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Effect of Feeding Total Mixed Fiber on Feed Intake and Milk Production in Mid-Lactating Dairy Cows

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ABSTRACT

This study determined the effect of total mixed fiber (TMF) from agro-industrial by-products as a roughage source for lactating dairy cows on digestibility, milk yield and milk composition. A completely randomized design was employed on fifteen 87.5% Holstein Friesian crossbreds in mid lactation. All cows had an average initial body weight of 416.03±34.66 kg and 115.20±20.32 days in milk. Cows were randomly allocated to three treatments (T1 = cows fed pineapple peel silage with rice straw (PS) *ad lib*; T2 = cows fed TMF *ad lib*; T3 = cows fed TMF *ad lib* and 1 kg less of concentrate (TMF-1). All cows were fed with 20.35% crude protein (CP) of commercial concentrate feed. The results revealed that the total dry matter intake of the PS group was higher than those of cows fed with TMF and TMF-1, respectively ($P < 0.05$). The apparent digestibility of dry matter (DM), organic matter, crude protein, neutral detergent fiber and acid detergent fiber in cows fed PS was lower ($P < 0.05$) than with TMF. Estimated energy intake of diet with PS (1.71 ± 0.15 Mcal per kilogram DM) was lower ($P < 0.05$) than energy fed with TMF (2.34±0.13 Mcal per kilogram DM) and TMF-1 (2.26±0.25 Mcal per kilogram DM). The milk yields of cows fed TMF and TMF-1 (14.55±1.95 and 14.32±1.76 kg.d^{-1}) were higher than cows fed PS ($P < 0.05$). However, the milk composition was not significantly different ($P > 0.05$) in all treatment groups.

Keywords: pineapple, sweet corn, agro-industrial by products, nutrient digestibility, dairy cow

INTRODUCTION

Concentrate and roughage are used in the feedstock of dairy cows to produce more rapid growth, quicker marketing and maximum milk production during lactation. While there is a variety of commercial concentrate feeds available, proper manufactured roughage feed is not readily available on the market. Most farmers in Thailand used forage crops and some agro-industrial byproducts such as cassava peels, cereal millings, vinasse, pineapple waste and the peel or husks of sweet corn to feed cattle (Okojie, 1999; Stemme *et al.*, 2005; Sruamsiri *et al.*, 2007). Agro-industrial by-products can be used in their fresh form, in ensiled form, and chopped and made into a silage bag when forage is in short supply. Nevertheless, using low quality roughage to produce silage is usually limited by the nutrients, palatability, feed digestibility and shelf life. Most by-product such as corn and pineapple peel can be used for making silage for feeding to ruminants,

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especially in the dry season. In Thailand and other countries in Southeast Asia, farmers use pineapple and sweet corn waste as cattle feed because of their palatability. Many researchers confirmed that ensiling pineapple waste or pineapple waste mixed with rice straw can improve substantially its nutritive value (Choopheng *et al*., 2005; Jitramano *et al*., 2005). Corn silage is a good source of energy in ruminant diets due its high energy and low fiber content (Johnson *et al.*, 2002). Sugar bagasse is the highly fibrous residue remaining after the sugar cane has been pressed to remove the sucrose (Martín *et al*., 2007). It has been used as a feed supplement for cattle (Randel *et al.*, 1971) and has been mixed with sweet corn husks and cobs for feeding to dairy cows (Suwannasin, 2009). In addition, the ethanol industry which used molasses or syrup as raw materials produce vinasse as a co-product by thermal concentration. Vinasse recovered from an ethanol plant, has been reported as suitable for use as animal feed (Cavani and Manfredini,1979; Stemme *et al*., 2005). However, sugar bagasse has limited properties for animal feed because it contains low levels of protein and is high in cellulose (Alvarez and Preston, 1976; Alvarez *et al*., 1978; Kewalramani *et al*., 1988). However, by mixing all sources of by-products from agro-industry and the alternative-energy industry to enrich such low quality feedstuffs, these materials will be more beneficial as animal feed. The concept of total mixed fiber (TMF) was then introduced to address this issue. TMF was produced from agricultural by-products such as corn cob, corn husk, pineapple peel, rice straw, bagasse and vinasse which can enhance each other's nutrient composition, palatability and suitability as an alternative roughage feed for dairy cows. If farmers have a good roughage source to feed their cows all year round, then they can reduce the concentrate fed to their dairy cows and reduce the cost of production. Thus, it is of considerable interest to investigate the nutritive value of such TMF and the overall performance of cows fed with it on small holder dairy farms in Thailand. This study aimed to investigate the feed intake, digestibility, milk yield and milk composition when TMF was used as a roughage source in lactating dairy cows.

MATERIALS AND METHODS

Animals, diets and management

Fifteen healthy, vaccinated, 87.5% multiparous Holstein Friesian lactating dairy cows in mid-lactation (in the second to fourth lactation) were used in this study. All cows were aged 4–6 yr and were 115.20±20.32 days in milk with an average body weight of 416.03±34.66 kg. All animals were randomly allocated to three treatments and allowed 3 wk of adjustment before the data were collected. All cows in all treatments were fed with 20.35% crude protein (CP) of commercial concentrate feed (Table 1). Cows were housed in individual pens and were fed *ad libitum* with roughage. Cows in Treatment 1 were fed with pineapple peel silage (PS) and rice straw whereas Treatment 2 and Treatment 3 cows were fed with total mixed fiber and total mixed fiber and one less kilogram of concentrate, respectively. The feed consumed by all dairy cows in each group was calculated based on the nutrient requirements for maintenance and production (National Regearch Council [NRC], 2001) with twice daily feeding at 0500 and 1400 hours before milking. Fresh, clean water and a mineral block were available at all times to all animals.

Measurements

Samples of all feeds were analyzed for dry matter (DM), crude protein (CP), ether extract (EE) ash and gross energy (GE) by proximate standard according to Association of Official Analytical Chemists (1990). The neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed by the detergent method (Goering and Van Soest, 1970). The cellulose of the rations was obtained throughout by calculating the difference between

Table 1 Chemical composition of concentrate and rice straw used in the experiment (as % dry matter).

Item	Concentrate	Rice straw	TMF
Dry matter	91.11	89.10	33.87
Crude protein	20.35	2.33	8.39
Ether extract	5.01	1.22	1.68
Ash	8.90	11.31	9.16
Crude fiber	11.81	33.37	31.12
Acid detergent fiber	23.11	45.67	49.31
Neutral detergent fiber	56.24	69.73	69.54
Calcium	1.76	-	0.71
Phosphorus	0.05	-	0.03
Gross energy ($cal.g^{-1}$)	3,956.43	3,366.51	3,975.18

TMF = Total mixed fiber.

the ADF and lignin (Van Soest, 1968). The pH was measured according to Bolsen *et al*. (1992). The volatile fatty acid content was analyzed according to Cheva-Isarakul and Cheva-Isarakul (1980).

Milk yield and composition analyses

The milk production of individual cows was recorded daily at each milking time. Milk was sampled once a week using a mixed sample containing 15 mL of morning milk and 15 mL of afternoon milk for the analyses of fat, protein, lactose and solids-not-fat (SNF) using a Fossomatic Milkoscan 203 (Foss Electric; Hillerød, Denmark). Milk urea nitrogen (MUN) was determined using the Sigma diagnostics procedure (Valadares *et al*., 1999) and the SNF content was determined as reported by Harding (1995). The 4% fat collected milk (FCM) was calculated following the method outlined by Walker *et al.* (2001).

Silage management

Pineapple peel was obtained from pineapple cannery plants in Prachuap Khiri Khan province and used in Treatment 1, while TMF was used in Treatments 2 and 3. The TMF was composed of pineapple peel, sweet corn husk and cob, bagasse, rice straw, and vinasse at the ratio of 20:60:10:5:5 (fresh weight basis). The bagasse and vinasse were obtained as by-products of the sugar industry and by the alcoholic fermentation of molasses, respectively. All raw materials mentioned above were mixed and packed in two layers of plastic bags and allowed to ferment for at least 21 d before opening. Each bag weighed 30 kg and was ready for feeding after fermentation. All feeds in each group were sampled to analyze their chemical composition and fermentation characteristics.

***In vivo* digestibility**

Fecal samples (about 20% of total amount daily) were collected from all cows for five consecutive days during the last period of the experiment by grab sampling. These samples were dried at 60 °C to a constant weight and ground (1 mm screen) and then analyzed for DM, ether extract, ash and CP content (Association of Official Analytical Chemists, 1990), and for NDF, ADF and ADL (Goering and Van Soest, 1970). Fecal and feed samples were analyzed for acid insoluble ash (AIA). The dry matter digestibility coefficient was determined from the ratio of AIA in the fecal and feed samples by the method of Hanbanjong and Sinjermsiri (1989) modified from Van Keulen and Young (1977) by the following formulas:

$$\% \text{ AIA} = (A–B)/W \times 100$$

where A is the weight of the crucible with ash, B is the weight of the empty crucible and W is the weight of the sample dry matter.

% Dry matter digestibility =
100 × (1–% AIA in feed/% AIA in feces)

Statistical analysis

The data were analyzed using a completely randomized design with three replicates and analysis of variance with the Statistical Analysis System software package (SAS, 1996). Duncan's new multiple range test was used to test the differences among treatment means (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Fermentation quality properties of silages

The nutrient composition (as % DM) for the PS and TMF are presented in Table 2. The PS contained lower dry matter (17.50%) and protein (6.09%) contents than the TMF. These results were in accordance with the results of Chandapillai and Selvarajah (1978), which reported 6.10% CP in PS, while Suksathit *et al*. (2011) reported 6.04% CP. However, the crude protein content of the PS was higher than the protein level reported by Abdullah and Mat (2008) for solid pineapple waste silage of 5.18% CP of DM. Phujang *et al*. (2010) reported a very low crude protein content in pineapple silage (3.80% CP). The EE (0.34%) and fiber constituents (23.98% CF) were also lower than that of the TMF (1.68% EE and 31.12% CF). Sweet corn husks and cobs which are one of the components of TMF contain high fat levels which improve the EE of silage (Sruamsiri *et al*., 2007). In addition, the supplement of rice straw, and bagasse increased the DM content of the TMF compared to those of the PS group (Kawashima *et al*., 2002; Suksombut, 2004).

The fermentation quality of silage has a major effect on the feed intake, nutrient utilization and milk production in ruminants (Huhtanen *et al.*, 2003). The current results showed that the pH and lactic acid content of the TMF were higher than in the PS and they were in the optimum ranges, as according to Catchpoole and Henzell (1971) the optimum standards for the pH, lactic acid and butyric acid are 4.2, 3–13% and less than 0.2% on a dry matter basis, respectively. Furthermore, Zobell *et al*. (2004) stated that lactic acid is important in silage and that good quality silage should contain more than 1.5% lactic acid.

Table 2 Chemical composition of different types of silage used in the experiment (as % dry matter).

Item	PS	TMF
Dry matter	17.50	33.87
Crude protein	6.09	8.39
Ether extract	0.34	1.68
Ash	6.74	9.16
Crude fiber	23.98	31.12
Nitrogen free extract	60.03	49.65
Acid detergent fiber (ADF)	34.72	49.31
Neutral detergent fiber (NDF)	68.39	69.54
Acid detergent lignin (ADL)	2.15	3.40
Hemicellulose (NDF - ADF)	33.67	20.23
Cellulose (ADF - ADL)	32.57	45.91
Silage parameters		
pH	3.07	3.65
Acetic acid	5.31	11.10
Butyric acid	1.63	3.16
Lactic acid	2.91	4.55

PS = Pineapple peel silage, TMF = Total mixed fiber.

Dry matter intake and digestibility

Dry matter and nutrient intake are presented in Table 3. The concentrate and total DMI of the PS group were higher than those of the TMF and TMF-1 groups, respectively ($P < 0.05$). The silage intakes of the TMF and TMF-1 groups were higher than those of the PS group. The PS used in this experiment was lower in dry matter content than that of the TMF which could have resulted in the low silage dry matter intake. However, the total DMI was higher after adding rice straw to the PS group. The TMF was composed of supplementations of agro-industrial by-products (pineapple peel, sweet corn husk and cob, bagasse, rice straw and vinasse). Although, bagasse and rice straw were low in digestibility and palatability, ensiling with other agro-industrial by-products could increase their feed intake and digestibility of feed (Promma *et al*., 1988). The use of the TMF and the TMF with 1 kg less of concentrate feed did not affect the silage intake. No significant differences were detected in the protein intake under all treatments.

The apparent digestibility, estimated digestible nutrient intake and estimated energy intake of dairy cows in mid-lactation are presented in Table 4. The apparent digestibility of DM, OM, CP, NDF and ADF were significantly higher ($P < 0.05$) in cows fed with the TMF and TMF-1 than those values in the PS group. The TMF was produced from agricultural by-products and the digestibility values remained higher than those in cows fed with pineapple silage with rice straw (PS). Several research studies on the use of agricultural by-products for making silage have reported many interesting parameters. Suksathit *et al.* (2011) reported that a diet containing only pineapple waste as the roughage source had higher digestibility of DM, OM, CP, NDF and ADF (82.66, 84.52, 84.10, 76.64 and 68.84%, respectively) than a diet with pangola hay as the sole roughage source. The higher digestibility of

Table 3 Dry matter intake of lactating dairy cows fed with different silage types (number = 15).

Item	PS	TMF	TMF-1	SEM	P-value
Concentrate intake					
(kg.d^{-1})	5.92^a	5.92^a	5.01^b	-	-
Percent body weight	1.40±0.12^a	1.43±0.13^a	1.24±0.06^b	0.01	0.02
(g per kg BW$^{0.75}$)	63.54±3.94^a	64.52±4.20^a	55.48±2.04^b	0.18	0.01
Silage intake					
(kg.d^{-1})	3.11±0.30^b	4.46±0.14^a	4.26±0.16^a	0.01	0.03
Percent body weight	0.74±0.10^b	1.08±0.09^a	1.05±0.06^a	0.04	0.01
(g per kg BW$^{0.75}$)	33.36±3.62^b	48.63±3.29^a	47.24±2.31^a	0.16	0.02
Rice straw intake					
(kg.d^{-1})	3.11±0.09	-	-	-	-
Percent body weight	0.75±0.08	-	-	-	-
(g per kg BW$^{0.75}$)	34.10±3.10	-	-	-	-
Total dry matter intake					
(kg.d^{-1})	12.21±0.35^a	10.39±0.13^b	9.28±0.16^c	0.12	0.02
Percent body weight	2.89±0.24^a	2.51±0.21^b	2.20±0.16^c	0.01	0.03
(g per kg BW$^{0.75}$)	130.99±8.33^a	113.15±7.28^b	102.73±3.94^c	0.35	0.01
Protein intake					
(kg per head per day)	1.47±0.02^b	1.58±0.01^a	1.38±0.01^c	0.10	0.03

^{a,b,c} = Means within the same row with different lowercase superscript letters differ significantly ($P < 0.05$).

SEM = standard error of the mean, BW = Body weight.

PS = Pineapple peel silage, TMF = Total mixed fiber, TMF-1 = Total mixed fiber and 1 kg less of concentrate.

such silage was due to the pineapple fiber having short fibrous particles and it usually had more digestible nutrients compared to hay and this may increase the rate of passage of feed particles. An increase in the rate of passage is associated with an increase in ADF digestibility (Guthrie and Wagner, 1988). An increase in the amount of pangola hay in the silage ration would result in a decrease in the apparent digestibility of DM, OM, CP, NDF and ADF. The results in the current study revealed that cows in the PS group that received rice straw in the ration in addition to pineapple silage showed lower digestibility. This study therefore agreed with the study of Wanapat *et al*. (1985) who stated that rice straw had low nutritive value and low digestibility of the DM content. Other studies reported by Arbabi *et al*. (2008) showed that corn silage had low DM digestibility (about 34.08%). Sruamsiri *et al*. (2007) also found that the digestibility of DM, OM, CP, NDF and ADF of ensiled sweet corn cobs and husks averaged 52.77, 56.90, 49.27, 59.34 and 46.53%, respectively, and were lower than feed supplemented with 10, 20 and 30% of Ipil-Ipil leaves in the silage, respectively.

Considering the estimated digestible nutrient intake, the cows fed the TMF and TMF-1 as the roughage source in the current study had higher ($P < 0.05$) nutrient digestibility (CP and ADF) than cows fed the PS with rice straw. The estimated energy intake, in terms of megacalories per day and megacalories per kilogram of DM was significantly higher ($P < 0.05$) in cows fed the TMF and TMF-1 than those cows fed the PS. The digestibility or ME content of silage is the most important factor influencing the milk production response, as an increase in silage digestibility will increase milk production (Kaiser *et al*., 2004). This result showed the higher nutritive values of feed intake which could be related to the high apparent digestibility of the DM and OM intake

Table 4 Effect of different fiber sources on nutrient digestibility and digestibility nutrient intake in lactating dairy cows.

Item	PS	TMF	TMF-1	SEM	*P*-value
Apparent digestibility (%)					
Dry matter (DM)	50.95±3.89[b]	67.19±3.72[a]	64.83±7.91[a]	1.84	0.02
Organic Matter	53.82±5.05[b]	69.77±4.04[a]	67.05±8.13[a]	1.99	0.03
Crude Protein	45.71±5.87[b]	70.92±3.36[a]	69.80±7.88[a]	2.00	0.03
Neutral detergent fiber	50.17±5.82[b]	68.75±5.48[a]	64.67±9.08[a]	2.33	0.04
Acid detergent fiber	45.81±6.37[b]	67.44±5.67[a]	62.80±11.76[a]	2.80	0.04
Estimated digestible nutrient intake ($kg.d^{-1}$)					
Dry matter (DM)	6.18±0.50	6.95±0.39	6.02±0.72	0.19	0.17
Organic Matter	5.64±0.55	6.27±0.37	5.42±0.64	0.18	0.21
Crude Protein	0.67±0.09[b]	1.12±0.05[a]	0.96±0.11[a]	0.03	0.01
Neutral detergent fiber	3.63±0.44	4.41±0.36	3.74±0.52	0.15	0.15
Acid detergent fiber	1.69±0.25[b]	2.39±0.21[a]	2.05±0.35[ab]	0.09	0.04
Estimated energy intake[1]					
Metabolizable Energy ($Mcal.d^{-1}$)	21.43±2.10	23.82±1.40	20.59±2.46	0.79	0.21
Metabolizable Energy (Mcal per kg DM)	1.71±0.15[b]	2.34±0.13[a]	2.26±0.25[a]	0.06	0.01

[a,b] = Means within the same row with different lowercase superscript letters differ significantly ($P < 0.05$).

SEM = Standard error of the mean.

PS = Pineapple peel silage, TMF = Total mixed fiber, TMF-1 = Total mixed fiber and 1 kg less of concentrate.

[1] = 1 kg of digestible organic matter = 3.8 Mcal ME (Kearl, 1982).

and eventually resulted in a higher intake of ME megacalories per day and megacalories per kilogram of DM.

Milk production and composition

Table 5 shows the milk yield and milk composition from dairy cow in mid-lactation. The results from the current study showed that cows fed the PS with rice straw as roughage had a lower milk yield (13.39 ± 1.39 kg.d^{-1}) than those cows fed the TMF and TMF-1, respectively. High milk production levels can be sustained when cows are fed with a mixed silage and concentrate diet (Kaiser *et al*., 2004). The current results support the report of Suwannasin (2009) who found that feeding cows with a partial mixed ration made from bagasse, vinasse and corn waste mixture could increase the milk yield. The production of fat corrected milk (4% FCM) was not significantly ($P > 0.05$) different in any of the feeding groups. The milk composition was similar between the cows fed the PS, TMF or TMF-1. Milk fat production was not significantly ($P > 0.05$) different among all treatments but tended to increase in the TMF-1 and TMF groups, respectively. The current study showed that solids-not-fat, total solids and lactose were unaffected by any of the dietary treatments.

Likewise, Swamiphak (1996) stated that the SNF percentage of raw milk in Thailand ranged between 8.13 and 8.67%. The MUN levels in the PS and TMF groups were not different but tended to be higher than in the TMF-1 group. However, Nelson (1996) reported that while the protein degradability fractions and energy were most likely balanced when the milk protein was in the range 3.0–3.2%, the MUN concentration should be 12–16 mg.dL^{-1}. The decrease by 1 kg of the concentrate yielded a low MUN ($P > 0.05$). The fat/protein ratio in milk yield was not significantly ($P > 0.05$) different in any of the feed groups and was in the optimum range for a positive energy balance (Flatt *et al*., 1969; Heur *et al*., 2000).

CONCLUSION

The results obtained in the present study showed that the TMF obtained from a mixture of by-products from agriculture, agro-industry and an ethanol plant was a good feedstock for dairy cows. The TMF had a higher dry matter content (33.87% DM) than the PS (17.50% DM) and could be used as a roughage source for feeding dairy cows without supplying rice straw with good results. Cows fed with the TMF exhibited higher

Table 5 Milk yield and milk composition in lactating dairy cows fed with different silage types (number = 15).

Item	PS	TMF	TMF-1	SEM	P-value
Milk yield (kg.d^{-1})	13.39±1.39^{b}	14.55±1.95^{a}	14.32±1.76^{a}	0.11	0.01
4% FCM (kg.d^{-1})	13.87±0.87	15.10±2.09	12.36±2.56	0.68	0.30
Milk composition (%)					
Fat	3.95±0.25	4.48±0.30	4.20±0.55	0.27	0.78
Protein	2.90±0.14	3.01±0.08	2.99±0.12	0.03	0.53
Solids-not-fat	7.92±0.39	8.24±0.23	8.18±0.35	0.09	0.54
Total solids	11.89±1.62	12.73±1.26	12.51±1.48	0.29	0.70
Lactose	4.36±0.22	4.53±0.13	4.50±0.20	0.05	0.55
Milk urea nitrogen (mg.dL^{-1})	15.00±2.24	16.40±1.48	13.80±1.30	0.60	0.40
Fat/Protein	1.36±0.13	1.48±0.35	1.37±0.39	0.08	0.85

^{a,b} = Means within the same row with different lowercase superscript letters differ significantly ($P < 0.05$).

SEM = Standard error of the mean.

PS = Pineapple peel silage, TMF = Total mixed fiber,TMF-1 = Total mixed fiber and 1 kg less of concentrate.

FCM = Fat collected milk.

milk yield and showed no significant difference in milk composition. The apparent digestibility and digestible nutrient intake of DM, OM, CP, NDF and ADF were higher in cows fed the TMF and TMF-1 than those fed normal pineapple silage (PS).

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