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Feeding Value of Whole Crop Rice Silage for Lactating Dairy Cows under High Ambient Temperature

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Abstract

Whole crop rice silage (WCRS) has recently attracted attention as forage for dairy cows. The nutritive value of WCRS (Forage rice cultivar: Nishiaoba) was examined by a balance trial (Experiment 1). The forage rice was harvested and ensiled in two ways (round-baled silage and container silage). On a dry basis, the contents of metabolizable energy, crude protein and neutral detergent fiber in WCRS were 1.7 Mcal/kg, 6.3% and 47.4%, respectively in round-baled silage, and 2.0 Mcal/kg, 7.4% and 46.6%, respectively in container silage. The feed value of Nishiaoba WCRS for lactating dairy cows under high ambient temperature was also investigated (Experiment 2). The daily milk yields of cows fed WCRS as part of their total mixed ration (rice TMR) and oats hay as part of their TMR (oats TMR) were 29.7 and 30.1 kg, respectively. The dry matter intakes (DMI) of cows when fed the rice TMR and oats TMR were 18.5 and 19.7 kg, respectively. There were no significant differences in DMI, milk yield and composition between cows fed the rice TMR and the oats TMR. The energy retention of the cows fed the rice TMR was significantly lower than that of the cows fed the oats TMR ($P < 0.05$). WCRS can be given, with other adequate roughages and concentrates, to dairy cows that produce 30 kg of milk daily, even under high ambient temperature.

Discipline: Animal industry
Additional key words: energy metabolism, milk yield

Introduction

The self-sufficiency rate of livestock feed in Japan is less than 25% on a calorie basis, and huge amounts of feed, including concentrates and roughage, is imported from overseas. Domestic roughage production is decreasing year by year and excess application of manure to fields is causing environmental damage. Rice consumption has also been decreasing, and many paddy fields have been reduced in size or used for producing other crops. The cultivation of forage crops in disused paddy fields is considered to be one way of maintaining the paddy fields and increasing roughage production.

During the last decade, new rice varieties for whole crop rice silage (WCRS) have been developed[13] and used as roughage for ruminants in Japan[7,11]. Recently, interest in WCRS also has increased in countries of East Asia such as China and South Korea. However, information on the nutritive value, and especially the metabolizable energy, of WCRS, and on the energy metabolism of cows fed WCRS, is limited. Furthermore, heat stress in dairy cows, especially in high yielding cows, results in a dramatic reduction in roughage intake and rumination has a negative impact on milk production[3,9]. Therefore, high quality roughage is required for heat-stressed dairy cows, and there is a need to determine whether WCRS can be used for these cows.

The present study was undertaken to investigate the

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feeding value of WCRS for dairy cows under high ambient temperature. First, we evaluated the nutritive value of WCRS (Nishiaoba) that was harvested and ensiled in two ways, round- baled silage and container silage (Experiment 1). Second, we investigated the effects of feeding WCRS on the milk production and energy metabolism of dairy cows under high ambient temperature (Experiment 2).

Materials and methods

1. Nutritive value of WCRS (Nishiaoba) (Experiment 1)

The variety, Nishiaoba, which was developed for whole crop silage for the first time by the National Agricultural Research Center for Kyushu Okinawa Region[18] was used in this experiment. Forage rice at the yellow ripe stage was harvested and ensiled for either round-baled silage or container silage as a model for bunker silage. To prepare the round-baled silage, forage rice was harvested by commercial mower, wilted for one day and then round-baled. After 4 months the silage was chopped with a round-bale cutter set to give 6-cm lengths, to feed dairy cows. To prepare the container silage, forage rice was harvested and cut into 4 cm-lengths, immediately ensiled in a silo container of 2 m^3 volume, and fed to the dairy cows after 4 months.

Four dry and non-pregnant Holstein cows were assigned to round-baled silage or container silage in a 2 × 2 crossover experimental design. This experiment consisted of two 14-day experimental periods, each comprising a 9-day treatment-adaptation period and a 5-day sampling period. During the experimental period, the cows were housed individually in open- circuit respiration chambers (18ºC; relative humidity, 60%) to determine apparent digestibility and measure the respiratory exchanges (5 days of collection). The details of the respiration trial are described in the report of Mukai et al.[10]. All cows were fed silage to meet the digestible energy (DE) requirement for maintenance recommended by the Japanese feeding standard for dairy cattle[1] and they were given 1.0 kg of soybean meal (dehulled, solvent extract) daily. Water and mineral blocks were available at all times. The WCRS and soybean meal were offered at 0830 and 1600 to both treatment groups. Feed refusals, feces and urine were collected daily at 1030 and were bulked for analysis.

2. The effects of WCRS (Nishiaoba) on milk production under high ambient temperature (Experiment 2)

Forage rice (Nishiaoba: Yellow ripe stage) was harvested and ensiled for round-baled silage. After 4 months the silage was chopped with a round-bale cutter set to give 2-cm lengths, to feed dairy cows. Four lactating Holstein cows in mid-lactation were assigned to a total mixed ration (TMR) containing WCRS (rice TMR) or TMR containing oats hay (oats TMR) instead of WCRS in a 2 × 2 crossover experimental design as described in experiment 1. The nutritive values of the WCRS and oats hay used in this experiment were, respectively, 5.9% and 5.0% crude protein (CP), 48.1% and 54.0% neutral detergent fiber (NDF), and 30.8% and 29.3% acid detergent fiber (ADF). The proportion of grain in the WCRS was 27.0%. All cows were fed the experimental diet (Table 1) four times a day, at 0830, 1030, 1600, and 1800, ad libitum. During the experimental period, the cows were housed individually in open circuit respiration chambers (28 ºC; relative humidity: 60%). The cows were milked twice daily, at 0830 and 1800, and milk samples were collected at each milking for compositional analysis. Feces and urine were collected daily at 1030 and were bulked for analysis.

Table 1. Ingredients and chemical composition as DM basis of experimental diets (Experiment 2)

	Oats TMR (%)	Rice TMR (%)
Oats hay	20.0	–
Whole crop rice silage	–	20.0
Sudangrass hay	12.0	12.0
Alfalfa hay cube	5.0	5.0
Beet pulp	3.0	3.0
Corn	20.0	20.0
Barley	13.0	13.0
Wheat bran	5.0	5.0
Soybean meal	11.0	11.0
Soybean hulls	5.0	5.0
Cotton seed	3.0	3.0
Fatty acid calcium salt	1.0	1.0
Vitamin & Mineral mix	2.0	2.0
TDN	72.9	72.1
CP	14.1	14.6
EE	3.0	3.0
CF	16.7	15.8
NFE	59.9	57.3
CA	6.2	9.1
NDF	34.6	33.0
ADF	20.0	19.5
GE (Mca/kg)	4.47	4.36

TDN was estimated from the Standard Tables of Feed Composition in Japan (2001).
TDN: total digestible nutrients, CP: crude protein, EE: ether extract, CF: crude fiber, NFE: nitrogen free extract, CA: crude ash, NDF: neutral detergent fiber, ADF: acid detergent fiber, GE: gross energy.

Blood samples were obtained at 1030 on the last day of the collection period.

Experiments 1 and 2 were carried out in accordance with the guide for care and use of laboratory animals for National Agricultural Research Center for Kyushu Okinawa Region.

3. Laboratory analysis

The organic acid content of each silage was measured by HPLC using BTB post labeling methods (column: Shodex Ionpak C-811; detector: UV 445 nm; eluent: 3 mM $HClO_4$; 1.5 ml/min; reagent: 0.2 mM Bromothymol blue, 8 mM Na_2HPO_4, 2 mM NaOH, 1.5 ml/min). The dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), and crude ash (CA) contents of the feed were determined by standard procedures[2]. The NDF and ADF contents of the feed were analyzed according to the procedure of Van Soest et al.[19]. Milk samples were analyzed for fat, protein, lactose, and solids-not-fat (SNF) contents by using a Foss Milko-Scan 133B (N. Foss Electric, Hillerød, Denmark).

The gross energy contents of the feed, refusals, feces, and urine were measured with an adiabatic bomb calorimeter (CA-4P, Shimazu Co., Kyoto, Japan). The nitrogen content of urine samples was determined by a standard procedure[2]. The digestibility of soybean meal (dehulled, solvent extract) was adopted from the values in the Standard Tables of Feed Composition in Japan[12]. The gross energy of milk (E:kcal) was determined by the equation of Sekine et al.[15]: E = 81.9 FAT (%) + 47.5 SNF (%) +1.2. Total heat production (HP) was calculated by indirect calorimetry from the respiration exchanges by the equation of Brower[4]: HP (kcal/day) = $3.866\ O_2 + 1.2\ CO_2 - 1.431\ N - 0.518\ CH_4$, where gas volume (L/day) is expressed at standard conditions and N (g/day) is the urinary nitrogen content.

The total protein (TP), albumin, urea nitrogen (UN), nonesterified fatty acid (NEFA), and glucose in plasma were measured with an automatic analyzer (7080 Clinical Analyzer, Hitachi Co., Tokyo, Japan).

4. Statistical analysis

The data were analyzed statistically according to the crossover design by using the general linear model procedure of SAS[14], with cows, periods and diets as the effects.

Results and discussion

1. Nutritive value of WCRS (Experiment 1)

The chemical composition and fermentation quality is shown in Table 2. The dry matter of round–baled silage was significantly higher ($P < 0.01$) than that of container silage. There were no significant differences in the fermentation quality between round-baled silage and container silage. The ADF content in round-baled silage was significantly higher ($P < 0.01$) than that of container silage. The Mg content in round-baled silage was significantly lower ($P < 0.05$) than that of container silage. There were no apparent differences in the other chemical compositions between round-baled silage and container silage.

The dry matter intake (DMI) and energy balance of cows fed the round-baled silage and container silage are shown in Table 3. There were no significant differences in DMI between cows fed round-baled silage and container silage. The energy excretions to feces and energy excretion to feces expressed as a percentage of gross energy intake of cows fed round-baled silage tended to be higher ($P < 0.10$) than those fed container silage. The N and CF digestibility of cows fed round-baled silage were significantly lower ($P < 0.05$) than those fed container silage (Table 4). The total energy excretions to methane when the cows were fed round-baled silage were significantly ($P < 0.10$) higher than when they were fed container silage. There were no significant differences in the partition of methane expressed as a percentage of gross energy intake between cows fed round-baled silage and container silage. Roughage intake was 0.6 kg greater

Table 2. Chemical composition and fermentation quality as DM basis of WCRS (Experiment 1)

	Round-baled	Container	SE
CP (%)	6.3	7.4	0.3
EE (%)	1.8	1.9	0.2
CF (%)	24.3	25.3	0.3
NFE (%)	53.7	51.0	0.8
CA (%)	13.8	14.4	0.8
NDF (%)	47.4	46.6	0.3
ADF (%)	30.4	29.2	0.1 **
GE (Mcal/kg)	4.0	4.0	0.6
K (%)	1.86	1.98	0.17
P (%)	0.14	0.17	0.01
Ca (%)	0.15	0.16	0.02
Mg (%)	0.11	0.14	0.0 *
DM (%)	49.6	34.0	0.3 **
pH	5.1	5.0	0.1
LA (g/kg)	8.0	7.3	1.91
AA + PA (g/kg)	11.3	15.4	1.9
BA (g/kg)	6.5	7.5	1.5

*: $P < 0.05$, **: $P < 0.01$.
LA: lactic acid, AA: acetic acid, PA: propionic acid, BA: butyric acid.

when cows were fed round-baled silage than when cows were fed container silage, which might have had an effect on the greater methane excretion of cows fed round-baled silage[16].

The DE and ME contents of the container silage were higher than those of the round-baled silage. The proportions of grain (by weight) in the round-baled silage and container silage that the dry cows received in the balance

Table 3. Energy balance of dry cow and DE, ME contents of WCRS (Experiment 1)

	Round-baled	Container	SE
Body weight (kg)	697.1	682.1	5.8
DMI (DMkg/day)			
WCRS	7.9	7.3	0.2
Soybean meal	1.0	1.0	–
Total intake	8.9	8.3	0.2
Total energy intake (Mcal/day)	36.1	33.7	0.8
Energy loss (Mcal/day)			
Feces	15.2	12.6	0.5 +
Urine	1.0	1.0	0.0
Methane	3.0	2.7	0.1 +
Heat production	16.9	16.6	0.3
Energy retention (Mcal/day)	0.0	0.8	0.4
Energy partition expressed as a percentage of total energy intake (%)			
Energy loss			
Feces	42.0	37.3	0.9 +
Urine	2.8	3.0	0.2
Methane	8.3	8.1	0.1
Heat production	47.0	49.3	0.6
Energy retention	0.0	2.3	1.0
Nutritive value of WCRS			
DE of WCRS (Mcal/kg)	2.2	2.4	0.0 +
ME of WCRS (Mcal/kg)	1.7	2.0	0.0 *

+: $P < 0.10$, *: $P < 0.05$.
DMI: dry matter intake, DE: digestible energy, ME: metabolizable energy.

Table 4. Digestibility of dry cow fed WCRS (Experiment 1)

	Round-baled	Container	SE
N (%)	28.3	47.6	1.9 *
EE (%)	35.4	49.7	4.3
CF (%)	43.3	49.7	0.6 *
NFE (%)	65.8	68.2	0.8

*: $P < 0.05$.

Table 5. The proportion of grain in WCRS and grain loss to feces of dry cow (%) (Experiment 1)

	Round-baled	Container	SE
Grain proportion in WCRS	24.3	30.8	1.8
Grain loss to feces	7.7	5.6	0.3 *

*: $P < 0.05$.
Grain loss to feces is expressed as a percentage of grain intake.

trial were 24.3% and 30.8%, respectively (Table 5). The proportion of grain loss to feces when cows were fed round-baled silage was significantly higher ($P < 0.05$) than the loss when cows were fed container silage. Islam et al.[8] reported that the nutritive value of grain is higher than that of the leaf or stem. In addition, the length of the silages cows are fed in the balance trials can partially have an effect on grain digestibility[11], this might have been the case in our experiment. Therefore, the nutritional value of the container silage was higher than that of the round-baled silage.

The DE and ME contents were 2.2 and 1.7 Mcal/kg, respectively, in the round-baled silage and 2.4 and 2.0 Mcal/kg in the container silage. The nutritive value of WCRS seemed to be almost the same as that of imported oats hay (DE: 2.3 to 2.5 Mcal/kg, ME: 1.9 to 2.0 Mcal/kg) as cited by the Standard Tables of Feed Composition in Japan[12]. Imported oats hay is used widely for dairy cows in Japan. Therefore, the feeding value of WCRS for lactating dairy cows compared to oats hay under high ambient temperature was investigated in Experiment 2.

2. Effects of WCRS on milk production under high ambient temperature (Experiment 2)

Round-baled silage was used in this experiment because this type of WCRS is used widely in Japan. There was no significant difference in DMI between when the cows were fed rice TMR and when they were fed oats TMR (Table 6). Milk yields when the cows were fed rice TMR and oats TMR were 29.7 and 30.1 kg, respectively (Table 6). Some researchers have reported that milk yield does not differ between cows fed WCRS and cows fed timothy hay[5,6] and sudangrass hay[17]. There were no significant differences in milk composition between rice TMR and oats TMR.

The energy balance of cows fed rice TMR or oats TMR is shown in Table 7. There were no significant differences in energy intake, energy loss to feces, urine,

Table 6. TMR intake and milk production of lactating cows (Experiment 2)

	Oats TMR	Rice TMR	SE
Body weight (kg)	644.6	635.9	4.3
DMI (kg/day)	19.7	18.5	0.6
Milk yield (kg/day)	30.1	29.7	0.5
Milk fat (%)	4.3	4.3	0.1
Milk protein (%)	3.3	3.3	0.0
Milk SNF (%)	9.0	9.0	0.1

DMI: dry matter intake.

Table 7. Energy balance of lactating cows (Experiment 2)

	Oats TMR	Rice TMR	SE
Energy intake (Mcal/day)	87.9	81.1	2.4
Energy loss (Mcal/day)			
Milk	23.3	23.1	0.2
Feces	28.1	26.3	1.4
Urine	1.6	1.5	0.1
Methane	4.5	4.7	0.1
Heat Production	28.0	27.1	0.6
Retention (Mcal/day)	2.3	–1.6	0.5 *
Energy partition expressed as a percentage of energy intake (%)			
Energy loss			
Milk	26.7	28.4	0.8
Feces	31.7	32.5	0.7
Urine	1.8	1.8	0.1
Methane	5.2	5.9	0.3
Heat production	32.0	33.5	0.4
Energy Retention	2.6	–2.1	0.7 *

*: $P < 0.05$.

methane and milk secretion, or heat production between rice TMR and oats TMR. The energy utilization of WCRS by dairy cows seemed to be almost equal to that of oats hay. Ishida et al.[6] also reported that energy metabolizability was not significantly different between cows fed 40% of WCRS and 40% of timothy hay as a component of TMR. However, energy retention of cows fed rice TMR was significantly lower ($P < 0.05$) than that of cows fed oats TMR in this experiment. The energy intake of the cows fed rice TMR was 6.8 Mcal lower than those that were fed oats TMR and this might have resulted in the decrease in energy retention of the cows fed rice TMR.

There was no significant difference in N digestibility between rice TMR (65.6%) and oats TMR (64.1%). However, the nitrogen excretion to urine when cows were fed rice TMR (112.3±1.1 g/day) tended to be higher ($P < 0.10$) than when they were given oats TMR (106.3±1.1 g/day). The plasma TP of the cows fed rice TMR tended to be lower than the cows fed oats TMR ($P < 0.10$) (Table 8). The plasma UN of the cows fed rice TMR tended to be higher than the cows fed oats TMR ($P < 0.10$), this indicates that there was an increase of ammonia production in the rumen. These results suggested that the nitrogen utilization of the cows when fed rice TMR seemed to be less than when they were fed oats TMR. Takahashi et al.[17] reported that plasma UN levels were significantly higher in cows receiving WCRS than in cows receiving sudangrass hay and plasma essential free amino acid levels were lower in cows receiving WCRS. In this experiment, the NFE and GE contents of WCRS were lower than those of oats hay, resulting in a decrease in nitrogen utilization and energy retention when the cows were fed rice TMR. Therefore, supplementation of the energy source is required when WCRS is used instead of oats hay for dairy cows producing 30 kg of milk daily. In addition, the excretion rate of rice grain in the cows when fed rice TMR was 49.0%, which was higher than in the report (30.2%) of Hosoda et al.[5]. Therefore it is necessary to improve the digestibility of the rice grain.

Table 8. Plasma metabolites of lactating cows (Experiment 2)

	Oats TMR	Rice TMR	SE
NEFA (mEq/l)	0.11	0.2	0.04
Glucose (mg/dl)	65.3	64.5	2.46
TP (g/dl)	7.28	7.05	0.05+
Albumin (g/dl)	4.08	4.05	0.04
UN (mg/dl)	14.6	18.5	0.72+

+: $P < 0.10$.
NEFA: non-esterified fatty acid, TP: total protein, UN: urea nitrogen.

In conclusion, on a dry basis the contents of metabolizable energy, crude protein and NDF in WCRS from round-baled silage were 1.7 Mcal/kg, 6.3%, and 47.4%, respectively. In WCRS from container silage they were 2.0 Mcal/kg, 7.4% and 46.6%. There were no differences in milk yield, composition and efficiency of milk production between cows fed rice TMR and those fed oats TMR under high ambient temperature. The energy retention of the cows fed rice TMR was lower than those fed oats TMR. These results suggested that, with energy supplementation, WCRS silage can be used for dairy cows producing 30 kg of milk daily even under high ambient temperatures.

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