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Physical Characteristics and Physically Effectiveness of Beet Pulp for Ruminant

Research Article

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ABSTRACT

Beet pulp as component of cattle feed can be processed in different way. Tis study was performed to characterize the physical properties of so called fine beet pulp (FBP); normal beet pulp (NBP) and pelleted beet pulp (PBP). The following parameters were determined: bulk density, kinetics of hydration, functional specific gravity (FSG), water holding capacity (WHC), soluble dry matter and intrinsic osmotic pressure (IOP) were investigated. Furthermore particle size distribution and its geometric mean were determined according to ASAE S424.1. All three types of beet pulp had similar composition, but different acid detergent insoluble nitrogen, bulk density, WHC, hydration rate, soluble matter and IOP. PBP had the highest (0.967 g/mL) and NBP had the lowest (0.623 g/mL) bulk density. WHC was 4.318, 5.261, 4.881 (g/DM) and hydration rate 0.0527, 0.0663, 0.0657 (g/DM/Min) for FBP, NBP and PBP, respectively. Grinding and pelleting significantly decreased WHC. Initial FSG of FBP was higher than of NBP and PBP (1.416 *vs.* 1.371 and 1.384, respectively). FSG changed with incubation time as particle size decreased. Final FSG of all three beet pulp types were similar. FBP had the highest soluble DM (28.61 *vs.* 17.98 and 23.66% of initial DM in NBP and PBP, respectively). In addition, FBP had the highest soluble ash (45.18 *vs.* 37.79 and 39.36% of initial ash in NBP and PBP, respectively). FBP had the highest IOP and there are not significant differences between NBP and PBP. The studied physical properties were highly correlated with the chemical composition of the pulp. So was bulk density negatively correlated with the neutral detergent fiber (NDF), crude protein (CP) and non-fiber carbohydrates (NFC), hydration rate and WHC and was positively correlated with the DM, EE, FSG, soluble DM and ash, and IOP. In addition, WHC was positively correlated with dry matter (DM), NDF, NFC, CP and EE, but also negatively correlated with bulk density, FSG, soluble DM, soluble ash and IOP. FSG was highly negatively correlated with DM, NDF, CP, NFC, EE, hydration rate and WHC and positive correlated with bulk density, soluble DM, soluble ash and IOP. The physical properties of beet pulp aid in establishing the nutritive value of feedstuffs for ruminant. They physical properties of feedstuff take into account the modifying role of the reticulo-ruminal function on the speed of the character of the quantitative and qualitative biochemical degradation process.

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

INTRODUCTION

The optimal utilization of diets by dairy cows is affected by the chemical composition as well as by the physical characteristics of its various components. The physical characteristics of feed particles determine the retention time of the feed components in the rumen and their passage rate into the reticulum and rest of the gut. Particle size affects the speed of postprandial ruminal emptying and subsequently determines the magnitude of voluntary feed intake. Therefore, optimal particle size could enable a larger feed intake which on its turn is a condition for high performance. These physical characteristics of feedstuffs for ruminants are rarely measured or seriously considered in the evaluation of digestibility next to particle size (Mertens, 1997), functional specific gravity (FSG) (Wattiaux, 1990; Teimouri Yansari *et al*. 2004; Teimouri Yansari and Pirmohammadi, 2009), hydration rate (Bhatti and Firkins, 1995; Wattiaux, 1990), water holding capacity (WHC) and ionion-cation exchange (Van Soest, 1994) determine the physical status of feed components. Physical characteristics become critical factors if correct lower limits for acceptable forage to concentrates ratios must be set for dairy (Mertens, 1997).

Effective dietary fiber sources are those that stimulate chewing and sustain normal milk fat yield with maintenance of a good ruminal structure (Teimouri Yansari *et al*. 2004). In addition, calculation of physically effective NDF (peNDF) values based on chewing activity allows the separation of physical and chemical effects of fiber and quantities the impact of replacing forage fiber with NFC of small particle size (Grant, 1997). However, some physical properties such as FSG (Bhatti and Firkins, 1995; Wattiaux, 1990; Teimouri Yansari and Pirmohammadi, 2009), WHC and hydration rate (Wattiaux, 1990; Teimouri Yansari *et al*. 2004) influenced on physically effective factor (pef), but only particle size measurement is central to all effective fiber systems. Beet pulp (BP), the dried residue from sugar beets is a bulky and highly palatable feed for dairy cows that may be fed in various ways BP is often used to reduce the content of NFC in the diets of dairy cattle. Much of the NFC in BP is pectin, which has a propensity for production of acetate rather than propionate in the rumen. The NDF in BP is highly fermentable in the rumen, and it can be used to supply fermentable fiber in the diet. BP has some effective fiber.

The objective of this study was to compare three physically different types of BP for physical parameters bulk density (BD), particle size, kinetics of hydration, FSG, WHC, and intrinsic osmotic pressure, all measured *in vitro*. This study forms a part of a larger study that evaluated effects of the three types including fine dried BP (FBP); normal dried BP (NBP) and pelleted BP (PBP) on effectiveness of BP. This paper discusses the effects on BD, kinetics of hydration, FSG, WHC, soluble DM, and intrinsic osmotic pressure (IOP).

MATERIALS AND METHODS

Sample preparation and composition

Two types including NBP and PBP were used in this experiment were prepared from feed manufacture of Khorasan province, Iran.

The FBP was prepared by milling NBP, using 2 mm screen pore size of miller. Feeding dried BP chips into the pelleting machine produced pellets. Pellets were obtained from dried BP 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 DM, OM, Kjeldahl N, ether extract, Ca, P (AOAC, 2002), NDF, ADF (Van Soest *et al*. 1991) and ash at 605 ˚C at 3 h. NFC was calculated by 100 - (% CP+% NDF+% Ash+% EE) Table 1; (NRC, 2001).

Physical measurements

Bulk density

Bulk density was determined by a modification of the method of Montgomery and Baumgardt (1965), as was described by Giger-Reverdin (2000).

Particle size measurements

Particle size of all types of BP was determined by dry sieving. The ASAE (2002) and original (Lammers *et al*. 1996) and new (Kononoff, 2002) Penn State Particle Separator (PSPS) sieves were used for measuring particle size distribution (Table 2). The geometric mean (GM) and the standard deviation of GM were calculated according to ASAE (2002); (Table 2). The NDF content of all materials retained on PSPS sieves was measured (Van Soest *et al*. 1991).

Using 3 systems, the pef of all types of BP were determined. According to Mertens (1997), the pef was determined based on proportion of DM retained on the 1.18-mm sieve (pef_m). Using the PSPS, the pef values were determined as the proportion of DM retained on 19 and 8 mm sieves (pef>8); (Lammers *et al*. 1996) and on 19, 8 and 1.18 mm sieves (pef>1.18); (Kononoff, 2002), respectively. By multiplying NDF content of the all types of BP by peNDFm, peNDF > 8 and peNDF > 1.18 was calculated (Table 2).

Kinetic of hydration and functional specific gravity

The kinetic of hydration, FSG and changes of specific gravity of all types of BP measured with 100 ml pycnometer (Wattiaux, 1990). The data obtained during hydration were used to determine the rate of hydration and water uptake using NLIN procedures of (SAS 1988; 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 IDM).

A and B: represent pool sizes of hydration.
k_a and k_b: represent respective fractional rates of hydration (minutes^{-1}).

Total WHC (gram/gram of insoluble DM (IDM) 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×ka) + (B×kb)] / (A+B) (Bhatti and Firkins, 1995).

Table 1 Chemical components of three types of beet pulp

Chemicals composition (%)	Three types of beet pulp			SEM
	Fine	Normal	Pelleted	
DM	94.36	94.35	94.62	2.25
OM	92.69	92.55	91.66	2.14
CP	9.61	9.69	9.58	0.41
NDF	39.67	40.12	39.68	0.54
ADF	23.88	23.91	24.21	0.31
ADL	1.66	1.69	1.71	0.18
EE	0.78	0.82	0.83	0.04
ASH	7.31	7.45	8.44	0.4
NFC	42.63	44.92	41.47	0.28
Ca	1.15	1.24	1.31	0.09
P	0.1	0.12	0.12	0.01
NDIP	50.3	49.5	50.3	0.04
ADIN	0.73^b	0.75^b	0.82^a	0.03

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
DM: dry matter; OM: organic matter; CP: crud protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; EE: ether extract; NFC: non-fiber carbohydrate; Ca: calcium; P: phosphorus; ADIN: acid detergent insoluble protein and ADIP: acid detergent insoluble protein.
SEM: standard error of the means.

Data were analyzed as a complete randomized design by ANOVA using proc GLM of SAS (1998). Means were separated using Duncan's multiple range test with an alpha level of 0.05.

Water holding capacity

WHC of all types of BP was measured using an adaptation of one of the methods proposed by Robertson and Eastwood (1981).

Feed solubilization

The filtrate sample collected after passage through the filter was oven-dried for 72 h at 105 ˚C, weighed and subsequently ashed at 605 ˚C for 3 h and weighed. Dry matter and ash solubilized were expressed as g^{-1} or as percentage of initial weight of the component considered.

Intrinsic osmotic pressure

2.5 g of sample was soaked in 50 mL of water for 24 h. Filtration was performed according to the WHC method already described, but without the addition of water. OIP was measured on the filtrate using the freezing point depression technique with a Mark 3 osmometer, manufactured by Fiske (USA) (Giger-Reverdin, 2000).

Statistical analysis

The data of BD, particle size measurements, kinetic of hydration parameters, initial FSG (FSG at 0.1 h were considered as initial FSG for all of samples), WHC, soluble DM, soluble ash and IOP were analyzed by a complete randomize designs as three types of BP were considered as treatment. Data were analyzed by using the GLM procedure of SAS (1998).

Table 2 Particle size measurements of feed ingredients were used in the experiment

Screen size	Beet pulp	
	Fine	Normal
19 mm	0.0	0.0
8 mm	3	26
Pan	97	74
GM	0.90^b	1.67^a
Standard deviation of GM	1.58	3.27
Pef > 8	0.03^b	0.26^a
19 mm	0.0	0.0
8 mm	0.0	10
1.18 mm	26	74
Pan	74	16
GM	1.22^b	3.26^a
Standard deviation of GM	1.91	2.01
Pef > 1.18	0.26^b	0.88^a
19 mm	0.0	0.0
12.7 mm	0.0	2.3
7.63 mm	0.0	10.7
3.96 mm	8	35.8
1.18 mm	32	35.9
Pan	71	15.3
GM	1.16	2.91^h
Standard deviation of GM	1.73	2.80
Pef_m	0.40	84.7^{ef}

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
GM: geometric mean of particle size.
pef_8, pef > 1.18 and pefm were physically effective factors that determined as a percentage of DM remaining on 19 and 8; 19, 8, and 1.18; and 1.18 mm screen using a dry sieving.

Correlation analyses of the physical and chemical properties of feed were done with CORR procedure of SAS (1998). In addition, regression analyses of the physical and chemical properties of feed were done with REG procedure of SAS (1998). The analysis of regression was done to getting the best predictor model including chemical components and physical properties of feeds. Therefore, the models were chosen with highest R^2 when P-value of all independents variable in the models was statistically significant (P<0.05). All determinations have been performed in three replicate, when calculated coefficient of variation was higher than 5, the measurements were repeated.

RESULTS AND DISCUSSION

Chemical composition

Chemical composition of three types of BP had not signifycant differences, except on acid detergent insoluble nitrogen (Table 1). Grinding of BP had not significant effect on acid detergent insoluble nitrogen, but pelleting, regardless of CP, significantly increased acid detergent insoluble nitrogen content of PBP (Table 1).

Bulk density

Bulk density varied greatly between feedstuffs (Table 3). There was a very high correlation (r=0.99) between BD50 and BD100). Therefore, it seems that both of variables may be used for outlining of the relationships between feeds BD and other chemical and physical properties. The variation coefficients were 1.91 and 2.11%, for BD50 and BD100, respectively. Therefore, the BD50 appears more precise than BD100. In contrast, Giger-Reverdin (2000), found that the BD100 was a more precise method than BD50. PBP had the highest density (0.967 g/mL) and NBP had the lowest (0.623 g/mL).

However, all types had BD50 and BD100 higher than the 0.5 g/mL. Grinding and pelleting significantly increased BD that is due to decreasing particle size and removing space between particles. The benefits of grinding and pelleting feed stuff include enhanced handling, improved animal performance, increased BD and flow ability, digestibility, decreased ingredient segregation, better palatability, decreases spillage and wind loss and a reduction of energy for prehension. Bulk density was negatively correlated with the NDF, CP, NFC, hydration rate and WHC, but was positively correlated with the DM, EE, FSG, soluble DM and ash and IOP (Table 4).

The following equation had maximum R^2 when all of chemical components (P<0.05) of all feeds were used *vs.* BD50 in analysis of regression:

Bulk density (g/mL)= 14.544 - 0.340 CP - 0.279 NDF + 0.079 Ash (R^2=0.999; P<0.0001; n=9; equation 1).

In current experiment, the best relationship between BD and NDF and CP were described with following model:

Bulk density (g/mL)= 17.532 - 0.421NDF (R^2= 0.818; P=0.0008; n=9; equation 2).

Bulk density (g/mL)= 19.702 - 1.968CP (R^2=0.920; P<0.0001; n=9; equation 3).

Particle size measurements

Grinding significantly decreased the proportion of retained particles on 19 and 8 mm screens, but increased the proportion of retained particles on a 1.18 mm screen and a pan (Table2). In addition, the GM of BP particles was decreased (Table2).

Regardless the type of BP, the lowest GM and the highest standard deviation of GM, were for the measurements of size with the 19 and 8 mm sieves. GM and standard deviation of GM obtained using 19, 8 and 1.18 mm sieves and ASAE were similar.

Water holding capacity, hydration kinetic and functional specific gravity

The WHC was measured by both of filtration and exponential curve fitting methods. Measured WHC that obtained via filtration, varied greatly between different types of BP (Table 3). NBP has the highest WHC and FBP had the lowest WHC. Grinding and pelleting significantly decreased WHC of BP.

However, calculated WHC that obtained via exponential curve fitting methods had not significantly differences (Table 3). Therefore, in regression analysis we used WHC that was resulting from filtration method. WHC had positive correlation with DM, NDF, NFC, CP, and EE, but had a negative correlation with BD, FSG, soluble DM, soluble ash and IOP (Table 4). Regardless the methods, NBP had the high WHC and hydration rate. Initial FSG of FBP was higher than NBP and PBP (Table 3). Changes of FSG over the incubation time (h) in pycnometers are shown in Figure 1.

Initial FSG (0.1 h) and final FSG increased when particle size decreased. FBP had an initial FSG more than NBP and PBP. However, the final FSG of all types were similar. FSG was high negatively correlated with DM, NDF, CP, NFC, EE, hydration rate and WHC and had positive correlation with BD, soluble DM, soluble ash, and IOP (Table4). Hydration rate was high negatively correlated with NDF, CP, NFC, EE and WHC, but had high positive correlation with DM, BD, FSG, soluble DM, soluble ash, and IOP (Table 4). The following equations had maximum R^2 when all of chemical components (P<0.05) of all types of BP used *vs.* WHC, FSG and hydration rate in analysis of regression:

WHC (g/g insoluble DM)= -82.359 + 2.547 CP + 1.466 NDF + 0.551 Ash
(R^2=0.997; P<0.0001; n=9; equation 4)

Hydration rate (g/g insoluble DM/h)= -1.097 + 0.027 NDF + 0.011 Ash
(R^2=0.953; P=0.0001; n=9; equation 5)

FSG= 5.252 – 0.092 NDF – 0.027 Ash (R^2=0.973; P<0.0001; n=9; equation 6)

In addition, the relationships between WHC, Hydration rate, and FSG with chemical composition were illustrated by following regression models:

WHC (g/g insoluble DM)= -54.729 + 1.495 NDF
(R^2=0.661; P=0.0078; n=9; equation 7)

WHC (g/g insoluble DM)= -4.899 + 0.223 NFC
(R^2=0.519; P=0.0286; n=9; equation 8)

Hydration rate (g/g insoluble DM/h)= -0.092 + 0.190 EE
(R^2=0.667; P=0.0071; n=9; equation 9

FSG= 4.071 – 0.067 NDF
(R^2=0.532; P=0.0256; n=9; equation 10)

FSG= 3.344 – 0.0203 CP
(R^2=0.250; P=0.1710; n=9; equation 11)

FSG= 1.866 – 0.011 NFC
(R^2=0.500; P=0.034; n=9; equation 12)

Soluble dry matter and ash

The FBP had the highest soluble DM (28.61 *vs*. 17.98 and 23.66% of initial DM in NBP and PBP, respectively. In addition, FBP had the highest soluble ash (45.18 *vs*. 37.79 and 39.36% of initial ash in NBP and PBP, respectively. There was no significant difference between soluble ash content of NBP and PBP (Table 3).

The correlation between the soluble DM and ash content with DM, NDF, CP, NFC, EE, hydration rate, WHC were negative, but with BD, FSG and IOP were positive (Table 4). The correlation between the soluble DM and ash was positive (Table 4). The following equations had maximum R^2 when all of chemical components (P<0.05) of all feeds used *vs*. soluble DM and ash in analysis of regression:

Soluble DM (% of DM)= 472.126 – 21.887 NDF + 4.582 OM
(R^2=0.974; P<0.0001; n=9; equation 13)

Soluble ash (% of ash)= 720.677 – 21.258 CP –10.846 NDF – 5.605 Ash
(R^2=0.995; P<0.0001; n=9; equation 14)

Intrinsic osmotic pressure

The FBP had the highest IOP and there are not significant differences between NBP and PBP (Table 3). IOP had positive correlation with BD, FSG, soluble DM and ash, but had negative correlation with DM, NDF, NFC, EE, hydration rate and WHC (Table 4).

The following equation had maximum R^2 when all of chemical components (P<0.05) of all feeds were used *vs*. IOP in analysis of regression:

IOP (mOsm/kg H2O) = 258.880 – 4.940NDF – 2.057Ash(R^2 = 0.815; P = 0.0002; n = 9; equation 15)

Relationships between physical parameters

The results of the current experiments show that BD had positive correlation with FSG, soluble DM and ash and IOP, but had negative correlation between BD with hydration rate and WHC. FSG of feeds was negatively correlated with hydration rate, WHC, but there were positive correlation between FSG with soluble DM and ash and IOP. Hydration rate has negative correlation with BD, FSG, soluble DM and ash and IOP, but there was positive correlation between Hydration rate and WHC. The amount of soluble DM and ash were positively correlated with BD, FSG and IOP, but were negatively correlated with hydration rate and WHC. Also, there was positive high correlation between soluble DM and ash (R=0.932; Table 4). The IOP had positive correlation with BD, FSG, soluble DM and ash, but had negative correlation with hydration rate and WHC.

Various types of BP have been analyzed by several physical methods: BD, hydration rate, FSG, particle size, WHC, soluble DM, soluble ash and IOP. Some of these methods already exist and have been adapted and others have been developed by Giger-Reverdin (2000). All of the physical characteristics measurement methods are quite easy to perform and the results are very repeatable. The data obtained by the physical and chemical methods have been correlated. All results were very similar to Giger-Reverdin (2000). According to Giger-Reverdin (2000), the physical methods gave new information about the nutritive value of feedstuffs for ruminant and they can be used to differentiate between feedstuffs and taken into account in feed formulation. They might explain part of the role played by rumen or on feedstuffs, which is not taken into account by the chemical approach.

Grinding and pelleting hay alters the physical characteristics of the BP and consequently, may affect the time that cows spend chewing. Chewing during eating and ruminating plays a key role in digestion and passage of feed through the gastrointestinal tract of the dairy cow. Chewing activity is associated with saliva secretion, solubilization of feed DM and physical breakdown of feed particles, which facilitates the ruminal fermentation process and passage of digesta. Changes in chewing activity could affect ruminal function, voluntary intake, and fat content of the milk yielded by cows (Teimouri Yansari *et al*. 2004; Mertens, 1997). Today's, dairy producers attempt to minimize the inclusion of forage in the diet; thus, emphasis is on the efficacy of the fiber source in maintaining fat content of milk and preventing disorders associated with high grain diets.

Table 3 Effects of feed source on physical properties of feed ingredients were used in the experiment

Physical properties	Three types of beet pulp			SEM	P-value
	Fine	Normal	Pelleted		
Bulk density 50^2 (g/mL)	0.767^b	0.625^c	0.864^a	0.0011	< 0.0001
Bulk density 100 (g/mL)	0.770^b	0.630^c	0.872^a	0.0007	< 0.0001
Initial FSG	1.416^a	1.371^c	1.384^b	0.0026	< 0.0001
WHC measured (g/DM)	4.318^c	5.261^a	4.881^b	0.0024	< 0.0001
WHC calculated (g/DM)	4.952	5.109	5.021	0.5200	0.5085
Hydration rate (g/DM/Min)	0.0527^b	0.0663^a	0.0657^a	0.0071	0.0002
Soluble dry matter (%)	28.61^a	17.98^c	23.66^b	0.1761	< 0.0001
Soluble ash (%)	45.18^a	37.79^b	39.36^b	0.5241	< 0.0001
Osmotic pressure (mOsm/kg H_2O)	47.87^a	45.36^b	45.49^b	0.2271	0.0068

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
FSG: functional specific gravity and WHC: water holding capacity.
SEM: standard error of the means.

Table 4 Correlation coefficient between physical and chemical components of cereals[1]

Item	1	2	3	4	5	6	7	8	9	10	11	12
1-DM	-	-0.055	0.094	-0.261	-0.312	0.079	-0.192	-0.012	0.079	-0.089	-0.083	-0.053
2-NDF	NS	-	0.910	0.705	0.263	-0.904	-0.730	0.544	0.813	-0.880	-0.674	-0.507
3-CP	NS	**	-	0.586	-0.025	-0.951	-0.499	0.246	0.604	-0.713	-0.434	-0.226
4-NFC	NS	*	NS	-	0.376	-0.540	-0.703	0.577	0.720	-0.735	-0.666	-0.560
5-EE	NS	NS	NS	NS	-	0.073	-0.572	0.817	0.633	-0.569	-0.718	-0.731
6-Bulk density	NS	**	***	NS	NS	-	0.388	-0.144	-0.497	0.618	0.306	0.143
7-FSG	NS	*	NS	*	NS	NS	-	-0.894	-0.971	0.942	0.968	0.874
8-Hydration rate	NS	NS	NS	NS	*	NS	**	-	0.904	-0.823	-0.951	-0.833
9-WHC	NS	**	NS	*	*	NS	***	***	-	-0.984	-0.977	-0.839
10-SDM	NS	**	*	*	NS	NS	***	**	***	-	0.932	0.805
11-SAsh	NS	*	NS	*	*	NS	***	***	***	**	-	0.895
12-OP	NS	NS	NS	NS	*	NS	*	*	**	**	**	-

[1] Correlation coefficient, above diagonal; P-values, below diagonal; n= 9.
DM: dry matter; NDF: neutral detergent fiber; CP: crud protein; NFC: non-fiber carbohydrate; EE: ether extract; FSG: functional specific gravity and WHC: water holding capacity.
NS: non significant.
* (P≤0.05); ** (P≤0.01) and *** (P≤0.001).

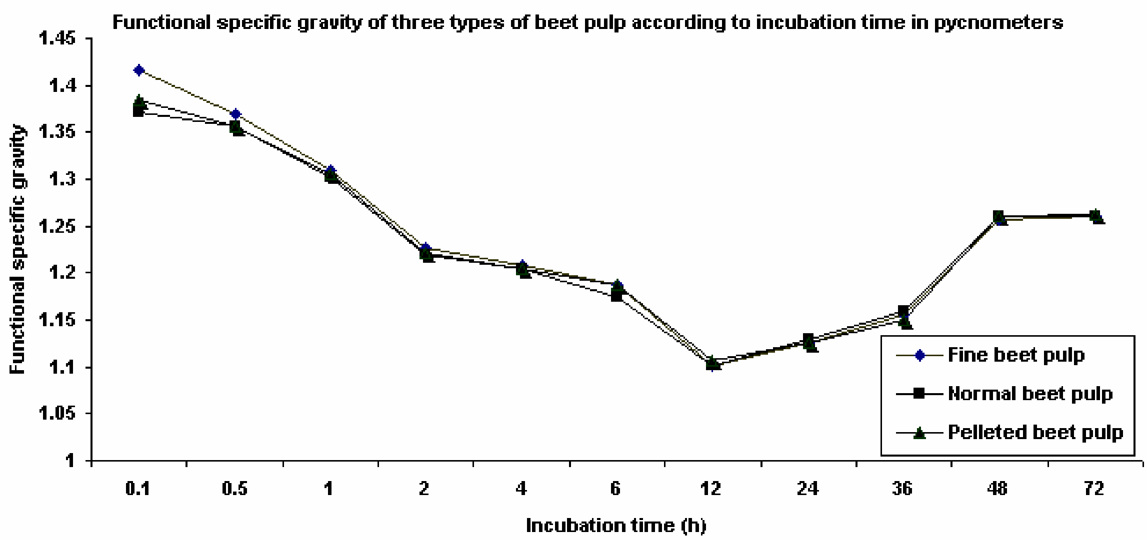

Figure 1 Functional specific gravity (FSG) of fine (♦), normal (■) and pelleted (▲) beet pulp according to incubation time (h) in pycnometers. Initial FSG (0.1 h) and final FSG increased when particle size decreased. Fine beet pulp had an initial FSG more than normal and pelleted beet pulp. However, the final FSG of all types were similar

Bulk density

Bulk density or packing density is the ratio of the mass of a collection of discrete pieces of solid material to sum of the volume of the solid in each piece, the voids within the pieces, and the voids among the pieces of the particular collection (ASTM, D3766, D32, 2000). The adapted method that used for BD measurements was very easy to perform and the precision of the method was quite good.

The results were close to the Giger-Reverdin (2000). There were differences between BD of different types (Table 3).

According to equation 1 to 3, the chemical component of feed including CP, NDF and ash can be used to accounting 99.9% of variation of BD of BP. The NDF and CP content of different types of BP accounted 81.8 and 92.0% of variation in BDs, respectively (equation 1 and 2). However, Giger-Reverdin (2000) found that had negatively correlated with cell wall content and NDF expressed 64.4% of variation of BD in different animal feeds (BD (g/mL)= 0.743 - 0.589 NDF (Kg/Kg DM) (R^2=0.644; equation 4)).

There was a negative correlation between NDF and BD (Table 4). Singh and Narang (1991) and Giger-Reverdin (2000) reported that feedstuffs with high NDF had low BD, might have more effect on rumen fill than feedstuffs with high BD. Hence, forages that occupy larger volumes per unit of DM weight should be have a greater effect on fill than another feeds (Wattiaux, 1990). Wattiaux (1990) and Van Soest (1994) reported that BD influences DMI, passage rate and ruminal mean retention time. Teimouri *et al.* (2004) found that chopping alfalfa significantly increased BD and DMI but decreased chewing activity, ruminal pH, and milk fat content. It seems reduced BD by grinding and pelleting may affect on DMI, retention time, and chewing activity.

Particle size measurements

Regardless the method, NBP had higher frequency of particles on top sieves than the FBP (Table 2). In all systems, the amount of feeds that retained on arranged sieves were significantly different. The values of peNDF were differences between the feeds. Regardless the method, NBP had higher peNDF than the FBP. The value of peNDF > 8 were lower than the peNDF > 1.18 and peNDFm. The value of peNDF > 8 was lower than others. Therefore, with the construction of an additional screen (1.18 mm); (Kononoff, 2002), the PSPS is capable to making peNDF measurements proposed by Mertens (1997) and Kononoff (2002). Additionally the third screen may be useful in measuring the particle size of grounded feeds and non-forage fiber sources as well as processed grains.

The concept of effective fiber was created to unite the chemical and physical nature of the forage and to quantify its value to rumen function. Chewing and rumination are known accurate measurements of the roughage characteristics for ruminant diets. The peNDF is defined as that dietary fiber source which effectively stimulates rumination and salivation (Mertens, 1997). Particles that were retained on a sieve measuring 1.18 mm pass out of the rumen slower than those, which are not retained. Therefore, particle size measurement in feeds and accounting, as an important factor in ration formulation is very helpful in ruminant nutrition. Inclusion of BP in early lactation diets allows the formulation of high NDF, moderate NFC diets of high energy density. However, it has limited forage replacement value (Armentano and Clark, 1997) and effectiveness factor of 0.40 (fraction of NDF) versus 1.0 for forages (Mertens, 1997). In addition, Mertens (1997) suggested that the pef of ground and pellet were 0.40 and 0.30, respectively. Although the cubing and pelleting process reduces forage particle size, reduces the chewing time, increases ruminal acidity, which is associated with cows going off feed, depresses fiber digestion, increases rate of particulate passage from the reticulorumen and may result in milk fat depression (Teimouri Yansari *et al.* 2004). However, the effects of particle size of by products in relation to their roles in the reticulorumen have rarely investigated. It seems that another physical characteristic, which have studied in this experiment, are more important on effectiveness of BP fiber.

Hydration rate, water holding capacity and functional specific gravity

Both filtration (Giger-Reverdin, 2000) and biexponential curve fitting methods (Wattiaux, 1990; Teimouri Yansari *et al.* 2004) were used to measure the WHC of BP samples. The values those estimated by biexponential curve fitting method for FBP and PBP were lower than the values obtained with filtration (Table 3). The results of filtration method were very close to Giger-Reverdin (2000) but the values of curve fitting method were different with previous studies. Bhatti and Firkins (1995) and Wattiaux (1990) found that exponential curve fitting method had lower estimation of WHC than filtration method. The previous studies (Bhatti and Firkins, 1995; Giger-Reverdin, 2000; Wattiaux, 1990) confirm the results of filtration method are more realistic. Therefore, we used the data of WHC these obtained with filtration method in regression analysis.

The high correlation of WHC with NDF (r=0.813) is in agreement with previous studies (Singh and Narang, 1991), as is the effect of pectin on WHC.

In ruminant, WHC may affect ruminal liquid pool size and the rate and extent of ruminal digestion (Allen and Mertens, 1988). Digesta WHC may influence the extent to which salivary secretions are retained intraruminally, influence the relationship between salivary production and ruminal liquid outflow (Froetschel and Amos, 1991). The effect of WHC on gut function is related to the susceptibility of fiber to fermentation. Wattiaux (1990) found that fermentation reduces the WHC of fiber. Froetschel and Amos (1991) reported an inverse relationship between WHC of ruminal digesta and passage rate and a positive correlation between WHC and ruminal liquid volume. Feedstuffs with a high WHC have generally low BD values. This could be because feedstuffs that have low BD could have numerous gas pockets within their cell wall matrix and these pockets might retain water when it is in excess, such as in the rumen, therefore they have a high fill effect and have a low transit rate. Giger-Reverdin (2000) reported that BP had highest WHC between 24 animal feeds that he used in his study. It seems that BP, which has high pectin content, had a higher WHC than feedstuffs with low pectin levels.

SG is the ratio of the mass (density) of a sample material to the mass (density) of an equal volume of water at the same specified temperature (ASTM, D1616, D19, 2000). SG is unit less because masses cancel out (Bhatti and Firkins, 1995). FSG is of interest to ruminant nutritionists because it is related to rate of hydration, digestion lag time and rate of passage from the rumen (Hooper and Welch, 1985). FSG accounts for the void spaces in a sample (from air or gas) can be determined for actual feed samples with pycnometers and FSG of feed particles is altered by exposure to ruminal conditions (Wattiaux, 1990). The FSG of all types BP significantly ranged from 1.371 in NBP to 1.416 in FBP. Siciliano-Jones and Murphy (1991) reported that SG affected by feeds and particle size and ranged from 1.3 to 1.5 (approximately 1.4 for by products).

There were high negative correlation between the FSG and feed compositions (Table 4). Those results agreed to Wattiaux (1990) and Hooper and Welch (1985). Particles with a density range of 1.2 to 1.5 seem to have the highest rate of passage in cattle (Murphy *et al.* 1989) and sheep (Katoh *et al.* 1988; Kaske and Engelhardt, 1990). Particles with an SG lower than 1.2 are likely to float above, and those higher than 1.5 are likely to sink below. Manipulating the diet to alter the FSG of particles in the rumen may help to obtain the desired effects on digestion in and passage from the rumen (Siciliano-Jones and Murphy, 1991).

Hydration rate was significantly different between the feeds (Table 3). The results were similar to Bhatti and Firkins (1995). Bhatti and Firkins found that hydration ground BP was 0.252. These values were higher than the hydration rate of ground beet in the current study, which may be due to difference in hydration solution in their study from that in ours.

However, Bhatti and Firkins (1995) found that hydration rate did not show any clear patterns in the feeds tested. Hydration of feeds is required before bacteria can infiltrate feed particles; therefore, hydration rate was expected to relate to the lag time of fiber digestion. However, Bhatti and Firkins (1995) reported that hydration of feed was not a major factor limiting fractional digestion rate of DM. FSG and changes of FSG over only in early incubation time were different. After 4 h incubation, all types had similar trend in changes of FSG. However, FSG, which accounts for the void spaces in a sample (from air or gas), can be determined for actual feed samples with pycnometer (Wattiaux, 1990). Particle density influences their rate of passage from the rumen (Ehle, 1984; Martz and Belyea, 1986) and thus ruminal turnover rate of feeds and possibly their level of intake (Singh and Narang, 1991). Particles with a density range of 1.2 to 1.5 seem to have the highest rate of passage in cattle (Murphy *et al.* 1989) and sheep (Katoh *et al.* 1988; Kaske and Engelhardt, 1990). Particles with an SG < 1.2 are likely to float above, and those > 1.5 are likely to sink with inert plastic particles (Murphy *et al.* 1989; Kaske and Engelhardt, 1990; Welch, 1986). FSG of forage particles is profoundly altered by exposure to ruminal conditions (Wattiaux, 1990) and this change is result of up taking ruminal liquor. WHC has an impact on microbial colonization and osmotic pressure is a factor that should be considered in the overall ecology of the rumen. Therefore, rate and extant of these changes is very important on ruminal mean retention time and digestion on rumen condition.

Feed solubilization

There was not high correlation between the SDM and chemical components of feeds but SDM was correlated with soluble ash (r=0.65). Therefore, the most portion of SDM was result of soluble ash. In roughages, SDM had high negative correlation to NDF, ADF, EE, WHC and peNDF > 1.18 and high positive correlation to lignin, NFC, osmotic pressure. In by products, there were high negative correlation between the SDM and cell wall components and negative correlation to HR and osmotic pressure.

Solubility might be an estimation of nutrient availability. However, some soluble substances (Millard products, soluble tannins and other phenolics) are not digestible (Van Soest, 1994). Giger–Reverdin (2000) noted that the quantities of SAsh and OM were not very well correlated and quantity of OM solubilized was not explained by chemical composition because they have not the same potential of solubility in feedstuffs. It was not significantly correlated with ash content. This result was the same of Giger-Reverdin (2000).

Intrinsic osmotic pressure

Osmotic pressure is a measurement of the potential energy difference between solutions on either side of a semi permeable membrane. A factor is designing the operating pressure of reverse osmosis equipment. The applied pressure must first overcome the osmotic pressure inherent in the chemical solution in order to produce any flux (ASTM, D6161, D19, 2000). The IOP of fees ranged from 39.20 (barely) to 112.57 (cotton seed; Table 3). The cereals had the lowest IOP. These results were very close (a little higher) to Giger-Reverdin (2000) that reported the IOP of barely, corn, wheat bran, soy bean meal, sugar BP, corn silage and alfalfa 36, 20, 73.5, 63, 40, 85 and 102.5, respectively. According to Giger-Reverdin (2000), IOP of a 2.5 g soaked samples in 50 mL of water were measured. These values were correspond with a 5 kg sample in 100 L. Comparing these values with data that obtained in dairy cows by *in vivo*, multiplying by four to give the theoretical intrinsic values for 20 kg of feed samples in a rumen of 100 L. Therefore, the value of IOP in BP was 176.8 $mOsml^{-1}$.

Giger-Reverdin (2000) found that some feeds have an IOP higher than 300 $mOsml^{-1}$ (wheat bran, corn gluten feed, lupine, citrus pulp, corn silage and alfalfa hay had a IOP 300, 330, 300, 320, 340 and 400 $mOsml^{-1}$, respectively).

The normal value for ruminal osmolality might be assumed to be around 300 $mOsml^{-1}$ (260-340 $mOsml^{-1}$) and might increase up to 400 $mOsml^{-1}$ after a meal (Bergen, 1972), this means that the feedstuffs alone mentioned above could induce IOP close to those observed *in vivo* after a meal (Giger-Reverdin, 2000).

CONCLUSION

The nutritive value of feedstuffs is based on chemical analysis that on its own is unable to explain some facts observed *in vivo*, such as acidosis or loss of appetite. As the chemical parameters and the physical ones described in this paper gave different information about feeds, the proposed methods might allow a new approach for feeding and help to reduce these problems. They are quite easy to perform and to standardize. Data obtained in different runs did not differ for a given feedstuff. The main drawback of these methods concerns the need to grind the samples, which is necessary to obtain repeatable data. Therefore, the feedstuffs are not analyzed as fed. These methods need to be tested more extensively *in vitro* and *in vivo* in order to test their usefulness. For example, BD, intrinsic IOP and WHC needed to be more extensively related to voluntary intake, particle size to risk of digestive disorders, solubility to nutrient availability. Some of the data issued from these methods could then be integrated into systems to predict the nutritive value of feeds, when the information given is not redundant compared to that of chemical analysis.

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