Effects of Replacing Nonfiber Carbohydrates with Nonforage Detergent Fiber from Cassava Residues on Performance of Dairy Cows in the Tropics*

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ABSTRACT : Four Holstein×Indigenous cows with ruminal canulas were used in a 4×4 Latin square design with 28 d periods to determine the effect of replacing nonforage fiber source (NFFS) from cassava residues for non-fiber carbohydrates (NFC) on ruminal fermentation characteristics and milk production. Dietary treatments contained 17% forage neutral detergent fiber (FNDF) from corn silage and 0, 3, 6 and 9% nonforage NDF from cassava residues and 11% nonforage NDF from other NFFS, so that levels of nonforage NDF were 11, 14, 17 and 20% dry matter (DM). Intakes of DM and net energy for lactation, average daily gain and milk fat percentage were not different (p>0.05). Ruminal pH, ammonia concentrations, acetate to propionate ratios, 24 h *in sacco* fiber digestibility significantly increased with increasing contents of nonforage NDF from cassava residues. Concentrations of VFA, urinary excretion of purine derivatives, milk protein percentage, production of milk and 4% FCM significantly decreased. These results suggest that NFC in diets is one of the limiting factors affecting productivity of dairy cows in the tropics and thus NFFS is better used as partial replacements for FNDF. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 7 : 967-972)***

Key Words : Nonforage Fiber, Cassava Residues, Dairy Cows, Tropics

INTRODUCTION

Fiber sources of forage or nonforage origin differ considerably in particle size (Mertens, 1997), specific gravity (Bhatti and Firkins, 1995), rate and extent of digestion (Grant, 1997) and passage rate (Firkins, 1997). Diets containing nonforage fiber sources (NFFS) and minimal forage are necessary to contain sufficient contents and particle size of forage neutral detergent fiber (FNDF) for stimulating rumination. To incorporate NFFS successfully into lactation diets, they must be replaced forage only to the point that compensatory rumination activity will be met or replaced concentrate only to the point that the production of fermentation acids needs to be controlled to avoid the incidence of ruminal acidosis.

Starch is one of the major products produced from the roots of cassava plants. Approximately, 5-6 million tons of fresh cassava roots in Thailand are yearly used to produce 1-1.2 million tones of dry starch and the rest is the small solid particle waste product so called cassava residues. Cassava residues contain 320-420 g of neutral detergent fiber (NDF) per kg dry matter (DM). Little information is available on the use of cassava residues as NFFS for replacement of concentrate in diets for dairy cows in the tropics. Cassava residues may be used as an energy source for lactation while reducing negative associate effect of readily fermentable starch in concentrate based-diets. An objective of this study was to evaluate the effect of increasing substitution rates of NDF from cassava residues for nonfiber carbohydrates (NFC) from cassava chips on mid lactation performance of dairy cows in the tropics.

MATERIALS AND METHODS

A study was conducted during summer months in Thailand. Four Holstein×Indigenous (93.75×6.25%) multiparous dairy cows in mid lactation were used in a 4×4 Latin square design with 28 d periods. Each cow was fitted with ruminal cannula. Cows averaged 120±7 days in milk at the start of the experiment.

Cassava residues were used as a nonforage fiber source (NFFS). Total mixed rations (TMR) were formulated to contain 17% forage neutral detergent fiber (FNDF) from corn silage and 0, 3, 6 and 9% nonforage NDF from cassava residues and 11% nonforage NDF from other NFFS, so that levels of nonforage NDF were 11, 14, 17 and 20% dry matter (DM). Similar levels of crude protein (CP) and energy were maintained as shown in Table 1. Total mixed rations were offered *ad libitum* in equal portions at 7.30 and 17.30 h. The experimental diets were sampled weekly and bulk for later chemical analysis.

Within the 28 d experimental periods, the first 4 d was regarded as a transitional period, the following 10 d as an adaptation, and within the last 14 d, intensive sampling was undertaken. Over the last 14 d, feed intake and milk yield were daily measured. Milk samples of 50 ml were collected at 3 d intervals at consecutive a.m. and p.m. milkings in bottles containing 2 bromo 2 nitro 1,3-propadiol and stored

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Table 1. Ingredients and chemical compositions of total mixed rations (TMR) containing nonforage neutral detergent fiber (NDF) from cassava residues

Item	TMR containing nonforage NDF, %			
	11.2	14.2	17.2	20.2
Ingredients, %				
Corn silage	34.5	34.5	34.5	34.5
Cassava residue	-	8.5	17	25.5
Cassava chips	29.5	20.6	10.5	1
Molasses	2	2	2	2
Full fat soybean meal	10	10	10	10
Soybean meal	10	10	10	10
Cotton seed meal	10	10	10	10
Urea	0.5	0.5	0.5	0.5
Tallow	-	1	2	3
Mineral-vitamins	3.5	3.5	3.5	3.5
Chemical compositions				
Crude protein, %	16	16.1	16.3	16.6
Ether extract, %	2.89	3.94	5.01	5.97
Total neutral detergent fiber, %	28.1	30.9	33.6	37.3
Total non-fiber carbohydrate, %	41.9	38.7	35.6	32.6
Total digestible nutrients, %	71.1	70.9	70.7	70.7
Net energy for lactation*, Mcal/kg DM	1.62	1.62	1.61	1.61

* NE_L: (Mcal/kg DM)=(0.0245×TDN)-0.12.

Table 2. Live weight changes and voluntary intake of total mixed rations (TMR) containing nonforage neutral detergent fiber (NDF) from cassava residues

Item	TMR containing nonforage NDF,%				SE
	11.2	14.2	17.2	20.2	
Nutrient intake					
Dry matter, kg/d	14.58	14.53	14.67	14.92	0.62
Dry matter, % BW	3.47	3.54	3.69	3.73	0.06
Crude protein, kg/d	2.33	2.34	2.39	2.43	0.02
Ether extract, kg/d	0.42[1]	0.57[2]	0.73[3]	0.89[4]	<0.01
Total neutral detergent fiber, kg/d	4.10[1]	4.49[2]	4.93[3]	5.57[4]	0.27
Total non-fiber carbohydrates, kg/d	6.11[4]	5.63[3]	5.22[2]	4.87[1]	0.29
Net energy for lactation, Mcal/d	23.61	23.54	23.62	24.02	1.65
Live weight change					
Initial weight, kg	420	408	395	411	4.13
Final weight, kg	428	417	398	414	4.36
Daily gain, g/d	0.286	0.321	0.107	0.107	0.04

[1, 2] Means within a row without a common superscript letter differ (p<0.01).

at 5°C for composition analysis. Cows were weighed once each week immediately following the a. m. milking prior to accessing feed and water. On day 24, digestibilities of DM, NDF and CP from ground (2 mm sieve) dietary materials and cassava residues were assessed using nylon bags with a pore size of 44 mm and measured 7×14 cm. On day 25, ruminal fluid was collected through a probe placed in a caudal position in the ventral sac of the rumen. The probe consisted of a thin stainless steel pipe with a small metal cage at one end which was covered with a double layer of nylon stocking material. Samples of ruminal fluid were taken before morning feeding and 4 and 8 h after feeding. Prior to acidification, samples were removed to a vial for measurement of pH. The remaining sample of 15 ml was acidified with 5 drops of concentrate H_2SO_4 and stored at -20°C prior to analysis of VFA and NH_3. On day 26-28, daily urine voided by each animal was collected into a container with 2 litres of 2% (V/V) CH_3COOH and 1% (V/V) H_2SO_4. The urine sample was diluted by 3-4 times just after collection and then stored at -20°C. Equal portions of the daily urine samples from each animal from each day were pooled prior to analysis of purine derivatives.

Contents of CP, ether extract (EE), DM and ash of the experimental diet were determined according to AOAC (1980). Neutral detergent fiber and acid detergent fiber (ADF) were measured following the method of Van Soest et al. (1991). Prior to analysis of VFA and NH_3, the acidified sample was thawed and centrifuged at 3,000 g at 4°C for 10 min. The supernatant was kept for analysis. The concentration and molar proportions of VFA were determined according to the method of Erwin et al. (1961). Iso-capric acid was used as an internal standard (Geissler et

Table 3. Effects of total mixed rations (TMR) containing nonforage neutral detergent fiber (NDF) from cassava residues on ruminal fermentation characteristics

Item	TMR containing nonforage NDF,%				SE
	11.2	14.2	17.2	20.2	
pH	6.19[a]	6.27[a,b]	6.32[b,c]	6.40[c]	0.11
NH_3-N, mg N/l	132.6[1]	145.1[2]	160.3[3]	176.9[4]	9.47
Acetate, %	59.9[1]	60.9[2]	62.4[3]	65.8[4]	1.04
Propionate, %	25.7[4]	24.1[3]	22.7[2]	19.3[1]	1.22
Butyrate, %	10.2	10.5	10.4	10.5	0.23
Isobutyrate, %	1.4	1.5	1.6	1.4	0.04
Valerate, %	1.3	1.5	1.4	1.5	0.04
Isovalerate, %	1.5	1.5	1.5	1.5	0.01
Total VFA, μm/ml	118.1[4]	115.0[3]	110.7[2]	102.4[1]	6.18
Acetate: propionate	2.33[1]	2.53[2]	2.75[3]	3.41[4]	0.01

[a, b and 1, 2] Means within a row without a common superscript letter and number differ ($p<0.05$) and ($p<0.01$), respectively.

Table 4. Effects of total mixed rations (TMR) containing nonforage neutral detergent fiber (NDF) from cassava residues on 24 h *in sacco* digestibility and purine derivatives excreted in urine

Item	TMR containing nonforage NDF, %				SE
	11.2	14.2	17.2	20.2	
24 h *in sacco* digestibility, %					
TMR					
Dry matter	79.7[a]	77.4[a,b]	76.0[b,c]	74.6[c]	3.01
Neutral detergent fiber	55.4[a]	56.9[a,b]	57.5[b,c]	58.1[c]	2.01
Crude protein	63.8	64.2	63.5	64.0	4.58
Cassava residues					
Dry matter	56.5	55.9	57.1	56.6	2.96
Neutral detergent fiber	57.0[a]	58.1[a,b]	59.5[b,c]	60.6[c]	2.11
Crude protein	50.5	50.0	51.4	51.7	3.20
Purine derivatives, mmol/d	260.3[3]	258.1[2,3]	254.9[2]	250.8[1]	4.56

[a, b and 1, 2] Means within a row without a common superscript letter and number differ ($p<0.05$) and ($p<0.01$), respectively.

al., 1976). The concentration of NH_3-N was analysed according to the method of Weatherburn (1967). Allantoin in urine was analysed according to the method of Borchers (1977) and uric acid was measured following the method described by Fujihara et al. (1987).

The statistical significance of the data was analysed by SAS (1989). The difference between treatments means was assessed by the least square means.

RESULTS

Values of nutrient composition on a DM basis for cassava residues were as follows: DM, 16.5%; CP, 2.53%; EE, 0.14%; NDF, 39.29%; ADF, 19.57%; ADL, 1.96%; NDIN, 4.77%; NFC, 58.89% and ash, 3.92%.

Chemical compositions of the experimental diets are shown in Table 1. Added tallow to the diets containing cassava residues was necessary to increase contents of energy, so that the dietary treatments contained a similar level of CP and calculated energy.

Dietary treatment effects on nutrient intake and live weight changes are presented in Table 2. Intakes of EE and total NDF increased with increasing contents of nonforage NDF from cassava residues in TMR ($p<0.01$) and of NFC decreased ($p<0.01$). Average daily gain and DMI ware not affected by dietary treatments ($p>0.05$).

Data for ruminal fermentation characteristics are presented in Table 3. Ruminal pH ($p<0.05$), ammonia concentration ($p<0.01$), molar proportion of acetate ($p<0.01$) and acetate to propionate ratios ($p<0.01$) were increased as contents of nonforage NDF from cassava residues increased. However, molar proportion of propionate and concentration of VFA were decreased ($p<0.01$).

Data for 24 h *in sacco* digestibility of the experimental diet and cassava residues and urinary purine excretion are presented in Table 4. No significant differences ($p>0.05$) were detected among treatments for CP digestibility of both the experimental diet and cassava residues and for DM digestibility of cassava residues. The DM digestibility of the experimental diet decreased with increasing contents of nonforage NDF from cassava residues but NDF digestibility of the experimental diet and cassava residues increased ($p>0.05$). Urinary excretion of purine derivatives was decreased with increasing contents of nonforage NDF from cassava residues ($p<0.01$).

Dietary treatment effects on milk yield and compositions are shown in Table 5. Production of milk

Table 5. Composition and yield of milk in dairy cows fed total mixed ration (TMR) containing nonforage neutral detergent fiber (NDF) from cassava residues

Item	TMR containing nonforage NDF,%				SE
	11.2	14.2	17.2	20.2	
Butter fat					
%	4.19	4.25	4.24	4.20	0.11
kg/d	0.72	0.72	0.71	0.66	0.06
Milk protein					
%	3.25^{3}	3.22^{3}	3.08^{2}	2.93^{1}	0.03
kg/d	0.56^{b}	0.55^{b}	0.52^{b}	0.46^{a}	0.03
Lactose					
%	4.86	4.87	4.84	4.84	<0.01
kg/d	0.84	0.83	0.82	0.76	0.04
Minerals					
%	0.70	0.70	0.69	0.69	<0.01
kg/d	0.12	0.12	0.12	0.11	<0.01
Solids-not-fat					
%	8.81^{3}	8.79^{3}	8.61^{2}	8.49^{1}	0.02
kg/d	1.52^{b}	1.49^{b}	1.45^{b}	1.32^{a}	0.04
Total solids					
%	13.00^{b}	13.04^{b}	12.85^{a}	12.67^{a}	0.15
kg/d	2.24^{2}	2.21^{2}	2.17^{2}	1.98^{1}	0.08
Milk yield, kg/d	17.26^{3}	16.98^{3,2}	16.86^{2}	15.64^{1}	1.02
Fat corrected milk (4%), kg/d	17.75^{2}	17.62^{2}	17.47^{2}	16.11^{1}	1.24

$^{a, b \text{ and } 1, 2}$ Means within a row without a common superscript letter and number differ ($p<0.05$) and ($p<0.01$), respectively.

($p<0.01$) and 4% FCM ($p<0.01$), milk protein ($p<0.05$), solids-not-fat ($p<0.05$) and total solid ($p<0.01$) and percentage of milk protein ($p<0.01$), solids-not-fat ($p<0.01$) and total solid ($p<0.05$) decreased with increasing contents of nonforage NDF from cassava residues.

DISCUSSION

Cassava residues contained a large proportion of NFC and potentially digestible fiber (cellulose=NDF-ADF: 25.72% and hemicellulose=ADF-ADL: 11.61%) and contained a small proportion of lignin. Cassava residues may supply energy needed for lactation or serve as partial replacements for forage fiber in those situation where forage availabilities is limited. In this study, cassava residues were used as a nonforage fiber source (NFFS) to dilute nonfiber carbohydrates (NFC) from cassava chips.

Dietary forage and nonforage NDF needed to be managed to achieve the proper balance between effective fiber and NFC. Because NFC is calculated by difference, increased forage NDF or nonforage NDF will have to reduce NFC. In this study, forage NDF was constant (17% of DM) and nonforage NDF were from 11.1 to 20.3% of DM, so that dietary NDF increased from 28.1 to 37.3% of DM as dietary NFC declined from 41.9 to 32.6% of DM. The content of forage NDF was confirmed to have sufficient effective fiber for dairy cows in the tropics as reported by Kanjanapruthipong et al. (2001) and Kanjanapruthipong and Buatong (2003). In the temperate with high milk yield, when dietary NFC was greater than 45 to 50% or less than 25 to 30%, milk production was decreased (Hoover and Miler, 1991). However, little information is available on effects of dietary NFC on milk production in the tropics. The range of NFC in this study presumably fell within normal feeding guidelines.

Intake of OM was reduced linearly with increasing unsaturated fat in diets containing soy hulls as a NFFS (Pantoja et al., 1994). Increasing nonforage NDF from cassava residues, coupled with adding dietary fat, to increase energy densities had no effect on DMI. The different result may reflect the interaction between sources, chemical and physical characteristics of forage and nonforage NDF that influence rate of fiber digestion and rate of passage (Grant, 1997; Allen and Grant, 2000). However, the effect of amounts and sources of nonforage NDF replacing concentrate on DMI reported in literature is variable (Sharwar et al., 1992; Cunningham et al., 1993; Batajoo and Shaver, 1994; Swain and Armentano, 1994; Younker et al., 1998; Allen, 2000).

Alteration of dietary NFC or NDF influences ruminal fermentation patterns (Allen, 1997). However, fat supplementation at 5% of the diet does not appear to affect ruminal pH and concentration of VFA and acetate to propionate ratio (Ohajuruka et al., 1991; Wang et al., 2003). Increased substitution rates of nonforage NDF from cassava for NFC, coupled with adding dietary fat, resulted in higher ruminal pH, concentrations of ruminal fluid NH_3-N, acetate to propionate ratios and lower total VFA, reflecting the lower concentrations of NFC. Similar results ware observed in other studies (Batajoo and Shaver, 1994; Pantoja et al., 1994).

The competition between digestion and passage is important for NFFS utilization (Grant, 1997). In this study, apparently 24 h *in sacco* digestibility of dietary DM decreased with increasing substitution rates of nonforage NDF from cassava residues for NFC, probably because of the higher fiber and lower starch content of the diets. Dilution of starch with nonforage NDF appeared to increase digestibility because of reduced negative associative effects (Firkins, 1997). Many NFFS have a relatively small particle size (Mertens, 1997) and high specific gravity (Bhatti and Firkins, 1995), which probably allow considerable amounts of potentially available NDF to pass from the rumen. Increased 24 h *in sacco* NDF digestibility of nonforage NDF form cassava residues with increasing substitution rates of cassava residues for NFC was not represent the actual figure, because of ignoring the continuous competition of digestion and passage rates.

Rate of digestion of carbohydrates generally is the major factor controlling the energy available for growth of rumen microbes (Hoover and Stokes, 1991). Decreasing the quantity of readily fermentable carbohydrate decreased microbial N flow to the duodenum (Spicer et al., 1986). A similar result was observed in this study. Decreased flow of microbial N to the duodenum with increasing substitution rates of nonforage NDF from cassava residues for NFC can be explained by changes in microbial growth efficiency per se because of no difference in DMI across dietary treatments.

Depression in milk protein percentage has been attributed to changes in amino acids (Cant et al., 1993) and energy (Cant, 1993) utilization by the mammary gland. Decreasing NFC (Kanjanapruthipong et al., 2001) and added fat in the diet (Sarwar et al., 1994) decreased milk protein concentration. Increasing substitution rates of nonforage NDF from cassava residues for NFC, coupled with adding dietary fat, resulted in lower milk protein percentage. This reduction probably was due to reduced availability of microbial-N for absorption as mentioned above and thus reduced amino acids for mammary protein secretion.

Milk fat percentage has been used as a bioassay for the effectiveness of fiber from NFFS (Armentano and Pereira, 1997). Increasing contents of fiber form NFFS generally increase ruminal pH and acetate to propionate ratios (Armentano and Pereira, 1997). A similar result was observed in this study. Ruminal pH and the ratios of acetate to propionate were positively related (Firkins, 1997) and they were also closely correlated to milk fat percentages (Erdman, 1988). Ruminal pH and ratios of acetate to propionate were not indicative of milk fat percentages in this study, suggesting that changes in milk fat percentage may be not indicative of physical effectiveness of fiber from cassava residues. Increasing rates of particle passage from the rumen with increasing rates of substitution of nonforage NDF from cassava residues for NFC may be an explanation, because of no difference in DMI.

In general, production of 4% FCM as a proportion of intake of NE_L has a tendency to be higher in fat supplemented cows under temperate conditions because the effect of a higher efficiency of energy utilization of fat (Firkins and Eastridge, 1992; Cant et al., 1993). During heat stress, production of 3.5% FCM as a proportion of intake of NE_L was 1.12 for cows without fat supplementation and it was 1.02 for cows with 5% fat supplementation (Knapp and Grummer, 1991). Production of 4% FCM as a proportion of intake of NE_L reported in this study significantly decreased with increasing substitution rates of nonforage NDF from cassava residues for NFC, coupled with adding dietary fat. These results suggest that an excess of circulate acetate from β-oxidation of fat and perhaps uncouple energy may occur in diet with lower contents of NFC for dairy cows in the tropics. Production of milk or 4% FCM decreased with decreasing contents of NFC in diets for dairy cows in the tropics (Kanjanapruthipong et al., 2001). An increase in these production may be not indicative of an increased efficiency of energy utilization *per se* because of differences in DMI as reported by Kanjanapruthipong et al. (2001). Production of milk and 4% FCM as a proportion of intake of NFC reported in this study decreased with increasing nonforage NDF contents from cassava residues. This result suggests that NFC in diets is one of the major problems related to decreased productivity of dairy cows in the tropics.

Increasing substitution rates of nonforage NDF from cassava residues for NFC increased ruminal pH, NH_3-N, acetate to propionate ratio, and *in sacco* fiber digestibility, but decreased milk protein percentage, production of milk and 4% FCM. These results suggest that NFFS is better used as partial replacements for forage NDF in the diet for dairy cows in the tropics.

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