

## Effects of Neutral Detergent Fiber from Rice Straw on Blood Metabolites and Productivity of Dairy Cows in the Tropics

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**ABSTRACT :** This study aimed to assess the effects of neutral detergent fiber (NDF) from rice straw on blood metabolites and productivity of dairy cows in the tropics. Eight Holstein×indigenous (75-87.5% Holstein) were randomly allocated to dietary treatments according to a double 4×4 Latin square design. Contents of roughage NDF from rice straw were 12.8, 14.8, 16.8 and 18.8% dry matter (DM) and concentrate NDF content was 10.2% DM, so that levels of dietary NDF were 23, 25, 27 and 29% DM. Dietary treatments were isonitrogenous and isocaloric diets. The average maximum and minimum temperature humidity index during the experimental period were 85.6 and 76.9, respectively. Plasma glucose ( $p<0.05$ ), dry matter intake and 4% fat corrected milk ( $p<0.01$ ) decreased with increasing contents of roughage NDF from rice straw, while rectal temperature, serum urea, cortisol, low density lipoprotein-cholesterol ( $p<0.05$ ), serum total protein and  $\beta$ -hydroxybutyrate ( $p<0.01$ ) increased. Serum triglyceride, total cholesterol and high density lipoprotein-cholesterol were not affected ( $p>0.05$ ). Decreased rectal temperature and concentrations of serum cortisol were associated with decreasing levels of  $\beta$ -hydroxybutyrate and serum urea, but with increased concentrations of plasma glucose, DMI and 4% fat corrected milk indicating that lactating cows fed lower fiber diets were in lower oxidative stress. Therefore higher intake and metabolic efficiency in dairy cows fed diets lower in roughage NDF from rice straw would be of an advantage in productive systems under tropical conditions. (*Asian-Aust. J. Anim. Sci.* 2006. Vol 19, No. 3 : 356-362)

**Key Words :** Neutral Detergent Fiber, Rice Straw, Dairy Cows, Tropics

### INTRODUCTION

During heat stress, body temperature of cows increases and feed intake, particularly roughage intake, decreases, thereby decreasing milk production (Coppock and West, 1986). Greater maintenance costs associated with heat stress reduce the efficiency of energy utilization by the cows (NRC, 2001), while concentrations of forage neutral detergent fiber (NDF) are negatively related to the dietary energy concentration (Mertens, 1997). Fiber requirements of lactating cows in the tropics, therefore, are critical in the supply of energy requirements because their expenditure may exceed the energy consumed.

Rice straw is the main source of roughage particularly during summer months for dairy cattle in Thailand. Rice straw is lower in quality than oat straw and is more effective to maintain the ruminal pH due to higher chewing number and time in rumination (Goto et al., 2000). Time spent ruminating per unit roughage NDF intake decreases with decreasing roughage NDF contents in diets (Moon et al., 2004). The dietary NDF of 25% and roughage NDF of 60% from paragrass hay have been confirmed to have sufficient effective NDF for dairy cows in the tropics (Kanjanapruthipong et al., 2001). Paragrass hay is generally higher in quality than rice straw, and thus diets containing

rice straw as a source of roughage NDF may contain lower roughage NDF contents than the minimum roughage NDF reported in the literature. However, information is limited on the influence of lowering roughage NDF on metabolic efficiency in dairy cows under tropical conditions. An objective of this study was to evaluate diets containing dietary NDF of 23% DM and roughage NDF of 55% from rice straw on blood metabolites and productivity of dairy cows in the tropics.

### MATERIALS AND METHODS

A study was conducted during summer months from the beginning of March to the end of June. Ambient temperature and relative humidity were recorded with thermograph and hygograph (Classell, London). The temperature humidity index (THI) was calculated following the equation;  $THI = td - (0.55 - 0.55 RH) (td - 58)$ , where  $td$  is the dry bulb temperature ( $^{\circ}F$ ) and  $RH$  is the relative humidity expressed as a decimal (NOAA, 1976).

#### Animal, experimental design and dietary treatments

Eight Holstein×indigenous (75-87.5% Holstein) multiparous dairy cows averaging  $55 \pm 5$  days in milk were randomly allocated to dietary treatments according to a double 4×4 Latin square design with 28-d periods.

Dietary treatments consisted of 12.8, 14.8, 16.8 and 18.8% DM as roughage neutral detergent fiber (NDF) from rice straw and 10.2% DM as concentrate NDF, so that levels of dietary NDF were 23, 25, 27 and 29% DM. Total mixed

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**Table 1.** Ingredient and chemical composition of total mixed rations (TMR) containing different contents of neutral detergent fiber (NDF) from rice straw

Items	TMR containing roughage NDF (%)			
	12.8	14.8	16.8	18.8
Ingredients (% DM)				
Rice straw	18.6	21.4	24.1	26.8
Soybean meal	16	16	16	16
Fullfat soybean meal	11	11	11	11
Sunflower seed meal	2.3	3.3	3.8	4.3
Soysauce residues	5	5	5	5
Mungbean's protein concentrate	1.5	1.5	1.5	1.5
Cassava chips	38.5	33.5	29.5	25.5
Palm oil	-	1.2	2.1	2.9
Molasses	3.8	3.8	3.8	3.8
Urea	0.3	0.3	0.2	0.2
Mineral-vitamin mixture	3	3	3	3
Chemical composition (%)				
Crude protein	16.5	16.5	16.5	16.6
Rumen undegradable protein <sup>1</sup> (% CP)	35.7	36.0	36.2	36.2
Ether extract	3.2	4.4	5.3	6.1
Total neutral detergent fiber	22.8	24.7	27.1	28.8
Total non-fiber carbohydrates	52.4	49.3	45.7	43.0
Total digestible nutrients <sup>1</sup>	72.1	72.2	71.7	71.3
Net energy for lactation <sup>2</sup> (Mcal/kg DM)	1.65	1.65	1.64	1.63

<sup>1</sup> Calculated RUP and TDN. <sup>2</sup> NE<sub>L</sub> (Mcal/kg DM) = (0.0245×TDN)-0.12.

rations (TMR) were isonitrogenous and isocaloric as shown in Table 1. Rice straw was chopped into 2-3 cm lengths for TMR.

### Procedure and data collection

Experimental diets were offered *ad libitum* at 08:00 and 19:00 and were sampled weekly and bulked for later analysis of chemical composition. Within the 28 d experimental periods, the first 4 d was regarded as a transitional period, following 10 d for an adaptation period and within the last 14 d, milk sampling was undertaken. Milk samples of 50 ml were collected at 3 d intervals at consecutive a.m. and p.m. milking in bottles containing 2-Bromo-2-nitro-1, 3-propadiol and stored at 5°C for composition analysis. Over the last 14 d, feed intake, milk yield and rectal temperature were measured daily. Cows were weighed on the day before commencement of the trial and the last day of each period following the morning milking prior to accessing feed and water. Rectal temperature was recorded immediately after each milking with a digital electronic thermometer (Philips HF 365). On the last day, approximately 3 h after morning feeding, blood was collected by jugular venipuncture into serum separation tubes for analysis of lipid profiles, cortisol, urea nitrogen and total protein, into tubes containing sodium fluoride for plasma glucose analysis and into tubes containing potassium EDTA for β-hydroxybutyrate.

### Laboratory and statistical analyses

Crude protein (CP), ether extract (EE), ash and DM

contents of the experimental diets were measured according to the AOAC (1980). Neutral detergent fiber (NDF) and neutral detergent insoluble nitrogen (NDIN) were determined following the method of Van Soest et al. (1991). Total non-fiber carbohydrate (TNFC) is calculated following the equation; TNFC = 100-CP-EE-(NDF-NDIN)-ash. Milk components were measured with MilkoScan (Bentley 2000, USA). Commercial kits (Roche diagnostics, USA) were used in the analysis of serum cholesterol (Cobas integra no. 2055643), high density lipoprotein (HDL) cholesterol (Cobas integra no. 03038637), low density lipoprotein (LDL) cholesterol (Cobas integra no. 03038866), triglyceride (Cobas integra no. 2144620) and cortisol (Elecsys no. 11875116). The VITROS side methods (VITROS 950/950AT, Buckinghamshire, HP7 OHJ England) were used in the analysis of plasma glucose (VITROS GLU slide kit 1), serum urea nitrogen (VITROS BUN/UREA slide kit 1) and serum total protein (VITROS TP slide kit 4). Plasma β-hydroxybutyrate concentrations were assayed using a kinetic enzymatic method (RANBUT kit no. RB1007). Statistical analysis was carried out according to the general linear models procedure of SAS (1989) and the difference between treatments means was analysed by Least Squared Means.

## RESULTS

Animals on the experimental diets remained healthy throughout the experimental periods.

Chemical compositions of the experimental diets are

**Table 2.** Means for environmental conditions during the experimental period

Items	Months			
	March	April	May	Jun
Maximum temperature (°C)	37.4±2.8	38.1±2.1	37.0±3.0	35.1±1.6
Minimum temperature (°C)	24.8±3.5	27.3±2.7	25.7±3.1	24.3±1.8
Maximum relative humidity (%)	90±2.2	92±3.0	95±2.5	94±2.1
Minimum relative humidity (%)	35±9.3	37±8.4	48±8.0	54±7.6
Maximum THI <sup>1</sup>	84.5±5.2	85.7±4.1	86.8±2.8	85.5±3.7
Minimum THI <sup>1</sup>	75.0±6.7	80.0±5.0	77.7±5.4	75.0±3.3

<sup>1</sup> THI: Temperature humidity index.

**Table 3.** Rectal temperature, live weight changes and voluntary intake of total mixed rations (TMR) containing neutral detergent fiber from rice straw

Items	TMR containing roughage NDF (%)				SE
	12.8	14.8	16.8	18.8	
Nutrient intake					
Dry matter (kg/d)	13.95 <sup>A</sup>	13.83 <sup>A</sup>	13.57 <sup>B</sup>	12.39 <sup>C</sup>	0.25
Dry matter (% BW)	2.88 <sup>A</sup>	2.79 <sup>B</sup>	2.76 <sup>B</sup>	2.59 <sup>C</sup>	0.07
Crude protein (kg/d)	2.30 <sup>a</sup>	2.28 <sup>a</sup>	2.24 <sup>a</sup>	2.06 <sup>b</sup>	0.09
Ether extract (kg/d)	0.45 <sup>C</sup>	0.61 <sup>B</sup>	0.72 <sup>A</sup>	0.76 <sup>A</sup>	0.02
Total neutral detergent fiber (kg/d)	3.18	3.42	3.68	3.57	0.32
Total non-fiber carbohydrates (kg/d)	7.31 <sup>A</sup>	6.82 <sup>B</sup>	6.20 <sup>C</sup>	5.33 <sup>D</sup>	0.36
Net energy for lactation (Mcal/d)	23.02 <sup>A</sup>	22.82 <sup>A</sup>	22.25 <sup>B</sup>	20.20 <sup>C</sup>	0.51
Live weight change (kg)					
Initial weight	480	491	488	478	5.60
Final weight	489	499	493	480	5.84
Daily gain	0.32 <sup>a</sup>	0.29 <sup>a</sup>	0.19 <sup>b</sup>	0.07 <sup>c</sup>	0.06
Rectal temperature (°C)					
Morning milking	39.4 <sup>b</sup>	39.4 <sup>b</sup>	39.5 <sup>a,b</sup>	39.6 <sup>a</sup>	0.01
Afternoon milking	39.6 <sup>b</sup>	39.6 <sup>b</sup>	39.8 <sup>a,b</sup>	39.9 <sup>a</sup>	0.02

<sup>a, b and A, B</sup> Mean within a row without a common superscript letter and number differ ( $p < 0.05$ ) and ( $p < 0.01$ ), respectively.

**Table 4.** Blood metabolites in dairy cows fed total mixed rations (TMR) containing different contents of neutral detergent fiber (NDF) from rice straw

Blood metabolites	TMR containing roughage NDF (%)				SE
	12.8	14.8	16.8	18.8	
Serum urea nitrogen (mg/dl)	16.1 <sup>d</sup>	16.7 <sup>c</sup>	17.6 <sup>b</sup>	18.9 <sup>a</sup>	0.60
Serum total protein (g/dl)	7.50 <sup>B</sup>	7.50 <sup>B</sup>	7.85 <sup>A</sup>	7.93 <sup>A</sup>	0.24
Plasma glucose (mg/dl)	59.0 <sup>a</sup>	58.3 <sup>a,b</sup>	57.4 <sup>b,c</sup>	57.1 <sup>c</sup>	1.09
Plasma $\beta$ -hydroxybutyrate (mmol/l)	0.2886 <sup>D</sup>	0.2899 <sup>C</sup>	0.3540 <sup>B</sup>	0.3553 <sup>A</sup>	<0.01
Serum cortisol (nmol/l)	28.5 <sup>c</sup>	29.1 <sup>b,c</sup>	29.6 <sup>b</sup>	34.3 <sup>a</sup>	1.32
Serum triglyceride (mg/dl)	12.6	11.7	12.0	12.7	0.62
Serum cholesterol (mg/dl)	139.7	153.4	148.4	154.5	9.81
Serum HDL-cholesterol (mg/dl)	114.5	128.2	118.2	123.6	8.97
Serum LDL-cholesterol (mg/dl)	20.9 <sup>d</sup>	22.0 <sup>c</sup>	23.1 <sup>b</sup>	24.5 <sup>a</sup>	0.73

<sup>a, b and A, B</sup> Mean within a row without a common superscript letter and number differ ( $p < 0.05$ ) and ( $p < 0.01$ ), respectively.

shown in Table 1. With increasing contents of roughage NDF from rice straw, added palm oil to the diets was necessary, so that the dietary treatments contained a similar calculated energy. Values of analysed CP and calculated rumen undegradable protein of the experimental diets were similar.

Means for environmental conditions during the experimental periods are shown in Table 2. The average maximum and minimum temperature were 36.9 and 25.5, while the average maximum and minimum relative humidity were 92.8 and 43.5%. The combination of high

temperature and relative humidity led to extremely high maximum and minimum THI averaging 85.6 and 76.9.

Dietary treatment effects on nutrient intake, live weight change and rectal temperature are presented in Table 3. Intake of DM ( $p < 0.01$ ), CP ( $p < 0.05$ ), TNFC ( $p < 0.01$ ) and NEL ( $p < 0.01$ ) decreased with increasing roughage NDF contents in the diets, while intake of EE increased. Average daily gain decreased with increasing roughage NDF contents in TMR, whereas rectal temperature increased ( $p < 0.05$ ).

Data for blood metabolites are presented in Table 4.

**Table 5.** Milk compositions and yield in dairy cows fed total mixed rations (TMR) containing different contents of neutral detergent fiber from rice straw

Items	TMR containing roughage NDF (%)				SE
	12.8	14.8	16.8	18.8	
Butter fat					
%	3.88 <sup>C</sup>	3.95 <sup>B,C</sup>	4.02 <sup>A,B</sup>	4.07 <sup>A</sup>	0.10
kg/d	0.74	0.72	0.71	0.68	0.05
Milk protein					
%	3.05 <sup>a</sup>	3.00 <sup>a,b</sup>	2.97 <sup>a,b</sup>	2.95 <sup>b</sup>	0.14
kg/d	0.58 <sup>a</sup>	0.55 <sup>a,b</sup>	0.52 <sup>b,c</sup>	0.49 <sup>c</sup>	0.05
Lactose					
%	4.86	4.84	4.83	4.75	0.18
kg/d	0.92 <sup>a</sup>	0.89 <sup>a,b</sup>	0.85 <sup>b,c</sup>	0.80 <sup>c</sup>	0.07
Minerals					
%	0.70	0.70	0.70	0.69	<0.01
kg/d	0.13	0.13	0.12	0.12	<0.01
Solids-not-fat					
%	8.61 <sup>a</sup>	8.54 <sup>a,b</sup>	8.50 <sup>b,c</sup>	8.39 <sup>c</sup>	0.13
kg/d	1.64 <sup>a</sup>	1.56 <sup>a,b</sup>	1.50 <sup>b</sup>	1.40 <sup>c</sup>	0.06
Total solids					
%	12.49	12.49	12.52	12.46	0.74
kg/d	2.37 <sup>a</sup>	2.29 <sup>a,b</sup>	2.20 <sup>b,c</sup>	2.09 <sup>c</sup>	0.09
Milk yield (kg/d)	19.00 <sup>A</sup>	18.30 <sup>B</sup>	17.60 <sup>C</sup>	16.74 <sup>D</sup>	0.19
Fat corrected milk (4%, kg/d)	18.66 <sup>A</sup>	18.16 <sup>B</sup>	17.65 <sup>C</sup>	16.92 <sup>D</sup>	0.16

<sup>a, b</sup> and <sup>A, B</sup> Mean within a row without a common superscript letter and number differ ( $p < 0.05$ ) and ( $p < 0.01$ ), respectively.

Concentrations of serum urea nitrogen ( $p < 0.05$ ), total protein ( $p < 0.01$ ), plasma  $\beta$ -hydroxybutyrate ( $p < 0.01$ ), serum cortisol ( $p < 0.05$ ) and LDL-cholesterol ( $p < 0.05$ ) increased with increasing roughage NDF contents in TMR. However, concentrations of plasma glucose decreased with increasing roughage NDF contents in TMR ( $p < 0.05$ ) and serum triglycerides, total cholesterol and HDL-Cholesterol were not affected ( $p > 0.05$ ).

Dietary treatment effects on milk composition and yield are presented in Table 5. Concentrations of milk protein and solids-not-fat and yield of protein, lactose, solids-not-fat and total solids decreased with increasing roughage NDF contents in the diets ( $p < 0.05$ ), whereas concentration of butter fat increased ( $p < 0.01$ ). Milk yield and 4% fat corrected milk decreased with increased roughage NDF contents in TMR ( $p < 0.01$ ).

## DISCUSSION

Under heat stress conditions, contents of roughage NDF in diets are critical and problematic in the supply of energy requirements to lactating cows. Lactating cows need to consume more energy to supply their 7 to 25% increased maintenance requirement (NRC, 2001). As contents of roughage NDF are increased, energy density decreases (Mertens, 1997). Energy contents in this study were adjusted by increasing contents of palm oil with increasing contents of roughage NDF from rice straw. Therefore, dietary treatments were isocaloric diets.

The minimum THI values in this study ranging from 75

to 80 exceeded the upper critical point of 72 for optimal productivity, while the maximum THI values ranging from 84.5 to 86.8 exceeded the lower range of danger zone of 78 for survival of Holstein cows (Johnson, 1987). These environmental conditions indicate the extreme heat stress to dairy cows during summer months in Thailand.

Chemical and physical characteristics of diets can have a large effect on DMI. Diets that produce higher proportions of propionic acid can have more hypophagic effects due to a combination of increased osmolality in the reticulo-rumen and specific effects of propionic acid (Allen, 2000). However, a primary appetite control is linked to the induction of acetate burn-off when the nutrients absorbed are imbalanced (Leng et al., 1993). Physical factors that limit intake of higher fiber diets are bulk density, ruminal fill, rate and extent of digestion, passage rate, rumination and total chewing time (Sudweeks et al., 1981). Higher fiber diets produce higher ratios of acetate to propionate in the rumen (Schwartz and Gilchrist, 1975). In this study, DMI decreased with increasing contents of forage NDF from rice straw. This depression can be a combination of the hypophagic effects of acetic acid and physical factors derived from higher fiber contents.

Body temperature rises when heat load exceeds heat dissipation. Increased heat load is associated with increased THI (Zähler et al., 2004), milk production (Purwanto et al., 1990), and feed intake and fiber contents in diets (Reynolds et al., 1991). Under temperate conditions, beef heifers fed pelleted diets (prepared from grinding roughage) with 75% alfafa, 25% concentrate (high fiber) or 25% alfafa, 75%

concentrate (low fiber) produced 2.9 to 3.9 MJ/d more heat for the higher fiber diets than for the lower diets, but high intake heifers produced 17.5 to 18.4 MJ/d more heat than low intake heifers (Reynolds et al., 1991). The values of the fiber effect are likely under estimated due to the reduction in fiber length, which is not generally used in lactating cows. Under heat stress conditions, milk temperature and DMI in mid lactating cows declined with increasing roughage NDF (West et al., 1999). However, lactating cows fed higher fiber diets decreased DMI and had higher body temperature of 0.28°C than those fed lower fiber diets (Scott and Grant, 1960). With increasing roughage NDF from rice straw, a similar result was also observed. These results suggest that the heat production from the higher fiber diets can seriously contribute to heat load during extreme heat stress in dairy cows.

Blood urea has been used as an indicator of the balance between the availability of dietary degradable protein (RDP) and fermentable carbohydrates in the rumen (Firkins, 1996) and of protein metabolism and status in dairy cows (Roseler et al., 1993). NH<sub>3</sub> that is synthesised to urea by the liver can originate from an excess of dietary RDP and deamination of absorbed protein to yield energy substrates (Oldham, 1984). In this study, TMR contained similar levels of rumen undegradable protein as recommended by NRC (1988). Increased concentrations of serum urea with increasing roughage NDF from rice straw, coupled with decreasing DMI and 4% fat corrected milk suggested that there were increased energy maintenance requirements and thus increased protein being metabolized to meet energy requirements.

Blood protein has been used as an indicator of nutritional status. Surprisingly serum total protein, in this study, increased with increasing contents of roughage NDF from rice straw but it was within the range reported in literature (Logue et al., 1999). The reason for the higher serum total protein is not known. The possible explanation is that rates of protein catabolism might be higher than those of protein anabolism. This claim might be supported by higher concentration of serum urea while lower milk protein secretion with increased contents of roughage NDF from rice straw.

Blood  $\beta$ -hydroxybutyrate can be synthesized by the ruminal epithelium from butyrate via hydroxymethylglutaryl-CoA (Baird et al., 1970) and by the liver from acetyl-CoA (McCarry and Foster, 1980). In fasted ruminants, fatty acids are the major precursor for  $\beta$ -hydroxybutyrate (Leng and West, 1969), due possibly to the depletion of the mitochondrial oxaloacetate pools and thus restricting complete oxidation of acetyl-CoA (McCarry and Foster, 1980). Energy deficit is indicated by the levels of  $\beta$ -hydroxybutyrate above 0.7 mmol/l (Ward and Parker, 1999). The figures of  $\beta$ -hydroxybutyrate reported in this study

were not indicative of energy deficit because body weight was not lost. However, increased concentrations of  $\beta$ -hydroxybutyrate with increasing roughage NDF from rice straw, coupled with added palm oil, could be due to an decreased supply of blood glucose resulting in decreased availability of the mitochondrial oxaloacetate and thus increased incomplete extrahepatic oxidation of acetyl-CoA to CO<sub>2</sub>.

Propionic acid is the major precursor for hepatic glucose production (Danfaer et al., 1995). Higher fiber diets produce lower proportions of propionic acid in the rumen (Schwarz and Gilchrist, 1975). Decreased plasma glucose with increasing roughage NDF from rice straw in this study was probably due to reduced gluconeogenesis from lowering proportions of propionic acid produced in the rumen.

Characteristically cortisol levels rise during hypoglycaemia (Bloom et al., 1975), resulting in increased glucose production (Brockman and Laarveld, 1986). An increase in cortisol concentrations is associated with decreased intakes of hay (Sekine et al., 2003), roughage NDF and DM (West et al., 1999). A similar result was also observed in this study. Higher DMI, lower concentrations of  $\beta$ -hydroxybutyrate and a more positive energy balance had a lower reactive oxygen species production across the lactation (Poelarends, et al., 1999). In this study, increased concentrations of serum cortisol associated with increased levels of  $\beta$ -hydroxybutyrate, but with decreased concentrations of plasma glucose, DMI and 4% fat corrected milk, suggest that lactating cows fed higher fiber diets under extreme heat stress were in higher oxidative stress.

Increased concentrations of blood cholesterol in cattle reflect increased absorption of fatty acids packaged in the lipoproteins from the small intestine (Staples et al., 1998), the major site of *de novo* cholesterol synthesis in ruminants (Noble, 1981). Increased forage to grain ratios fed to lactating cows do not elevate plasma cholesterol (Grummer and Carrol, 1988). A similar result was also reported in this study. With no exceptions of roughage NDF levels from rice straw fed to lactating cows, high density lipoprotein (HDL) cholesterol represented >80% of serum cholesterol, consistent with the level reported in literature (Banchart, 1993). Surprisingly, concentrations of low density lipoprotein (LDL) cholesterol increased in lactating cows fed TMR with increasing contents of roughage NDF from rice straw. The reason for this increment is not known. Increased acetyl-CoA in lactation in cows fed TMR with increasing contents of roughage NDF from rice straw (as discussed above) might result in stimulation activity of  $\beta$ -hydroxymethylglutaryl-CoA synthase but inhibiting activity of  $\beta$ -hydroxymethylglutaryl-CoA reductase. This depression may increase cholesterol acyltransferase activity

and decrease synthesis of LDL receptors (Grummer and Carroll, 1988).

Under heat stress, an increase in metabolic efficiency is an advantage in reducing heat production (Coppock and West, 1986). Cows with lower feed intake and milk yield produced much less heat than cows with higher feed intake and milk yield (Purwanto et al., 1990). As contents of roughage NDF are increased, DMI of dairy cows decreases (West et al., 1999; Kanjanapruthipong et al., 2001). However, with similar DMI, lactating cows fed TMR containing 18% roughage NDF had lower feed intake per meal (1.22 vs. 1.51 kg/meal), higher numbers of meals per day (21.0 vs. 16.6 meals/d) and produced lower 4% fat corrected milk (33 vs. 35 kg/d) than cows fed TMR containing 12% roughage NDF (Halachmi et al., 2004). This lower productivity is probably due to higher maintenance costs (Baldwin et al., 1985). In this study, lactating cows fed TMR with increasing contents of roughage NDF from rice straw decreased both DMI and 4% fat corrected milk. These results suggest that the higher maintenance cost can seriously impair the efficiency of energy utilization of higher roughage NDF diets as compared to lower roughage NDF diets, although the magnitude of the maintenance cost is not large (Baldwin et al., 1985).

Decreased rectal temperature and concentrations of serum cortisol associated with decreasing levels of  $\beta$ -hydroxybutyrate and serum urea, but with increased concentrations of plasma glucose, DMI and 4% fat corrected milk, indicated that lactating cows fed lower fiber diets were in lower oxidative stress. Under heat stress, an increase in both intake and metabolic efficiency in dairy cows fed diets containing lower roughage NDF from rice straw would be of an advantage in productive systems.

## REFERENCES

- Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating cattle. *J. Dairy Sci.* 83:1598-1624.
- Association of Official Analytical Chemist. 1980. *Official Methods of Analysis*. 13<sup>th</sup> Ed. AOAC, Washington, DC.
- Baird, G. D., K. G. Hibbit and J. Lee. 1970. Enzymes involved in acetoacetate formation in various tissues. *Biochem. J.* 117:703-709.
- Baldwin, B. R., N. E. Forsberg and C. Y. Hu. 1985. Potential for altering energy partition in the lactating cow. *J. Dairy Sci.* 68:3394-3402.
- Bauchart, D. 1993. Lipid absorption and transport in ruminants. *J. Dairy Sci.* 76:3864-3881.
- Bloom, S. R., A. V. Edwards, R. N. Hardy, K. W. Malinowska and M. Silver. 1975. Endocrine responses to hypoglycaemia in the calf. *J. Physiol. (London)*, 244:783-803.
- Brockman, R. P. and B. Laarveld. 1986. Hormonal regulation of metabolism in ruminants: A review *Livest. Prod. Sci.* 14:313-334.
- Coppock, C. E. and J. W. West. 1986. Nutritional adjustments to reduce heat stress in lactating dairy cows. In: *Proc. Georgia Nutr. Conf. Feed Industry*. Atlanta. GA. Univ. Georgia, Athens. GA. pp. 19-26.
- Danfaer, A., V. Tetens and N. Agergaard. 1995. Review and an experimental study on the physiological and quantitative aspects of gluconeogenesis in lactating ruminants. *Comp. Biochem. Physiol.* 111B:201-210.
- Firkins, J. L. 1996. Maximizing microbial protein synthesis in the rumen. *J. Nutr.* 126:1347s-1354s.
- Goto, M., T. Morio, E. Kojima, Y. Nagano, Y. Yamada, A. Horigane and H. Yamada. 2000. Characteristics of digestion dynamics of rice and oat straw relating to microbial digestion in the rumen of sheep given high-concentrate diets. *Asian-Aust. J. Anim. Sci.* 13(9):1219-1227.
- Grummer, R. R. and D. J. Carroll. 1988. A review of lipoprotein cholesterol metabolism: Importance to ovarian function. *J. Anim. Sci.* 66:3160-3173.
- Halachmi, I., E. Maltz, N. Livshin, A. Antler, D. Ben-Ghedalia and J. Miron. 2004. Effects of replacing roughage with soy hulls on feeding behavior and milk production of dairy cows under hot weather conditions. *J. Dairy Sci.* 87:2230-2238.
- Johnson, H. D. 1987. Bioclimates and livestock. In: *Bioclimatology and the Adaptation of Livestock* (Ed. H. D. Johnson). Elsevier Science publishers, Amsterdam, Netherlands. pp. 3-16.
- Kanjanapruthipong, J., N. Buatong and S. Buaphan. 2001. Effects of roughage neutral detergent fiber on dairy performance under tropical conditions. *Asian-Aust. J. Anim. Sci.* 14(10):1400-1404.
- Leng, R. A. and C. E. West. 1969. Contribution of acetate, butyrate, palmitate, stearate and oleate to ketone body synthesis in sheep. *Rev. Vet. Sci.* 10:57-63.
- Leng, R. A., N. Jessop and J. Kanjanapruthipong. 1993. Control of feed intake and the efficiency of utilization of feed by ruminants. In: *Recent Advances in Animal Nutrition in Australia*. (Ed. D. J. Farrell). University of New England, Armidale, Australia, pp. 70-88.
- Logue, D. N., R. J. Berry, J. E. offer, S. J. Chaplin, W. M. Crawshaw, K. A. Leach, P. J. H. Ball and J. Bax. 1999. Consequences of "metabolic load" of lameness and diseases. In: *Metabolic Stress in Dairy Cows*. (Ed. J. D. Oldham, G. Simm, A. F. Green, B. L. Nielsen, J. E. Pryce and T. L. J. Lawrence). BSAS. Edinburgh. pp. 21-26.
- McGarry, J. D. and D. W. Foster. 1980. Regulation of hepatic fatty acid oxidation and ketone body production. *Annu. Rev. Biochem.* 49:395-420.
- Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. *J. Dairy Sci.* 80:1463-1481.
- Moon, Y. H., S. C. Lee and Sung S. Lee. 2004. Effects of neutral detergent fiber concentration and particle size of the diet on chewing activities of dairy cows. *Asian-Aust. J. Anim. Sci.* 17(11):1535-1540.
- National Oceanic and Atmospheric Administration. 1976. *Livestock hot weather stress*. US Dept. Commerce. National Weather Serv. Central Reg., Operations Manual Lett. C-31-36.
- National Research Council. 1988. *Nutrient Requirement of Dairy*

- Cattle. 6<sup>th</sup> Rev. Ed. National Academic Press, Washington. DC. p. 157.
- National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7<sup>th</sup> Rev. Ed. National Academic Press, Washington. DC. p. 360.
- Noble, R. C. 1981. Digestion, absorption, and transport of lipids in ruminant animals. In: *Lipid Metabolism in Ruminant Animals*. W. W. Christie Ed. Pergamon Press, Oxford. pp. 57-93.
- Oldham, J. D. 1984. Protein-energy interrelationships in dairy cows. *J. Dairy Sci.* 67:1090-1114.
- Poelarends, J. J., L. Kruijt, H. van der Gaast and R. F. Veerkamp. 1999. Effect of milk yield and energy balance on neutrophil function in dairy cows. In: *metabolic Stress in Dairy Cows*. (Ed. J. D. Oldham, G. Simm, A. F. Groen, B. L. Nielsen, J. E. Pryce and T. L. J. Lawrence). BSAS Edinburgh. pp. 203-208.
- Purwanto, B. P., Y. Abo, R. Sakamoto, F. Furumoto and S. Yamamoto. 1990. Diurnal patterns of heat production and heart rate under thermoneutral conditions in Holstein Friesian cows differing in milk production. *J. Agric. Sci. (Camb)*. 114:139-142.
- Reynolds, C. K., H. F. Tyrrell and P. J. Reynolds. 1991. Effects of diet forage-to-concentrate ratio and intake on energy metabolism in growing beef heifers: whole body energy and nitrogen balance and visceral heat production. *J. Nutr.* 121:994-1003.
- Roseler, D. K., J. D. Ferguson, C. J. Sniffen and J. Herrena. 1993. Dietary protein degradability effects on plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. *J. Dairy Sci.* 76:525-534.
- SAS/STAT<sup>®</sup> User's Guide, Version 6, 4<sup>th</sup> Edition. Vol 2. 1989. SAS Inst., Cary, NC.
- Schwartz, H. M. and F. M. C. Gilchrist. 1975. Microbial interactions with the diet and the host animal. In: *Digestion and Metabolism in Ruminant*. (Ed. I. W. McDonald and A. C. I. Warner). The University of New England Publishing Unit. NSW. Australia. pp. 165-179.
- Sekine, J., M. A. M. Abdel-Rahman, A. E. A. Ismail, R. M. Dosoky, H. E. M. Kamel and M. Hishinuma. 2003. Effect of three different species of hay on dry-matter intake and serum cortisol of ewes. *Asian-Aust. J. Anim. Sci.* 16(9):1239-1396.
- Shibata, M. and A. Mukai. 1979. Effect of heat stress and hay-concentrate rations on milk production, heat production and some physiological responses of lactating cows. *Jpn. J. Zootech. Sci.* 50:630-637.
- Staples, C. R., J. M. Burke and W. W. Thatcher. 1998. Influence of supplemental fats on reproductive tissues and performance of lactation cows. *J. Dairy Sci.* 81:856-871.
- Stott, G. H. and E. G. Moody. 1960. Tolerance of dairy cows to high climatic temperatures on low roughage ration. *J. Dairy Sci.* 43:871(Abstr.).
- Sudweeks, E. M., L. O. Ely, D. R. Mertens and L. R. Sisk. 1981. Assessing minimum amounts and form of roughages in ruminant diets: Roughage value index system. *J. Anim. Sci.* 53:1406-1411.
- Van Soest, P. J., J. B. Robertson and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583-3597.
- Ward, W. R. and C. S. Parker. 1999. Field evidence of metabolic stress in dairy cows ? In : *Metabolic Stress in Dairy Cows*. (Ed. J. D. Oldham, G. Simm, A. F. Green, B. L. Nielsen, J. E. Pryce and T. L. J. Lawrence). BSAS. Edinburgh. pp. 21-26.
- West, J. W., G. M. Hill, J. M. Fernandez, P. Mandevbu and B. G. Mullinix. 1999. Effects of dietary fiber on intake, milk yield, and digestion by lactation dairy cows during cool or hot, humid weather. *J. Dairy Sci.* 82:2455-2465.
- Zähner, M., L. Schrader, R. Hauser, M. Keck, W. Langhans and B. Wechsler. 2004. The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables. *Anim. Sci.* 78:139-147.