate nutritive value of BP. In this experiment, based on chemical composition, the degradation parameters and the ED values were in a range that reported in literature, however, degradation rate of CP was much higher than the others. Pereira and Gonzalez (2004) reported that there were marked differences between samples for all the degradation kinetic parameters and for the ED values. The values of soluble and slowly degradable fraction for CP were closely complementary, since the potential extent of CP degradation was relatively similar (from 86.7 to 95.5%). Consequently, both fractions were closely correlated. Therefore, the ED of CP was closely correlated with both fractions. The variation of the ED values for both DM and CP were mainly caused by the variation of their 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, soluble CP and NDIN for CP degradation. The appearance of multiple correlations between ED values and soluble CP or many chemical parameters is logical, because most of these factors are intercorrelated (Pereira and Gonzalez, 2004). The results of this experiment and Pereira and Gonzalez (2004) confirmed that the high and positive correlation between the degradation rate of DM and NDF is result of low degree of lignification of BP that does not seem to be an important barrier to ruminal degradation.

Kinetic of hydration, and functional specific gravity

Kinetics of ruminal hydration of three types of BP is presented in Table 2.

Table 1 The Kinetics of ruminal digestion of three types of beet pulps

Item	Three types of beet pulp			SEM	P-value
	Fine	Normal	Pelleted		
Degradability of dry matter					
Soluble fraction (%)	31.00^{a}	25.33^{b}	22.67^{b}	0.005	*
Slowly digestible fraction (%)	59.00^{a}	57.00^{ab}	55.66^{b}	0.004	NS
Potential extent of dry matter (DM) degradation (a+b)	90.00^{a}	82.33^{b}	78.33^{c}	0.002	***
Indigestible fraction (%)	10.00^{c}	17.67^{b}	21.67^{a}	0.003	***
Fractional rate of degradation (%/h)	11.2^{a}	10.3^{b}	10.1^{b}	0.006	*
Effective degradability (%/h)[1]					
Kp= 0.04	72.90^{a}	65.81^{b}	65.30^{b}	0.002	***
Kp= 0.05	71.75^{a}	63.66^{b}	59.90^{c}	0.002	***
Kp= 0.06	69.37^{a}	61.31^{b}	57.59^{c}	0.002	***
Degradability of neutral detergent fiber					
Soluble fraction (%)	28.00^{a}	25.00^{b}	22.00^{c}	0.003	**
Slowly digestible fraction (%)	58.00^{a}	54.00^{b}	53.00^{b}	0.002	***
Potential extent of NDF degradation (a+b)	86.00^{a}	79.00^{b}	75.00^{c}	0.002	***
Indigestible fraction (%)	14.00^{c}	21.00^{b}	25.00^{a}	0.003	***
Fractional rate of degradation (%/h)	9.8^{a}	8.8^{b}	8.4^{c}	0.001	**
Effective degradability (%/h)					
Kp= 0.04	69.19^{a}	62.12^{b}	57.90^{c}	0.003	***
Kp= 0.05	66.40^{a}	59.43^{b}	55.22^{c}	0.003	***
Kp= 0.06	63.97^{a}	57.10^{b}	52.91^{c}	0.003	***
Degradability of crude protein					
Soluble fraction (%)	21.00^{a}	18.00^{b}	14.00^{c}	0.002	**
Slowly digestible fraction (%)	66.00^{a}	65.00^{a}	63.00^{b}	0.002	*
Potential extent of CP degradation (a+b)	87.00^{a}	83.00^{b}	77.00^{c}	0.002	***
Indigestible fraction (%)	13.00^{c}	17.00^{b}	23.00^{a}	0.002	***
Fractional rate of degradation (%/h)	10.8^{a}	10.0^{b}	9.7^{c}	0.001	***
Effective degradability (%/h)					
Kp= 0.04	69.20^{a}	64.39^{b}	58.68^{c}	0.002	***
Kp= 0.05	66.16^{a}	61.29^{b}	55.64^{c}	0.002	***
Kp= 0.06	63.47^{a}	58.58^{b}	53.01^{c}	0.002	***

[1] The equation ED= [a + b × K_d / (K_d+Kp)] was used to calculate effective degradability (ED). In this equation, Kp represents the flow rate of particles out of the rumen that was considered equal to 0.04, 0.05 and 0.06 (Ørskov and MacDonald, 1979).
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
* (P≤0.05); ** (P≤0.01) and *** (P≤0.001).
NS: not significant.

Table 2 Kinetics of ruminal hydration of three types of beet pulps

Item	Three types of beet pulp			SEM	P-value
	Fine	Normal	Pelleted		
Initial water content (g/g insoluble dry matter (DM))	0.062	0.064	0.064	0.051	NS
Hydration rate (g/g insoluble DM/h)	0.065^{b}	0.075^{a}	0.064^{b}	0.002	***
Water holding capacity (g/g insoluble DM)	3.25^{c}	4.21^{a}	3.87^{b}	0.021	***

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
*** (P≤0.001).
NS: not significant.
SEM: standard error of the means.

Initial water content (g/g insoluble DM) was not significantly different among three types of BP pulps. Hydration rate (g/g insoluble DM/h) and WHC (g/g insoluble DM) were significantly different among the three types of BP. Grinding and pelleting significantly decreased hydration rate and WHC of BP. Therefore, NBP had the highest hydration rate and WHC. In addition, there was no significant difference on hydration rate between NBP and PBP, but WHC was significantly different between NBP and PBP (Table 2).

Changes in FSG over incubation time are shown in Table 3. Grinding and pelleting of BP increased FSG for FBP and PBP over incubation time (Table 3). Initial FSG and final FSG increased when were grinded and pelleted. Over the ruminal incubation, FSG of all typed of BP were higher than ruminal liquid that measured by Wattiaux (1990) that was 1.001 2 to 1.008 9. In addition, after the ruminal incubation to 2 h for FBP and NBP and to 4 h for PBP, the FSG of different types of BP were higher than critical size (Poppi *et al*. 1980) for passage from reticulorumen orifice.

In ruminant, the voluntary dry matter intake and ruminal filling is related to the bulk density of forages (Wattiaux, 1990), but ruminal retention time and passage rate are related to FSG of feeds (Wattiaux, 1990; Kaske and Engelhardt, 1990; Kaske and Engelhardt, 1992; Teimouri Yansari *et al*. 2004).

Ramanzin *et al*. (1994) found that the FSG of DM of original unwashed feedstuffs estimated at 0 h soaking was not significantly related to the various chemical components. However, the FSG of DM of unwashed feedstuffs estimated after 15 h of soaking, as well as that of the insoluble fractions of washed feedstuffs (both after 0 and 15 h of soaking) and that of soluble fractions, showed significantly positive correlations with various fibrous fractions and negative correlations with CP and fat. Correlations were highly significant and positive between WHC and fibrous fractions, except lignin. On average, the FSG of DM of three type of BP was higher than those reported for forage particles (Wattiaux, 1990; Ramanzin *et al*. 1994; Teimouri Yansari *et al*. 2004) and were in agreement with the few data available for concentrates (Wattiaux, 1990; Ramanzin *et al*. 1994). Solubility effect on FSG is important because soluble DM is in many feedstuffs a substantial fraction of total DM and has an FSG different from that of the insoluble fraction (Ramanzin *et al*. 1994). This result is in agreement with the results of Wattiaux (1990) in forages and confirms that measurements of FSG should be made on the insoluble DM of feedstuffs.

The WHC of three BP samples were 3.25, 4.21 and 3.87 (g/g insoluble DM) in FBP, NBP and PBP, respectively. As mentioned in material and methods, using an exponential model (cure fitting method; Wattiaux (1990); Teimouri Yansari *et al*. (2004)) the values of WHC were estimated. Using the centrifugation method and polyester bags, Ramanzin *et al*. (1994) found an average higher WHC (6.44 and 597 g/g insoluble DM) than the filtration methods (Giger-Reverdin, 2000; 5.37 g/g insoluble DM). However, many experiments (Wattiaux, 1990; Teimouri Yansari *et al*. 2004) explained that the estimated WHC with an exponential model was lower than the WHC that obtained with filtration or the centrifugation method. Giger-Reverdin (2000) found that WHC was highly correlated with NDF (R^2=0.456) and ADF (R^2=0.418), but not with lignin (R^2=0.013). It increased with the cell wall content of feedstuffs and decreased with the bulk density. However, BP had a WHC value higher than other feed because of high pectin content.

By the way, for stimulating chewing activity, particles must be retaining in rumen. The extent of FSG especially for concentrate and by products is a better indicator of ruminal mean retention time than the particle size (Kaske and Engelhardt, 1990; Teimouri Yansari *et al*. 2004).

When particle reached to threshold of size and FSG, they must pass the rumen. BP has a size lower than critical point that can easily pass from the riticulorumen orifice. It seems that FSG is more important to control ruminal retention time, consequently ruminal degradation of BP.

Relationship of degradation and hydration parameters

As a general conclusion, the correlation between digestion and hydration parameters is significantly high. Soluble fraction of DM, NDF and CP had high positive and negative correlation with slowly digestible and indigestible fractions, respectively. In addition, soluble fraction of DM, NDF and CP had high negative correlation with hydration rate, WHC, initial and final FSG. Slowly digestible fraction of DM, NDF and CP had similar trend to soluble fraction of DM, NDF, and CP (Table 4). In contrary, indigestible fractions of DM, NDF and CP had high positive correlation with hydration rate, WHC, initial and final FSG. Fractional rate of degradation of DM, NDF and CP had high positive correlation with soluble and slowly digestible and negative correlation with indigestible fractions, with hydration rate, WHC, initial and final FSG. The ED of DM had negative correlation with indigestible fractions of DM, NDF and CP, hydration rate, WHC, initial and final FSG, but positive correlation with soluble and slowly digestible fractions of DM, NDF and CP and fractional rate of degradation of DM, NDF and CP (Table 4).

The ED degradability of DM had close correlation with ED of NDF (r=0.966) and CP (r=0.989). Therefore, the values in Table 4 showed only the values of degradability for DM. The ED degradability of DM had negative correlation with soluble, slowly digestible fraction, fractional rate of degradation, ED of DM, hydration rate, WHC, initial and final FSG, indigestible fraction of NDF and CP, but high direct correlation with soluble and slowly digestible fraction of NDF and CP and fractional rate of degradation of NDF and CP. Pereira and Gonzalez (2004) found that the ED of DM was significantly correlated with the soluble, slowly degradable and fractional rate of degradation for 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 the soluble, slowly degradable, and fractional rate of degradation parameters. In addition, the ED of CP showed close and direct correlations with the soluble CP, CP and ash content that the closest correlations were recorded with the CP content. On the contrary, the ED of CP showed inverse correlations with the proportion of NDIN and the NDF and ADF contents (Pereira and Gonzalez, 2004). In addition, Haj-Ayed *et al*. (2000) found that ED of CP in vetch-oat hays was positively correlated at a lower level with the CP content and at high level with NDF.

Table 3 Changes in the functional specific gravity over incubation time

Beet pulp types	Functional specific gravity of beet pulp over the incubation time (h)							
	0.1	2	4	6	12	24	36	48
Fine beet pulp	1.243[a]	1.209[a]	1.148[b]	1.018[d]	1.003[d]	1.094[c]	1.117[c]	1.123[c]
Normal beet pulp	1.285[a]	1.274[a]	1.106[f]	1.056[c]	1.001[d]	1.056[c]	1.118[b]	1.136[b]
Pelleted beet pulp	1.312[a]	1.302[a]	1.235[b]	1.112[c]	1.054[e]	1.098[c]	1.135[c]	1.132[c]

The means within the same row with at least one common letter, do not have significant difference (P>0.05).

Table 4 Correlation coefficients (%, above diagonal) between digestion and hydration parameters and their P-values (below diagonal)

Parameter[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	-	0.54	-0.95	0.91	0.97	-0.16	-0.74	-0.93	-0.89	0.95	0.88	0.96	0.85	0.83	-0.89	0.92	0.90
2	NS	-	-0.77	0.65	0.72	-0.15	-0.56	-0.79	-0.80	0.64	0.69	-0.69	0.81	0.52	-0.76	0.78	0.78
3	***	*	-	-0.92	-0.99	0.19	0.76	0.99	0.96	-0.94	-0.95	0.98	-0.95	-0.93	-0.81	0.94	-0.98
4	**	NS	**	-	0.94	-0.35	-0.82	-0.92	-0.91	0.87	0.96	-0.95	0.90	0.81	0.77	-0.84	0.94
5	***	*	***	**	-	-0.19	-0.77	-0.99	-0.96	0.95	0.96	-0.99	0.95	0.92	0.83	-0.93	0.98
6	NS	NS	NS	NS	NS	-	0.76	0.73	0.84	-0.60	-0.83	0.73	-0.78	-0.55	-0.41	0.53	-0.84
7	**	NS	*	**	*	**	-	0.73	0.94	-0.94	-0.95	0.97	-0.96	-0.96	-0.81	0.96	-0.97
8	**	*	***	**	***	*	**	-	0.94	-0.94	-0.95	0.98	-0.96	-0.96	-0.81	0.96	-0.97
9	**	*	***	**	***	*	**	**	-	-0.91	-0.90	0.94	-0.91	-0.87	-0.70	0.86	-0.97
10	**	NS	***	**	***	NS	**	**	**	-	0.85	-0.97	0.84	0.92	0.85	-0.95	0.88
11	***	*	***	***	***	*	***	**	**	**	-	-0.96	0.96	0.84	0.82	-0.87	0.98
12	***	*	***	***	***	*	***	***	**	***	***	-	-0.93	-0.92	-0.87	0.94	-0.96
13	**	*	***	**	***	NS	***	***	**	**	***	**	-	0.87	0.77	-0.89	0.98
14	**	*	**	**	**	NS	***	***	**	**	**	**	**	-	0.78	-0.89	0.97
15	**	NS	**	**	**	NS	**	**	**	**	**	**	**	**	-	-0.89	0.77
16	**	*	**	**	**	NS	***	***	**	**	**	**	**	***	**	-	-0.89
17	**	*	***	**	***	**	***	***	***	**	***	***	***	**	**	**	-

1: soluble fraction of DM (%); 2: slowly digestible fraction of DM (%); 3: indigestible fraction of DM (%); 4: fractional rate of degradation of DM (%/h); 5: effective degradability of DM (%/h); 6: hydration rate (g/g insoluble DM/h); 7: water holding capacity (g/g insoluble DM); 8: initial functional specific gravity; 9: final functional specific gravity; 10: soluble fraction of NDF (%); 11: slowly digestible fraction of NDF (%); 12: indigestible fraction of NDF (%); 13: fractional rate of degradation of NDF (%/h); 14: soluble fraction of CP (%); 15: slowly digestible fraction of CP (%); 16: indigestible fraction of CP (%) and 17: fractional rate of degradation of CP (%/h).
* (P≤0.05); ** (P≤0.01) and *** (P≤0.001).
NS: not significant.

For DM degradability, NDF and ADL contents explained 79.4% of the total variation, while for CP degradability; the cellulose content explained 83.9%. Rodriguez (1996) showed that the soluble fraction was linked to the cell content (complementary to the NDF fraction) while the slowly degradable and indegradable fractions were mainly linked to fiber components and lignin, respectively. Consequently, the variability of the soluble and slowly degradable fractions was linked to the variability of the fiber fractions while a higher variability of the undegradable fraction was related to the higher variability of lignin and ADIN.

Using the stepwise procedure, physical characteristics (hydration kinetics and degradation parameters) and chemical fractions as independent variables, we obtained regression equations to estimate relationships between degradation and hydration kinetic with soluble fraction (Figure 1), slowly degradable fraction (Figure 2) and indigestible fraction (Figure 3) of DM for BP samples. For DM degradability, soluble fraction of DM explained 82.4, 94.8, 2.7, 54.2, 87.3 and 79.7% of the total variation of factional rate of degradation, ED, hydration rate, WHC, initial and final FSG, respectively (Figure 1).

In addition, the slowly degradable fraction of DM explained 34.1, 50.0, 2.2, 31.4, 62.2 and 63.4% of the total variation of fractional rate of degradation, ED, hydration rate, WHC, initial and final FSG, respectively (Figure 2).

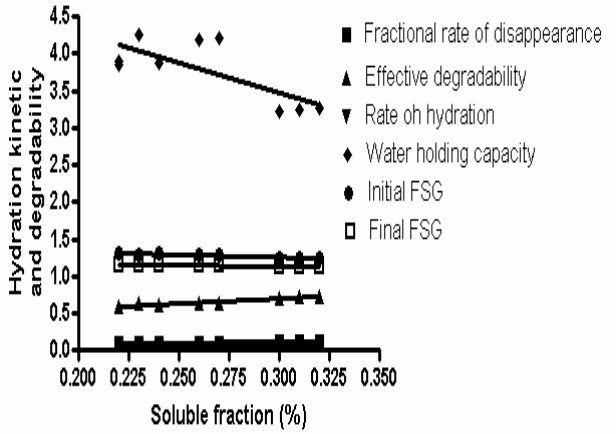

Figure 1 Relationships between degradation and hydration kinetics with the soluble fraction of DM in beet pulp samples. Relationships with the soluble fraction of dry matter are shown with the following equations:
1) The fractional rate of degradation (%/h)= 0.073 + 0.121 × soluble fraction of DM (%) (R^2=0.824; P=0.0007)
2) Effective degradability (%/h)= 0.304 + 1.317 × soluble fraction of DM (%) (R^2=0.948; P=0.0007)
3) Hydration rate (g/g insoluble DM/h)= 0.071 – 0.024 × soluble fraction of DM (%) (R^2=0.027; P=0.6753)
4) Water holding capacity (g/g insoluble DM)= 5.917 – 8.115 × soluble fraction of DM (%) (R^2=0.542; P=0.0238)
5) Initial FSG= 1.472 – 0.730 × soluble fraction for DM (%) (R^2=0.873; P=0.0002)
6) Final FSG= 1.173 – 0.127 × soluble fraction for DM (%) (R^2=0.797; P=0.0012)

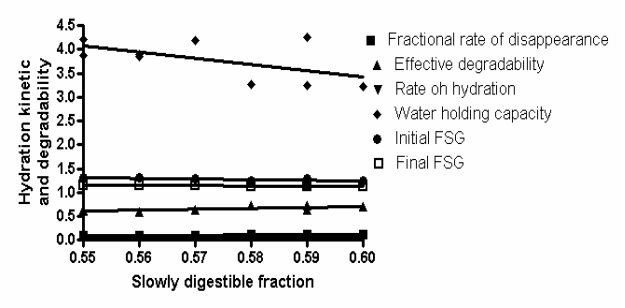

Figure 2 Relationship between degradation and hydration kinetics parameters with slowly digestible fraction of beet pulp samples. Relationships with slowly digestible fraction of dry matter are shown with the following equations:
1) Fractional rate of degradation (%/h)= -0.0003 + 0.184 × slowly digestible fraction of DM (%) (R^2=0.431; P=0.0546)
2) Effective degradability (%/h)= -0.512 + 2.003 × slowly digestible fraction of DM (%) (R^2=0.500; P=0.0333)
3) Hydration rate (g/g insoluble DM/h)= 0.094 – 0.046 × slowly digestible fraction of DM (%) (R^2=0.022; P=0.7063)
4) Water holding capacity (g/g insoluble DM)= 11.214 – 12.991 × slowly digestible fraction of DM (%) (R^2=0.314; P=0.1168)
5) Initial FSG= 2.021 – 1.296 × slowly digestible fraction for DM (%) (R^2=0.622; P=0.0115)
6) Final FSG= 1.277 – 0.239 × slowly digestible fraction for DM (%) (R^2=0.634; P=0.0102)

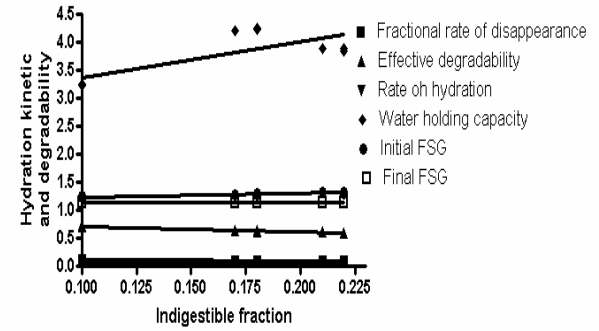

Figure 3 Relationship between degradation and hydration kinetic with indigestible fraction of beet pulp samples. Relationships with indigestible fraction of dry matter are shown with following equations:
1) Fractional rate of degradation (%/h)= 0.120 – 0.094 × indigestible fraction of DM (%) (R^2=0. 856; P=0.0004)
2) Effective degradability (%/h)= 0.819 – 1.021 × indigestible fraction of DM (%) (R^2=0.991; P<0.0001)
3) Hydration rate (g/g insoluble DM/h)= 0.064 + 0.020 × indigestible fraction of DM (%) (R^2=0.031; P=0.6497)
4) Water holding capacity (g/g insoluble DM)= 2.735 + 6.352 × indigestible fraction of DM (%) (R^2=0.517; P=0.0175)
5) Initial FSG= 1.184 – 0.588 × indigestible fraction for DM (%) (%) (R^2=0.986; P<0.0001)
6) Final FSG= 1.233 + 0.104 × indigestible fraction for DM (%) (R^2=0.929; P<0.0001)

For DM degradability, indigestible fraction of DM explained 85.6, 99.1, 3.1, 51.7, 98.6 and 92.9 % of the total variation of fractional rate of degradation, ED, hydration rate, WHC, initial and final FSG, respectively (Figure 3). In addition, fractional rates of degradation, explained 89.1, 12.2, 68.0, 84.7 and 92.9 % of the total variation of ED, hydration rate, WHC, initial and final FSG, respectively (Figure 4).

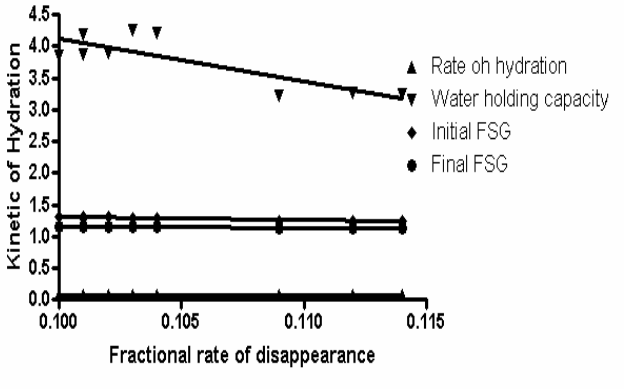

Figure 4 Relationship between fractional rates of degradation and hydration kinetics of DM for beet pulp samples. Relationships with fractional rates of degradation of dry matter are shown with following equations:
1) Effective degradability (%/h)= -0.355 + 9.571 × fractional rates of degradation of DM (%/h) (R^2=0.891; P=0.0001)
2) Hydration rate (g/g insoluble DM/ h)= 0.108 – 0.386 × fractional rates of degradation of DM (%/h) (R^2=0.122; P=0.3572)
3) Water holding capacity (g/g insoluble DM)= 10.948 – 68.192 × fractional rates of degradation of DM (%/h) (R^2=0.680; P=0.0062)
4) Initial FSG= 1.847 – 5.390 × fractional rates of degradation for DM (%/h) (R^2=0.847; P=0.0004)
5) Final FSG= 1.243 – 0.975 × fractional rates of degradation for DM (%/h) (R^2=0.929; P=0.0006)

Using the stepwise procedure, relationships between NDF degradability coefficient and hydration parameters were significantly explained with the following equation

A) Soluble fraction of NDF (a)= 1.327 – 0.841 × initial FSG (R^2=0.878; P=0.0002; equation 1).
B) Slowly digestible fraction of NDF= 1.481 – 0.727 × final FSG (r^2=0.894; P=0.0001; equation 2).
C) Indigestible fraction of NDF= -1.808 + 1.568 × initial FSG (R^2=0.953; P<0.0001; equation 3).
D) Fractional rate of degradation for NDF= 0.349 – 0.203 × initial FSG (R^2 0.926; P<0.0001; equation 4).
E) ED for NDF= 2.690 – 1.609 × initial FSG (R^2=0.966; P<0.0001; equation 5).
F) WHC= 12.155 – 15.227 × slowly digestible fraction of NDF (R^2=0.688; P=0.0057; equation 6).
G) Initial FSG= 1.659 – 0.601 × ED of NDF (R^2=0.966; P<0.0001; equation 7).
H) Final FSG= 1.207 – 0.105 × indigestible fraction for NDF (R^2=0.889; P=0.0001; equation 8).

The best prediction soluble (R^2=0.878), slowly degradable (R^2=0.894), indegradable fraction (R^2=0.953 and 0.994) and fractional rate of degradation (R^2=0.926) of NDF were derived from the initial FSG (equation 1, 2, 3, 4 and 5). In addition, the best prediction WHC (R^2=0.688), initial FSG (R^2=0.966) and final FSG (R^2=0.889) were derived from the slowly digestible fraction of NDF (equation 6), ED of NDF (equation 7), and indigestible fraction for NDF (equation 8).

Using the stepwise procedure, relationships between CP degradability coefficient and hydration parameters were significantly explained with the following equation:

A) Soluble Fraction of CP= 1.640 + 0.022 × WHC – 1.208 × initial FSG (R^2=0.966; P<0.0001; equation 9).
B) Slowly digestible Fraction of CP= 1.155 – 0.397 × initial FSG (R^2=0.653; P=0.0084; equation 10).
C) Indigestible fraction of CP= -1.522 - 1.937 × hydration rate + 1.429 × initial FSG (R^2=0.985; P<0.0001; equation 11).
D) Fractional rate of degradation for CP= 0.273 – 0.003 × WHC – 0.224 × initial FSG (R^2=0.990; P<0.0001; equation 12).
E) ED for CP= 2.468 + 1.498 × hydration rate – 1.507 × initial FSG (R^2=0.989; P<0.0001; equation 13).
F) WHC= 22.432 – 11.296 × indigestible fraction of CP + 163.511 × fractional rate of degradation (R^2=0.981; P<0.0001; equation 14).
G) Initial FSG= 1.809 – 2.970 × fractional rate of degradation - 0.353 × ED of CP (R^2=0.988; P<0.0001; equation 15).
H) Final FSG= 1.251 – 1.089 × fractional rate of degradation for CP (R^2=0.938; P<0.0001; equation 16).

The best prediction soluble and fractional rate of degradation for CP was derived from the WHC and initial FSG (R^2=0.966; equation 8 and R^2=0.990; equation 13, respectively). Similar to NDF fraction, slowly digestible fraction of CP was derived from initial FSG (R^2=0.653; equation 10), but indigestible fraction and ED of CP was derived from Hydration rate and initial FSG (R^2=0.985; equation 11 and R^2=0.989; equation 13). WHC was a function of indigestible fraction and fractional rate of degradation of CP (R^2=0.981; equation 14). Initial FSG of CP was derived from fractional rate of degradation and ED of CP (R^2=0.988; equation 15), but final FSG well explained with fractional rate of degradation for CP (R^2=0.938; equation 16). The results of current experiment were confirmed with previous experiments (Rodriguez, 1996; Gonzalez *et al*. 2001; Pereira and Gonzalez, 2004). Pereira and Gonzalez (2004) reported that a good prediction of the ED of DM (R^2=0.933) was obtained from the contents of NDF and ADF as the first and second predictive variables. The best prediction (R^2=0.954) of the ED of CP was derived from the concentrations of CP and NDF and the CP content allowed to explain 87.8% of the variation.

CONCLUSION

The grinding and pelleting of BP had significant effects on degradation parameters of DM, NDF and CP. The rate and extent of degradation for DM, NDF and CP were high and had similar trend. Grinding and pelleting significantly increased and decreased soluble fraction of DM, NDF and CP, respectively. It seems that the significant difference on potential degradable fraction and fractional rate of degradation may be result of the differences in soluble fraction of DM, NDF and CP. The high and positive correlation between the degradation rate of DM and NDF is result of low degree of lignification of BP that does not seem to be an important barrier to ruminal degradation. Grinding and pelleting significantly decreased hydration rate and WHC, increased initial and final FSG over incubation time. The correlation between digestion and hydration parameters is significantly high. In addition, the correlations between digestion and hydration parameters were significantly high. As beet pulp has size lower than critical size, can easily pass from the reticulorumen orifice, therefore, its functional specific gravity is more important to control ruminal retention time and degradation.

REFERENCES

Allen M.S. and Mertens D.R. (1988). Evaluating constraints on fiber digestion by rumen microbes. *J. Nutr*. **118,** 261-270.

AOAC. (2002). Official Methods of Analysis. Vol. I. 17th Ed. Association of Official Analytical Chemists, Arlington, VA, USA.

Ben-Ghedalia D.E., Yosef J., Miron D. and Est Y. (1989). The effects of starch- and pectin- rich diets on the quantitative aspects of digestion in sheep. *Anim. Feed Sci. Technol*. **24,** 289-298.

Bhatti S.A. and Firkins J.L. (1995). Kinetics of hydration and functional specific gravity of fibrous feed by-products. *J. Dairy Sci*. **73,** 1449-1460.

Catherine M.G., Crepeau C.R.M. and Thibault J. (1999). Glucuronic acid directly linked to galacturonic acid in the rhamnogalacturonan backbone of beet pectins. *Europe J. Biochem*. **266,** 566-574.

DePeters E.J., Fadel J.G. and Arosemena A. (1997). Digestion kinetics of neutral detergent fiber and chemical composition within some selected by-product feedstuffs. *Anim. Feed Sci. Technol*. **67,** 127-140.

Ehle F.R. and Stern M.D. (1986). Influence of particle size and density on particulate passage through alimentary tract of Holstein heifers. *J. Dairy Sci*. **69,** 564-571.

Giger-Reverdin S. (2000). Characterization of feedstuffs for ruminants using some physical parameters. *Anim. Feed Sci. Technol*. **86,** 53-69.

Gonzalez J., Centeno C. and Lamrani F. (2001). *In situ* rumen degradation of amino acids from different feeds corrected for microbial contamination. *Anim. Res*. **50,** 253-264.

Haj-Ayed M., Gonzalez J., Caballero R. and Alvir M.R. (2000). Nutritive value of on-farm vetch-oat hays. I. Voluntary intake and nutrient digestibility. *Ann. Zootech*. **49,** 381-389.

Kaske M. and Englhardet W.V. (1990). The effect of size and density on mean retention time of particles in the gastrointestinal tract of sheep. *Br. J. Nutr*. **63,** 683-704.

Kaske M., Hatiboglu S. and Englhardet W.V. (1992). The influence of density and size of particles on rumination and passage from the reticulo-rumen of sheep. *Br. J. Nutr*. **67,** 235-244.

McDougall E.I. (1948). Studies on ruminant saliva1: the composition and out put of sheep's saliva. *Biochem. J*. **4,** 39-45.

Ørskov E.R. and McDonald I. (1979). The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agric. Sci*. **92,** 499-503.

Pereira J.C. and Gonzalez J. (2004). Rumen degradability of dehydrated beet pulp and dehydrated citrus pulp. *Anim. Res*. **53,** 99-110.

Poppi D.P., Norton B.W., Minson D.J. and Hendrickson R.E. (1980). The validity of the critical size theory for particles leaving the rumen. *J. Agric. Sci*. **94,** 275-280.

Ramanzin M., Bailoni L. and Bittante G. (1994). Solubility, water-holding capacity and specific gravity of different concentrates. *J. Dairy Sci*. **11,** 174-781.

Richardson J.M., Wilkinson R.G. and Sinclair L.A. (2003). Synchrony of nutrient supply to the rumen and dietary energy source and their effects on the growth and metabolism of lambs. *J. Anim. Sci*. **81,** 1332-1347.

Rodríguez C.A. (1996). Estudio de la colonización microbiana de los alimentos en el rumen. Implicaciones sobre la estimación de la degradabilidad ruminal de las materias nitrogenadas mediante técnicas *in situ*. Ph D. Thesis. Universidad Politécnica de Madrid, Spain.

SAS Institute. (1998). SAS®/STAT Software, Release 8. SAS Institute, Inc., Cary, NC. USA.

Teimouri Yansari A., Valizadeh R., Naserian A., Christensen D.A., Yu P. and Eftekhari Shahroodi F. (2004). Effects of alfalfa particle size and specific gravity chewing activity, digestibility and performance of Holstein dairy cows. *J. Dairy Sci*. **87,** 3912-3924.

Torrent J., Johnson D.E. and Kujawa M.A. (1994). Co-product fiber digestibility: kinetic and *in vivo* assessment. *J. Anim. Sci*. **72,** 790-795.

Van Soest P.J., Robertson J.B. and Lewis B.A. (1991). Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci*. **74,** 3583-3597.

Wattiaux M.A. (1990). A mechanism influencing passage of forage particles through the reticulo-rumen: change in specific gravity during hydration and digestion. Ph D. Thesis. University of Wisconsin, USA.