Effect of Replacing Corn and Wheat Bran With Soyhulls in Lactation Cow Diets on *In Situ* Digestion Characteristics of Dietary Dry Matter and Fiber and Lactation Performance

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ABSTRACT : An *in situ* digestion trial (Experiment 1) and a lactation trial (Experiment 2) were conducted to determine the effects of replacing corn and wheat bran with soyhulls (SH) in lactating dairy cow diets on the extent and kinetics of digestion of DM and NDF, and lactation performance. In experiment 1, five mixed feeds consisting of mixed concentrate and roughages (50:50 on a DM basis) were formulated on isonitrogenous and isoenergetic bases to produce five levels (0, 25, 50, 75 and 100%) of SH replacement for corn and wheat bran. SH had high *in situ* digestion (92 and 89% for potentially digestible DM and NDF) and fairly fast digestion rate (7.2 and 6.3 %/h for DM and NDF). Increasing level of SH replacement resulted in increased NDF digestibility (linear, p=0.001-0.04) and similar DM digestibility (beyond 12 h incubation, p=0.10-0.41). As level of SH replacement increased, percentage of slowly digestible fraction (b) of DM increased (linear, p=0.03), percentage of rapidly digestible fraction (a) of DM tended to decrease (linear, p=0.14), and DM digestion lag time tended to be longer (linear, p=0.13). Percentage of potentially digestible fraction (a+b) and digestion rate (c) of slowly digestible fraction of dietary DM remained unaltered (p=0.36-0.90) with increasing SH in the diet. Increasing level of SH for replacing corn and wheat bran in the diet resulted in increases in percentages of b (quadratic, p<0.001), a (linear, p=0.08), a+b (quadratic, p=0.001) and a tendency to increase in c for NDF (linear, p<0.19). It was also observed that there was a satisfactory fit of a non-linear regression model to NDF digestion data (R^2=0.986-0.998), but a relatively poor fit of the model to DM digestion data (R^2=0.915-0.968). In experiment 2, 42 lactating Holstein cows were used in a randomized complete block design. SH replaced corn and wheat bran in mixed concentrates at 0, 25, and 50%, respectively. These mixed concentrates were mixed with roughages and fed *ad libitum* as complete diets. Replacing corn and wheat bran with SH at 0, 25 and 50% levels did not influence (p=0.56-0.95) DM intakes (18.4, 18.6, and 18.5 kg/d), milk yields (27.7, 28.4 and 27.6 kg/d), 4% fat-corrected-milk (FCM) yields (26.2, 27.6, and 27.3 kg/d) and percentages of milk protein (3.12, 3.17 and 3.18%), milk lactose (4.69, 4.76 and 4.68%) and SNF (8.50, 8.64, and 8.54%). On the other hand, milk fat percentges linearly increased (3.63, 3.85 and 3.90% for SH replacement rates of 0, 25 and 50% in the diet, p=0.08), while feed costs per kg FCM production were reduced. ***(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 12 : 1691-1698)***

Key Words : Soyhulls, Lactation Performance, *In Situ* Digestion, Lactating Cows

INTRODUCTION

Soyhulls (SH) are byproducts from the dehulling operation in soybean crushing plants. Although high in fiber (67% for NDF and 50% for ADF; NRC, 1989), SH can be easily digested in the rumen and provide a fairly large amount of energy for ruminant animals because of its low lignin content (2%, NRC, 1989). Hsu et al. (1987) reported that the *in situ* DM digestibility of SH was 90.6% at 27 hour and a complete digestion was achieved at 36 hours incubation. Similarly, Klopfenstein and Owen (1987) reported that digestibility of NDF in SH was 95%. When SH are fed with hay, the TDN value was as high as for citrus pulp or oats (Wagner et al., 1965). Therefore, SH are generally considered as "bulky concentrates" rather than roughage (Hintz et al., 1964).

SH have a great potential for use in lactating dairy cow diets in China. Because of poor quality of roughages, high levels of cereal grain-based concentrates have to be used to meet the nutrient requirements for high producing dairy cows. This often results in a decreased milk fat percentage, lowered rumen pH, decreased fiber digestion, and increased incidence of metabolic disorders, such as acidosis and abomasal displacement. To minimize the negative effects associated with feeding large quantities of grains, addition of highly digestible fiber, such as SH, to dairy cow diets to replace cereal concentrate ingredients should be a useful practice. Corn and wheat bran are the two major cereal concentrate ingredients for dairy cows in China. Compared with corn and wheat bran, SH is usually economically priced (600-800 versus 1,100 *yuan* of Chinese currency per metric ton). Partial replacement of corn and wheat bran with SH in dairy cow diets, therefore, would be both nutritionally and economically beneficial to dairy production in China.

Previous research (MacGregor et al., 1976; Bernard and McNeill, 1991; Nakamura and Owen, 1989; Coomer et al., 1993; Wagner et al., 1965) indicated that SH could be successfully fed as a replacement for

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high starch concentrate in dairy cow diets. Replacement of a portion of corn (MacGregor et al., 1976; Bernard and McNeill, 1991; Nakamura and Owen, 1989), citrus or oats (Wagner et al., 1965), or corn and wheat (Coomer et al., 1993) with SH maintained DM intake, 3.5% FCM yield and feed efficiency similar to the diet with no SH. When SH replaced a portion of the concentrates, cows usually produced milk with higher milk fat percentage, compared with cows fed the control diet (Nakamura and Owen, 1989; Coomer et al., 1993; Weiss, 1995). Based on the review paper of Kung and Lin (1997), the maximum rate of SH inclusion in lactating cow diets is about 20 to 25% of total ration dry matter. Until now, no information is available on dairy cow lactation performance when SH is fed as a replacement for both corn and wheat bran in concentrate diets.

The objectives of the present study were to determine the effects of replacing corn and wheat bran in dairy cow diets with SH on (1) *in situ* digestion characteristics of dietary DM and NDF; (2) lactation performance; and (3) economic feasibility under the current situation of milk production and feed price systems in China.

MATERIALS AND METHODS

Experiment 1. *In situ* digestion trial

Experimental diets: Five mixed feeds with 5 levels of SH replacement were prepared as complete feeds and balanced to meet NRC (1989) requirements for 25-30 kg milk production per day. SH replaced a portion of corn and wheat bran contained in the control feed to provide 0, 25, 50, 75 or 100% of SH replacement. Feed formulations and chemical compositions of the experimental feeds are listed in table 1. All of the five feeds were ground through a 1 mm screen in a Wiley mill (Huanghua, China) for *in situ* study. SH, containing 12.2% CP, 65.3% NDF and 48.1% ADF on DM basis was shipped from Zhangjiagang F. T. Z. Donghai Oil and Grains Industries Co., Ltd, Jiangsu Province. Other ingredients were obtained from local sources.

In situ digestion procedure: Two ruminally fistulated crossbred steers (average body weight, 510 kg) were used to determine *in situ* DM and NDF digestibilities of the five diets and SH. Steers were housed individually in stalls and fed mixed concentrate (3 kg daily), Chinese wildrye grass hay (2.5 kg daily) and dry corn stover cubes (freely available). The mixed concentrate consisted of 69.6% ground corn, 24% soybean meal, 2.2% bone meal, 1.8% limestone, 1.2% salt, and 1.2% vitamin-trace mineral premix (DM basis).

Nylon bags were made of dacron cloth (8×12 cm) with an approximate pore size of 50 μm and with heat-sealed edges. Approximately 5 g of soyhulls or diet samples were weighed into previously-dried (70℃) and tared bags. Bags were then tied to a chain and placed in the ventral rumen sac of steers through rumen fistulae. Bags were removed from the rumen after 6, 12, 24, 48, and 72 h incubation. Immediately after removal from the rumen, bags were washed with tap water to remove particles adhering to the outside of bags and rinsed until water running through the bag was clear. Bags were then dried (70℃, 48 h, forced-draft oven), after which residues were removed and analyzed for DM and NDF.

In situ digestion data for DM and NDF were fitted to the model of McDonald (1981):

$$P=a+b(1-e^{-c(t\ -\ L)})$$

where P (%)=rumen digestibility of DM or NDF at

Table 1. Formulations and chemical composition of mixed feeds for *in situ* digestion study (Experiment 1)

	SH replacement level (%)				
	0	25	50	75	100
Ingredient (% of DM)					
Corn silage (partial ears)	20.0	20.0	20.0	20.0	20.0
Chinese wildrye grass	7.5	7.5	7.5	7.5	7.5
Brewers' grains	15	15	15	15	15
Dry corn stover	7.5	7.5	7.5	7.5	7.5
Ground corn	20.0	16.5	11.15	6.5	1.7
Wheat bran	5.0	2.35	2.0	1.0	0
SH	0	6.25	12.5	18.75	25.0
Soybean meal (SBM)	12.5	12.5	12.5	12.5	12.5
Distillers' corn	3.0	3.0	3.0	3.0	3.0
Cottonseed meal	3.0	3.0	3.0	3.0	3.0
Linseed meal	3.0	3.0	3.0	3.0	3.0
Trace mineral premix[a]	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Bone meal	1.6	1.7	1.85	2.05	2.1
Oystershell	0.9	0.7	0.5	0.1	0
Chemical composition					
DM (%)	92.3	92.4	92.1	92.4	92.1
NE_L (MJ/kg)[b]	6.49	6.49	6.49	6.49	6.49
CP (% of DM)	17.2	17.3	17.9	17.3	17.8
NDF (% of DM)	39.2	41.8	45.1	48.3	51.4
ADF (% of DM)	26.5	29.2	32.1	34.9	37.8
Ca (% of DM)	0.94	0.92	0.91	0.88	0.88
P (% of DM)	0.69	0.66	0.67	0.68	0.66

[a] Trace mineral premix composition: Fe 10,000 mg/kg; Cu 2,400 mg/kg; Mn 8,400 mg/kg; Zn 13,000 mg/kg; I 160 mg/kg; Se 70 mg/kg; Co 100 mg/kg; VA 960,000 IU/kg; VD3 200,000 IU/kg; VE 7,500 IU/kg.

[b] Calculated according to tabular values (NRC, 1989).

time t, a (%)=rapidly digestible fraction, b (%)=slowly digestible fraction, c (%/h)=digestion rate of fraction b, t (hours)=time spent in the rumen, and L (hours)=lag time for digestion. The constants a, b, c, and L for each diet were calculated using non-linear regression procedure (SAS, 1991). Theoretically potential digestion extents were calculated as (a+b).

Experiment 2. Lactation performance trial

Forty-two Chinese Holstein cows (average body weight 564.5 kg, days in milk 102±12 days, milk yield ranged 22 to 28 kg daily) were assigned to one of four incomplete blocks based on date of parturition, lactation number and daily milk yield. Cows within blocks were assigned randomly to one of three treatments. The treatments were three mixed concentrates with 0, 25 or 50% SH replacements for corn and wheat bran as used in Experiment 1. The ingredient composition of the mixed concentrates are shown in table 2. The concentrates were balanced to provide similar nutrient density for NE_L, CP and minerals.

Cows were housed in an individual tie-stall barn and fed three times (07:00, 14:00 and 21:00 h) daily. Roughages fed to cows consisted of Chinese wildrye grass (*Aneurolepidium chinense*) hay (2.5 kg/d), dry corn stover cube (1 kg/d for first 4 weeks of trial only), wet brewers grains (16 kg/d) and corn silage (with partial ears; offered *ad libitum*). The mixed concentrates were fed to cows at the rate of 0.4 kg DM/d per kg milk production. Orts of roughage ingredients were weighed and removed daily between 22:00 and 23:00 h. Cows were milked three times between 08:30 and 10:30 h, 15:00 and 17:00 h, and 21:30 and 23:30 h daily. Drinking water was available at all times in the open lot area.

The trial lasted for a total of 13 weeks; the first week was for diet adjustment and the remaining 12 weeks were for milk production record. Cows were weighed on two consecutive days, at the beginning and at the end of the trial. Each roughage or mixed concentrate offered and refused was recorded daily. Orts were sampled on an individual cow basis on week 4, 8 and 12 of the trial period. Milk production was measured using a milk meter, and was recorded every two weeks. Separate milk samples from a.m. and p.m. milkings were taken every four weeks (wk 4, wk 8, and wk 12) for subsequent analyses of fat, protein, lactose and solids-non-fat (SNF) concentrations.

Table 2. Ingredient composition of mixed concentrates used in lactating trial (Experiment 2)

Item	SH replacement level (%)		
	0	25	50
Ingredient (% of DM)			
Ground corn	40	33	22.3
Wheat bran	10.0	4.7	4.0
SH	0	12.5	25.0
SBM	25.0	25.0	24.0
Distillers' corn	6.0	6.0	6.0
Cottonseed meal	6.0	6.0	6.0
Linseed meal	6.0	6.0	6.0
Trace mineral premix[a]	1.0	1.0	1.0
Salt	1.0	1.0	1.0
Bone meal	3.2	3.4	3.7
Oystershell	1.8	1.4	1.0
Chemical composition			
NE_L (MJ/kg)[b]	7.36	7.36	7.28
CP (% of DM)	22.4	22.4	22.2
NDF (% of DM)	18.3	23.5	30.0
ADF (% of DM)	8.7	14.0	19.7
Ca (% of DM)	1.54	1.50	1.48
P (% of DM)	1.02	0.99	0.99

[a] Containing 10,000 mg/kg Fe; 2,400 mg/kg Cu; 8,400 mg/kg Mn; 13,000 mg/kg Zn; 160 mg/kg I; 70 mg/kg Se; 100 mg/kg Co; 960,000 IU/kg VA; 200,000 IU/kg VD3; 7,500 IU/kg VE.

[b] Calculated according to table values (NRC, 1989).

Chemical analyses

Samples of SH, diets and nylon bag residues from Experiment 1, and of roughages, mixed concentrates and orts from Experiment 2, were analyzed for DM (105℃ oven drying overnight), N (AOAC, 1984), and NDF and ADF (Goering and Van Soest, 1970). The concentrations of fat, protein, lactose and SNF in milk were determined using an infrared milk analyzer by the Beijing Dairy Research Institute Laboratory.

Statistical analysis

Data were analyzed using the general linear models procedure of SAS (1991) according to a randomized complete block design. Orthogonal CONTRASTS were used to test for linear and quadratic responses to SH replacements for corn and wheat bran in the diet. Least square means for treatments were generated using the least square option.

RESULTS AND DISCUSSION

Experiment 1. Digestion

In situ digestion extents and kinetics of SH: In situ digestion extents of DM and NDF from SH are shown in figure 1. As expected, DM and NDF of SH were extensively digested in the rumen. At 48 h incubation, the *in situ* digestion of DM and NDF of SH were 86 and 81%. By fitting a non-linear regression model (McDonald, 1981) to the data, the *in situ* digestion rates of DM and NDF from SH were calculated to be 7.2 and 6.3 %/h for incubation from 6 to 72 h,

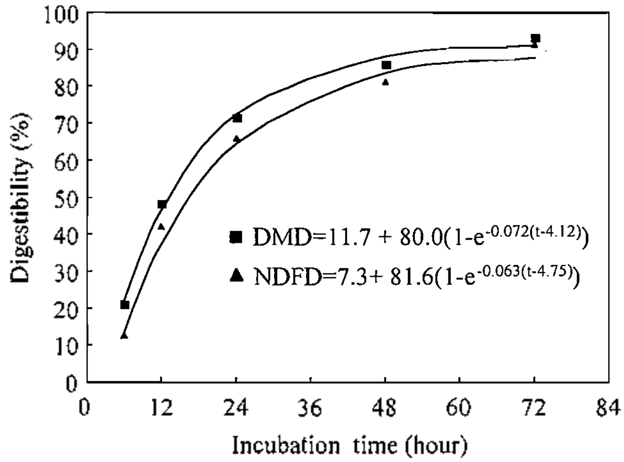

Figure 1. *In situ* digestion of DM (DMD) and NDF (NDFD) of SH

respectively (table 3). A high degree of fit of the model to the digestion data was obtained for DM (R^2_{DMD}=0.999) and NDF (R^2_{NDFD}=0.986; table 3 and figure 1). SH had a high percentage of potentially digestible DM (91.7%) and NDF (88.9%). Although SH are high in NDF (65.3% on a DM basis, determined in this laboratory), they are highly digested by rumen microorganisms (Quicke et al., 1959; Kung and Lin, 1997) due to low lignification (2% lignin, NRC, 1989). Klopfenstein and Owen (1987) reported that SH were digested very rapidly, having *in vitro* digestibility over 90%. Extent and rate of SH DM digestion *in situ* were 104% at 36 h incubation and 7.7 %/h respectively, when SH were incubated in the rumen of cattle fed alfalfa hay (Hsu et al., 1987). When SH were incubated in steers fed an alfalfa hay-based diet, SH had a fairly high *in situ* NDF digestion rate (7.5%/h) and great DM *in situ* digestion extent or potential digestible percentage (92%) in the rumen (Anderson et al., 1988).

Table 3. *In situ* digestion kinetics of DM and NDF of SH (Experiment 1)

Digestion kinetics[a]	DM	NDF
a (%)	11.7	7.3
b (%)	80.0	81.6
(a+b) (%)	91.7	88.9
c (%/h)	7.2	6.3
L (h)	4.1	4.8
R^2	0.999	0.986

[a] Based on the model of McDonald (1981): $P=a+b(1-e^{-c(t-L)})$.

***In situ* digestion extents and kinetics of mixed feeds with SH:** Increasing level of SH replacing corn and wheat bran in mixed feeds linearly (p=0.001) decreased digestion extents of feed DM at 6 and 12 h incubation, but did not affect (p=0.1-0.41) the digestion of DM beyond 12 h incubation (table 4). A higher digestion rate of starch in corn and wheat bran compared with NDF in SH may explain why DM digestibility for feeds with SH was lower than those with no SH at 6 and 12 h incubation. Beyond 12 h incubation, the feeds with incremental levels of SH had similar DM digestion extents, indicating that SH can be used as an easily digestible fiber source in ruminant diets. As SH replacement in the feeds increased, NDF digestibility responded linearly (p=0.001-0.04, table 4). Compared with the diet with no SH, diets with SH had higher NDF digestibility.

Table 4. Extent of *in situ* DM and NDF digestion of diets with incremental levels of SH[a] (Experiment 1)

Incubation time (h)	SH replacement level (%)					SEM	Contrast (p=)	
	0	25	50	75	100		L[b]	Q[c]
			---DM digestibility (%)---					
6	25.2	23.9	23.0	22.5	19.5	0.9	0.00	0.41
12	38.6	36.3	34.3	31.7	33.7	1.9	0.02	0.26
24	53.6	54.0	53.2	51.9	49.5	2.0	0.11	0.41
48	69.0	71.1	71.0	68.2	68.8	1.1	0.30	0.15
72	75.1	76.6	75.2	74.9	74.0	1.4	0.10	0.11
			---NDF digestibility (%)---					
6	9.7	8.7	8.2	11.2	11.5	1.0	0.04	0.19
12	21.8	20.7	24.8	28.0	29.2	1.2	0.00	0.39
24	43.1	47.9	47.2	48.2	47.9	1.1	0.01	0.07
48	54.1	61.6	64.2	64.6	64.6	0.7	0.00	0.05
72	64.6	69.1	70.7	70.8	70.3	0.5	0.00	0.05

[a] SH=soyhulls.
[b] L=linear response.
[c] Q=quadratic response.

The increased NDF digestibility of the diets due to addition of SH must be related to the nature of the NDF from different sources. As described early, NDF in SH is highly digestible and should be more digestible than the NDF contained in other dietary ingredients. Furthermore, inclusion of SH in concentrate diets for replacement of corn and wheat bran may have a positive associative effect on fiber digestion. Although our estimation of *in situ* NDF digestion was done in the same ruminal environment, the inner environment where diet samples were located within nylon bags may be different from the environment outside of the bags as reported by Noziere and Michalet-Doreau (1996). A positive associative effect on *in vivo* NDF digestion resulting from addition of SH in the diet was reported previously (Anderson et al., 1988; Nakamura and Owen, 1989).

Results of digestion kinetics are presented in table 5. As level of SH replacement increased, percentage of slowly digestible fraction (b) of dietary DM increased (linear, p=0.03), percentage of rapidly digestible fraction (a) of DM tended to decrease (linear, p=0.14), and DM digestion lag time tended to be longer (linear, p=0.13). A direct explanation for these observations is that fiber in SH may have a relatively slower digestion rate and longer digestion lag time compared with starch in corn or wheat bran. Percentages of potentially digestible fractions (a+b) and digestion rate (c) of slowly digestible fraction of dietary DM remained unaltered (p=0.36-0.90) when SH in the diet increased. As shown in table 5, for NDF, increasing level of SH replacement resulted in increases in b (quadratic, p<0.001), a (linear, p=0.08) and a+b (quadratic, p=0.001), along with a tendency for an increase in c (linear, p<0.19). The increased proportion of potentially digestible fraction of dietary NDF with increasing level of SH in the diet may be mainly related to more digestible NDF in SH than in other diet ingredients. Moreover, inclusion of SH in mixed concentrates may alter the microbial environment to favor cell wall digestion within nylon bags. Further *in vivo* digestion and ruminal microbiology work is needed for demonstration of this hypothesis. A quadratic response (p=0.01) of lag time for dietary NDF digestion was detected as level of SH in the diet increased, for which no satisfactory explanation can be made.

Fitting the mathematical model of McDonald (1981) to these *in situ* digestion data showed a satisfactory fit to the NDF digestion data (R^2=0.986-0.998), but a relatively poor fit to the DM digestion data (R^2=0.915-0.968, table 5). A possible explanation would be that there should be at least two distinct components in the b fraction for dietary DM, i.e., the relatively rapidly digestible starch and relatively slowly digestible NDF, while for NDF there is only one single consistent component, NDF itself. Xiong et al. (1990) compared a two-component model with a one-component model for describing enzymatic digestion kinetics of a 50:50 mixture of uncooked and fully cooked ground sorghum grain, and found that the

Table 5. *In situ* DM and NDF digestion kinetics of diets with incremental levels of SH in concentrate mixtures (Experiment 1)[a]

Item	SH replacement level (%)[b]					SEM	Contrast (p=)	
	0	25	50	75	100		L[c]	Q[d]
DM digestion								
a (%)	10.1	9.5	8.3	8.5	6.2	1.8	0.14	0.77
b (%)	68.6	71.3	72.0	71.4	72.2	0.9	0.03	0.17
(a+b) (%)	78.7	80.8	80.3	79.9	78.4	2.0	0.80	0.36
c (%)	4.5	4.4	4.5	4.0	4.3	0.5	0.59	0.90
L (h)	0.7	1.0	1.3	1.1	1.3	0.3	0.13	0.29
R^2	0.915	0.957	0.934	0.968	0.965	-	-	-
NDF digestion								
a (%)	1.9	2.5	3.7	2.9	5.4	1.0	0.08	0.65
b (%)	63.9	68.6	69.0	69.8	66.7	0.5	0.00	0.00
(a+b) (%)	65.8	71.1	72.7	72.7	72.1	1.1	0.00	0.01
c (%)	4.5	5.1	5.1	5.0	5.3	0.4	0.19	0.69
L (h)	3.2	4.6	4.7	3.1	4.0	0.4	0.75	0.01
R^2	0.995	0.993	0.994	0.998	0.986	-	-	-

[a] Based on the model of McDonald (1981): $P=a+b(1-e^{-c(t-L)})$.

[b] SH=soyhulls.

[c] L=linear response.

[d] Q=quadratic response.

two-component model was much better in describing the digestion kinetics of that grain mixture. In this case, a more appropriate model for fitting to the DM digestion data of mixed diets needs to be developed in further study.

Experiment 2. Lactation performance

Chemical composition of total diets: Chemical composition of the diets fed to the lactating cows is presented in table 6. Concentrations of the dietary NE_L, CP, Ca and P were similar among three diets. Percentages of dietary NDF and ADF increased with increasing SH which is a reflection of the higher concentrations of NDF and ADF in SH. In the present study, levels of SH included in the total ration of the two SH diets were 6.8 and 13.6%. These SH levels were lower than those (25 to 48%) used in previous experiments (MacGregor et al., 1976; Nakamura and Owen, 1989). The main reason for the lower replacement levels in the present study was that this was the first SH feeding trial in China and the dairy farm manager did not want to take any risk of a negative response from SH replacement.

Feed intake: DM, CP and NDF intake data are listed in table 7. Increasing SH replacement had no effect on DM and CP intake (kilograms per day and percentage of body weight, p=0.09-0.63), while significantly increased NDF intake (linear, p<0.001). When corn and wheat bran were replaced by SH in lactation diets, physical and chemical differences in dietary composition apparently were not great enough to elicit negative responses for DM or CP intake. In general, feeds high in fiber are considered to be low in digestibility, resulting in feed intake limited by physical fill. In this study, the similar DM intake with increasing SH in the diet must be related to the high rate of NDF digestion and high rate of passage of SH. Previous reports also indicated that there was no significant difference in DM or CP intake in dairy cows when SH replaced corn (Nakamura and Owen, 1989; MacGregor et al., 1976; Firkins and Eastridge, 1992; Bernard and McNeill, 1991; Sarwar et al., 1992) and oats or citrus pulp (Wagner et al., 1965).

Milk production: Cow body weight change and lactation data are shown in table 8. Replacing corn and wheat bran with SH at rates of 25 and 50% in

Table 6. Ingredients and chemical composition of diets fed to lactating cows (Experiment 2)

Item	SH replacement level (%) 0	25	50
Ingredient (% of DM)			
Corn silage (partial ears)	17.7	17.6	17.5
Brewers' grains	16.8	16.7	16.7
Dry corn stover	1.1	1.1	1.1
Chinese wildrye hay	10.7	10.6	10.6
Ground corn	21.5	17.8	12.1
Wheat bran	5.4	2.5	2.2
SH	0	6.8	13.6
SBM	13.5	13.6	13.0
Distillers' corn	3.2	3.2	3.2
Cottonseed meal	3.2	3.2	3.2
Linseed meal	3.2	3.2	3.2
Trace mineral premix[a]	0.5	0.5	0.5
Salt	0.5	0.5	0.5
Bone meal	1.7	1.9	2.0
Oystershell	1.0	0.8	0.6
Chemical composition			
DM (%)	66.1	66.2	66.1
NE_L (MJ/kg)[b]	6.65	6.65	6.61
CP (% of DM)	18.3	18.3	18.3
NDF (% of DM)	37.3	40.0	43.5
ADF (% of DM)	24.0	26.8	29.9
Ca (% of DM)	0.99	0.97	0.96
P (% of DM)	0.74	0.71	0.71

[a] Containing 10,000 mg/kg Fe; 2,400 mg/kg Cu; 8,400 mg/kg Mn; 13,000 mg/kg Zn; 160 mg/kg I; 70 mg/kg Se; 100 mg/kg Co; 960,000 IU/kg VA; 200,000 IU/kg VD3; 7,500 IU/kg VE.

[b] Calculated according to table values (NRC, 1989).

Table 7. Intake of dietary DM, CP and NDF as influenced by diets with SH replacing corn and wheat bran (Experiment 2)

Item	SH replacement level (%)[a] 0	25	50	SEM	Contrast (p=) L[b]	Q[c]
DM intake (kg/d)	18.38	18.57	18.53	0.20	0.63	0.51
DM intake (% of BW)	3.15	3.42	3.35	0.09	0.14	0.09
CP intake (kg/d)	3.36	3.40	3.39	0.04	0.62	0.52
CP intake (% of BW)	0.58	0.63	0.61	0.02	0.16	0.09
NDF intake (kg/d)	6.85	7.42	8.03	0.09	0.00	0.73
NDF intake (% of BW)	1.18	1.36	1.43	0.04	0.00	0.17

[a] SH=soyhulls.

[b] L=linear response.

[c] Q=quadratic response.

Table 8. Lactation performance of cows on diets with SH replacing grain concentrate[a] (Experiment 2)

	SH replacement level (%)[b]				Contrast (p=)	
	0	25	50	SEM	L[c]	Q[d]
Number of cows	14	14	14	-	-	-
BW (kg)	586.3	549.6	557.5	14.2	0.18	0.16
BW change (kg/d)	0.21	0.16	0.13	0.06	0.36	0.82
Milk production (kg/d)	27.7	28.4	27.6	0.9	0.95	0.44
4% FCM production (kg/d)	26.2	27.6	27.3	1.1	0.56	0.46
4% FCM production/DMI	1.42	1.49	1.47	0.05	0.56	0.46
Milk composition						
Fat (%)	3.63	3.85	3.90	0.09	0.08	0.50
Protein (%)	3.12	3.17	3.18	0.06	0.62	0.76
Lactose (%)	4.69	4.76	4.68	0.04	0.68	0.10
Solid-non-fat (SNF) (%)	8.50	8.64	8.54	0.09	0.85	0.29

[a] Corn and wheat bran.
[b] SH=soyhulls.
[c] L=linear response.
[d] Q=quadratic response.

the diets had no significant effect on body weight change, total milk production, 4% FCM production and feed conversion of FCM (kilograms of 4% FCM per kilogram of DMI). Percentages of milk protein, lactose and SNF were unaffected (p=0.1-0.95) by SH replacement. Milk fat percentages, however, tended to increase (linear, p=0.08) when cows were fed diets with incremental levels of SH. Increased milk fat response to increased dietary SH levels was reported previously (Coomer et al., 1993; Nakamura and Owen, 1989; Weiss, 1995). In other lactation trials, however, feeding cows on diets with SH for replacing corn grains (Bernard and McNeill, 1991; MacGregor et al., 1976), high moisture corn (Cunningham et al., 1993), or oats or citrus pulp (Wagner et al., 1965) had no effect on either milk production or milk fat percentage. The milk fat content of control (zero SH replacement) was rather low (3.10-3.13%) in those trials showing an increased milk fat response to SH replacement (Nakamura and Owen, 1989; Coomer et al., 1993). The milk fat percentages of the control were fairly high (3.46-4.18%) in those trials showing no response to SH replacement (Cunningham et al., 1993; Bernard and McNeill, 1991; MacGregor et al., 1976). In the present study, because the milk fat content of the control (zero SH replacement) was 3.63%, a non-significant (p=0.08) linear response to SH replace- ment was observed. It appears that the milk fat response to SH replacement may interact with the initial milk fat content of the control.

Economic analysis: Data on daily feed cost inputs and 4% FCM production in lactating cows are presented in table 9. The current feed costs expressed as Chinese currency, RMB in *yuan*/kg DM (the exchange rate has been 8.3 *yuan* RMB=1 USD) were corn silage with partial ears, 0.58; Chinese wildrye grass hay, 0.65; dry corn stover cube, 0.42; brewers' grains, 0.78; mixed concentrates, 1.50, 1.46 and 1.41 for SH replacement of 0, 25, and 50%, respectively. The total feed cost inputs for producing 1 kg of 4% FCM were 0.782 *yuan* when cows were fed the control (zero SH) diets. When corn and wheat bran in the diets were replaced by SH at the levels of 25 and 50%, the feed cost to produce each unit of 4% FCM reduced by 5.8 and 7.3% (0.782 *yuan*/kg FCM vs. 0.737 and 0.725 *yuan*/kg FCM), indicating a pronounced economic benefit from use of SH in lactating cow diets.

IMPLICATIONS

In situ study indicates that soyhulls had a very high digestion extent and fairly fast digestion rate of dry matter and fiber. Based on feeding trial results, soyhulls, when available and economically priced, can replace at least 50% of corn and wheat bran in diets fed to lactating dairy cows with no change in milk production, 4% fat-corrected-milk production, milk protein, lactose, and solids-non-fat percentages. Increasing soyhulls in cow diets increased milk fat percentage, but decreased feed cost per unit of 4% FCM production. Results of the present trials indicated that when replacing corn and wheat bran at the rate of up to 50% in lactating cow diets, soyhulls had similar feeding values to corn and wheat bran.

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Table 9. Cost analysis of feeds consumed by cows fed SH to replace corn and wheat bran in diets (Experiment 2)

	SH replacement level (%)		
Item	0	25	50
Daily DM intake (kg/head)			
Corn silage (partial ears)	3.25	3.27	3.26
Chinese wildrye grass hay	1.97	1.96	1.97
Dry corn stover	0.20	0.20	0.20
Brewers' grains	3.09	3.11	3.10
Mixed concentrate	9.88	10.05	10.01
Daily feed cost (*yuan*/head)			
Corn silage (partial ears)	1.885	1.897	1.891
Chinese wildrye grass hay	1.281	1.274	1.281
Dry corn stover cube	0.084	0.084	0.084
Brewers' grains	2.410	2.426	2.418
Mixed concentrate	14.820	14.673	14.114
Total feed cost (*yuan*/d/head)	20.480	20.354	19.788
4% FCM production (kg/d)	26.2	27.6	27.3
Feed cost (*yuan*)/kg FCM	0.782	0.737	0.725

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REFERENCES

Anderson, S. J., J. K. Merrill, M. L. McDonnell and T. J. Klopfenstein. 1988. Digestibility and utilization of mechanically processed soybean hulls by lambs and steers. J. Anim. Sci. 66:2965-2976.

AOAC. 1984. Official Methods of Analysis. 14th ed. AOAC, Washington, DC.

Bernard, J. K. and W. W. McNeill. 1991. Effect of high fiber energy supplements on nutrient digestibility and milk production of lactating dairy cows. J. Dairy Sci. 74:991-995.

Coomer, J. C., H. A. E. Amos, C. C. Williams and J. G. Wheeler. 1993. Response of early lactation cows to fat supplementation in diets with different non-structural carbohydrate concentrations. J. Dairy Sci. 76:3747-3754.

Cunningham, K. D., M. J. Cecava and T. R. Johnson. 1993. Nutrient digestion, nitrogen and amino acid flows in lactating cows fed soybean hulls in place of forage or concentrate. J. Dairy Sci. 76:3523-3535.

Firkins, J. L. and M. L. Eastridge. 1992. Replacement of forage or concentrate with combinations of soybean hulls, sodium bicarbonate, or fat for lactating dairy cows. J. Dairy Sci. 75:2752-2761.

Goering, H. K. and P. J. Van Soest. 1970. Forage Fiber Analyses (apparatus, reagents, procedures, and some applications). Agric. Handbook. No. 379. ARS-USDA, Washington, DC.

Hintz, H. F., M. M. Mathias, H. F. Ley Jr. and J. K. Loosli. 1964. The effects of processing and of feeding hay on the digestibility of soybean hulls. J. Anim. Sci. 23:43-46.

Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey Jr. and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls, and soybean hulls as roughage sources for ruminants. J. Anim. Sci. 65:244-255.

Klopfenstein, T. J. and F. G. Owen. 1987. Soyhulls: an energy supplement for ruminants. Anim. Health Nutr. 43:48.

Kung, L. and C. J. Lin. 1997. Soyhulls in beef and dairy cattle nutrition. Am. Soybean Assoc. Tech. Bul., AN 16-1997, Singapore.

MacGregor, C. A., F. G. Owen, L. and D. McGill. 1976. Effect of increasing ration fiber with soybean mill run on digestibility and lactation performance. J. Dairy Sci. 59:682-689.

McDonald, I. 1981. A revised model for the estimation of protein degradability in the rumen. J. Agric. Sci. (Camb.). 96:251-252.

Nakamura, T. and F. G. Owen. 1989. High amounts of soyhulls for pelleted concentrate diets. J. Dairy Sci. 72:988-994.

Noziere, P. and B. Michalet-Doreau. 1996. Variation of *in sacco* method: influence of sampling site, nylon bag or rumen contents, on fibrolytic activity of solid-associated microorganisms. Anim. Feed Sci. Technol. 57:203-210.

NRC. 1989. Nutrient Requirements of Dairy Cattle. (6th Rev. Ed.). National Academy Press, Washington, DC.

Quicke, G. V., O. G. Bentley, H. W. Scott, R. R. Johnson and A. L. Moxon. 1959. Digestibility of soybean hulls and flakes and the in vitro digestibility of the cellulose in various milling by-products. J. Dairy Sci. 42:185-186.

Sarwar, M., J. L. Firkins and M. L. Eastridge. 1992. Effects of varying forage and concentrate carbohydrates on nutrient digestibilities and milk production by dairy cows. J. Dairy Sci. 75:1533-1542.

SAS. 1991. SAS Users Guide: Statistics (Version 6.12 Ed.) SAS Inst. Inc., Cary, NC.

Wagner, D. G., J. K. Loosli, H. F. Hintz and R. G. Warner. 1965. Value of soybean flakes for milk production. J. Dairy Sci. 48:553-555.

Weiss, W. P. 1995. Full lactation response of cows fed diets with different sources and amounts of fiber and ruminal degradable protein. J. Dairy Sci. 78:1802-1814.

Xiong, Y., S. J. Bartle and R. L. Preston. 1990. Improved enzymatic method to measure processing effects and starch availability in sorghum grain. J. Anim. Sci. 68:3861-3870.