The Nutritive Value and Digestibility of Rice Straw Supplemented with Palm Kernel Cake and Ensiled with Urea and Microbial Inoculants.

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ชื่อวิทยานิพนธ์	คุณค่าทางอาหารและการย่อยได้ของฟางข้าวที่เสริมด้วยกากเนื้อในเมล็ดปาล์ม และหมักด้วยยูเรียและจุลินทรีย์
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บทคัดย่อ

การทดลองนี้มีวัตถุประสงค์เพื่อศึกษาคุณค่าทางอาหาร และค่าการย่อยได้ของฟางหมัก 4 ชนิด (ทรีทเมนท์) ทรีทเมนท์ ที่ 1 มีส่วนประกอบ คือ ฟางข้าว, น้ำ, กากเนื้อในเมล็ดปาล์ม และกากน้ำตาล ทรีทเมนท์ ที่ 2 คือ ทรีทเมนท์ ที่ 1 บวกกับ จุลินทรีย์ อี เอ็ม, ทรีทเมนท์ ที่ 3 เหมือน ทรีทเมนท์ที่ 1 บวกกับ ยูเรีย และ ทรีทเมนท์ ที่ 4 เหมือนกับ ทรีทเมนท์ ที่ 1 บวกกับ ยูเรีย และจุลินทรีย์ อี เอ็ม ส่วนประกอบทางเคมี ได้แก่ วัตถุแห้ง, อินทรีย์วัตถุ, เยื่อใย, ไขมัน, เถ้า , ลิกโนเซลลูโลส, เซลลูโลส, และลิกนิน ของฟางหมักทั้ง 4 ชนิดไม่มีความแตกต่างกัน ส่วนเปอร์เซ็นต์โปรตีน ของฟางหมักที่มียูเรีย เท่ากับ 11.457 - 11.490 และกลุ่มที่ไม่มียูเรียมีโปรตีน เท่ากับ 7.975 - 8.192 % ($P < 0.05$)

คุณลักษณะของฟางหมักพบว่า กลุ่มฟางหมักที่มียูเรียมี ค่า pH ระหว่าง 8.952 - 8.977 และมีกลิ่นของแอมโมเนีย กลุ่มที่ไม่มียูเรีย มีค่า pH ระหว่าง 5.332 - 5.337 นอกจากนี้ยังพบการเจริญของเชื้อราเล็กน้อย ในเฉพาะกลุ่มของฟางหมักที่ไม่มียูเรีย

ค่าสัมประสิทธ์การย่อยได้ในตัวสัตว์ของฟางหมักทั้งทรีทเมนท์ 1, 2, 3 และ 4 มีดังต่อไปนี้ คือ การย่อยได้ ของวัตถุแห้งมีค่าเท่ากับ 48.463, 53.053, 58.753 และ 57.476 % ตามลำดับ อินทรีย์วัตถุ เท่ากับ 54.699, 57.428, 63.677 และ 62.401 % ตามลำดับ โปรตีนรวม เท่ากับ 70.410, 72.859, 76.748 และ 77.182 % ตามลำดับ ไขมัน เท่ากับ 61.849, 66.841, 71.788 และ 72.883 % ตามลำดับ เยื่อใยหยาบ (crude fiber) เท่ากับ 66.098, 70.944, 77.149 และ 76.722 % ตามลำดับ เยื่อใยรวม (NDF) เท่ากับ 52.433, 58.599, 64.289 และ 65.487 % ตามลำดับ เยื่อใยทนกรด (ADF) เท่ากับ 50.876, 56.657, 57.558 และ 56.910 % ตามลำดับ เซลลูโลส เท่ากับ 74.434, 81.778, 83.008 และ 82.227 % ตามลำดับ และโภชนะที่ย่อยได้ทั้งสิ้น (TDN) เท่ากับ 50.835, 52.930, 58.874 และ 57.715 % ตามลำดับ ค่าสัมประสิทธิ์การย่อยได้ของสารเหล่านี้ คือ วัตถุแห้ง อินทรีย์วัตถุ โปรตีน เยื่อใยหยาบ เยื่อใยรวม และโภชนะที่ย่อยได้ทั้งสิ้น ในกลุ่มฟางหมักที่มียูเรียจะสูงกว่ากลุ่มที่ไม่มียูเรีย ($P < 0.01$) ค่า -

สัมประสิทธิ์การย่อยได้ ของ เยื่อใยทนกรด และ เซลลูโลส ในกลุ่มฟางหมักยูเรีย และฟางหมักที่มีจุลินทรีย์ อี เอ็ม มีค่าไม่แตกต่างกันทางสถิติ ($P > 0.05$) แต่มีความแตกต่างกับฟางหมักที่ไม่มีทั้งยูเรีย และจุลินทรีย์ อี เอ็ม ($P < 0.05$)

การหาค่าการละลายได้ของวัตถุแห้งในฟางหมักสำหรับ ทรีทเมนท์ ที่ 1, 2, 3 และ 4 โดยวิธีใช้ถุงไนลอน และในหลอดทดลองพบว่า มีค่าเท่ากับ 45.433 และ 20.402, 49.743 และ 24.821, 53.344 และ 28.896 , 53.106 และ 29.602 % ตามลำดับ ค่าเหล่านี้มีแนวโน้มในทางเดียวกันกับค่าสัมประสิทธ์การย่อยได้ของวัตถุแห้งโดยสัตว์ทดลอง ปริมาณของวัตถุแห้งที่แพะกินต่อวันสำหรับฟางหมักทรีทเมนท์ ที่ 1, 2, 3 และ 4 เท่ากับ 34.640, 40.480, 44.312 และ 50.110 กรัม ต่อน้ำหนักเมแทบอลิค หนึ่ง กิโลกรัม ตามลำดับ

ในการทดลองที่ 2 ฟางหมักยูเรียระดับยูเรีย 1.5, 3.0, 4.5 และ 6.0 % ร่วมกับจุลินทรีย์ พด. 1 จำนวน 25 กรัม มีค่าการย่อยได้ของวัตถุแห้ง เท่ากับ 52.554, 55.210, 56.053 และ 54.864 % ตามลำดับ การทดลองที่ 3 ใช้ฟางหมักกับ พด. 1 ที่ระดับ 0, 25, 50 และ 75 กรัม ร่วมกับ ยูเรีย 3.0 % มีค่าการย่อยได้ของวัตถุแห้ง เท่ากับ 54.200, 55.769, 55.213 และ 56.017 % ตามลำดับ

การใช้ยูเรีย หรือจุลินทรีย์ อี เอ็ม ในการทำฟางหมัก สามารถช่วยเพิ่มค่าการย่อยได้และปริมาณอาหารที่สัตว์กิน การใช้ยูเรียที่ระดับ 6 % ร่วมกับ จุลินทรีย์ ไม่ทำให้ค่าการย่อยได้ของฟางหมักแตกต่างจากการใช้ยูเรียระดับ 6 % เพียงอย่างเดียว ดังนั้นการทำฟางหมักควรเลือกใช้ยูเรียหรือจุลินทรีย์เพียงอย่างใดอย่างหนึ่ง

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ABSTRACT

The primary experiment (Experiment 1) was conducted to evaluate the nutritive value and digestibility of straw haylage ensiled with urea and/or microbial inoculants. Four treatments were used. Treatment 1 contained rice straw, water, palm kernel cake, and molasses. Treatment 2 was the same as Treatment 1 with the addition of Effective Microorganisms or EM microbes. Treatment 3 was the same as Treatment 1 with the addition of urea, and Treatment 4 was the same as Treatment 1 with the addition of urea and EM microbes. The nutritive values of four straw haylages such as dry matter (DM), organic matter (OM), crude fiber (CF), ether extract (EE), ash, lignocellulose, cellulose, and lignin were not significantly different among treatment means. However, the percentage units of crude protein (CP) for straw haylage with urea added were 11.475 - 11.490%. These percentages were higher ($P < 0.05$) than those of groups with no urea added (7.975 - 8.192%).

The pH value of haylage with urea added was between 8.952 - 8.977 and had an ammonia odor, whereas

groups with no urea added had pH values between 5.332 - 5.337 and exhibited a small amount of mold.

The digestibility coefficients for Treatments 1, 2, 3, and 4 were 48.463, 53.053, 58.753, and 57.476% for DM; 54.699, 57.428, 63.677, and 62.401% for OM; 70.410, 72.859, 76.748, and 77.182% for CP; 61.849, 66.841, 71.788, and 72.883% for EE; 66.098, 70.944, 77.149, and 76.722% for CF; 52.433, 58.599, 64.289 and 65.487% for neutral-detergent fiber (NDF); 50.876, 56.657, 57.558, and 56.910% for acid-detergent fiber (ADF) ;74.434, 81.778, 83.008, and 82.227% for cellulose and total digestible nutrients (TDN) were 50.835, 52.930, 58.874, and 57.715%, respectively. The digestibility coefficients for DM, OM, CP, CF, NDF and TDN from haylages with urea added were higher ($P < 0.01$) than those of haylage with no urea added. There were no significant differences between the digestibility coefficients of ADF and cellulose from haylages treated with urea and EM microbes, but those coefficients were higher ($P < 0.05$) than that of Treatment 1 (no urea or EM microbes).

The *in sacco* and *in vitro* dry matter degradability (DMD) values of haylages from Treatments 1, 2, 3, and 4 were 45.433 and 20.402%, 49.743 and 24.821%, 53.344 and 28.896%, and 53.106 and 29.602%, respectively. These results showed the same trend as for *in vivo* DMD values. Dry matter intake (DMI) values for Treatments 1, 2, 3, and 4 were 34.640, 40.480, 44.312, and 50.110 $g/kgW^{0.75}/d$, respectively.

In one of two secondary experiments (Experiment 2), where treatments were prepared with increases in urea levels from 1.5, 3.0, 4.5, and 6.0% and 25g Poh Doh 1 microbes added, the DMD values were 52.554, 55.210, 56.053, and 54.846%, respectively. The results of the last experiment, Experiment 3, indicated that an increase in Poh Doh 1 level from 0 - 1.5% slightly increased the digestibility of the haylage.

The addition of urea or EM microbes to straw haylage can increase DMD and DMI values. However, there was no potential synergistic effect between urea and EM microbes that improved the DMD values at high levels of urea (6%). Therefore, straw haylage can be improved by ensiling the straw with either urea or EM microbes alone.

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Phadet Sangkhapaitoon

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LIST OF ABBREVIATIONS

ADCC	=	apparent digestibility coefficient for cellulose
ADCOM	=	apparent digestibility coefficient for organic matter
ADF	=	acid-detergent fiber
ADL	=	acid-detergent lignin
AIA	=	acid-insoluble ash
AO	=	*Aspergillus oryzae*
AOAC	=	Association of Official Analytical Chemists
β	=	beta
C	=	cellulose
°C	=	degree Celsius
CF	=	crude fiber
cfu	=	colony forming unit
cm	=	centimeter
CP	=	crude protein
CRD	=	Completely Randomized Design
CWC	=	cell wall contents
d	=	day
DE	=	digestible energy
DFM	=	direct fed microbial
DMD	=	dry matter digestibility
DMI	=	dry matter intake
DMRT	=	Duncan's Multiple Range Test
EE	=	ether extract
EM	=	Effective Microorganism

FDA	=	Food and Drug Administration
g	=	gram
GE	=	gross energy
h	=	head
HC	=	hemicellulose
IMT-GT	=	Indonesia-Malaysia-Thailand Growth Triangle
IVDMD	=	*in vitro* dry matter digestibility
Kcal	=	kilocalories
kg	=	kilogram
$kgW^{0.75}$	=	kilogram metabolic weight
LSD	=	Latin Square Design
µ	=	micron
m	=	meter
mg/l		milligram per liter
min	=	minute
ml	=	milliliter
mmol/l	=	millimole per liter
N	=	normality
NDF	=	neutral-detergent fiber
NFE	=	nitrogen-free extract
OM	=	organic matter
PKC	=	palm kernel cake
PPF	=	palm press fiber
rpm	=	revolutions per minute
SC	=	*Saccharomyces cerevisiae*
TDN	=	total digestible nutrients
TMR	=	total mixed rations
w/w	=	weight per weight

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CHAPTER 1

INTRODUCTION

1 Justification for Livestock Production in Thailand

The livestock industries in Thailand make a significant contribution to the country's agricultural production and economy. Various types of livestock throughout Thailand provide farm families with food (meat, milk, eggs), draft power, fertilizer, and supplementary income. Generally, Thailand has a problem with a shortage of green roughage for ruminants during the dry season. The raising of ruminants is mainly confined to small farms and are integrated with crop production where much of the available land is used for growing cash crops such as rice, corn, cassava, sugar cane, and perennial trees. The major feeds for ruminants are natural pasture or roadside grasses which are available in surplus quantities only in the wet season. The use of preserved roughages such as hay or silage is impractical due to the unavailability of necessary equipment and technological knowledge. Therefore, crop residues, especially rice straw, can play an important role in the nutrition of ruminants during the dry season and also when there is extended period of heavy rain. However, rice straw has low nutritive value; the nutrients present in rice straw cannot meet animal's requirements for production even

though attempts have been made to improve its nutritive value. At the same time, other crop residues are being investigated by researchers for their potential use as animal feed.

In southern region of Thailand, one advantage of the continued emphasis on crop cultivation is the production of various agricultural by-products. Under these circumstances, animals consume various feeds that are not directly usable for human consumption. In addition, a number of government agencies are active in southern Thailand, especially the Department of Livestock Development and the Bank of Agriculture and Cooperatives, in promoting the production of dairy and beef cattle. The southern region of Thailand is regarded as a disease-free zone as it has a low incidence of major diseases, especially foot and mouth disease (FMD).

In December 1993, at the request of the Governments of Indonesia, Malaysia, and Thailand, the Asian Development Bank (ADB) financed and implemented the Indonesia - Malaysia - Thailand Growth Triangle (IMT-GT) Development Project. Agriculture and fisheries is a sector component of the IMT-GT Development Project. The five border provinces of Southern Thailand- Songkhla, Pattani, Yala, Narathiwat, and Satun- comprise the Thai section of the IMT-GT area. These provinces are devoted to agricultural production such as rubber, coconut, oil palm, and livestock. In this area, religious beliefs and other motives impact the

livestock production system. For example, in Muslim communities the demand for beef is high, but for pork is quite low due to religious beliefs.

In all areas of southern Thailand, there will be more emphasis on increasing productivity with existing agricultural land by introducing modern inputs and technology, and agricultural outputs will be further processed to yield higher value-added products, particularly as forms of animal protein. Under these circumstances, agricultural products will not only be for the expanding local market, but also for export to foreign markets such as Malaysia, Indonesia, Brunei, and Singapore.

The experiments reported in this thesis were conducted in the southern region of Thailand to investigate how agricultural residues and by-products such as rice straw and palm kernel cake (PKC) could be better utilized as ruminant feeds. Rice straw plus PKC was ensiled with urea and microbial inoculants for 21 days to produce haylage for use as a partially mixed ration for ruminants. The outcomes from these experiments may lead to the production of total mixed rations (TMR) or complete feeds for ruminants in the future.

2 Review of Literature

2.1 Chemical Composition of Rice Straw

Roxas *et al.*(1985) and Sudana (1987) considered that the nutritive value of rice straw might be affected by genetic factors, for example variety and strain as well as environmental factors such as cultivation, soil fertility, fertilizer application, irrigation, and season. Another factor that might have an effect on the nutritive value of rice straw is the proportion of some of the plant fractions, particularly the leaf and stem fraction. Wilson (1994) reported that rice straw of a high cell wall content (CWC) is of low digestibility being composed principally of hemicellulose, pectin, cellulose, and lignin and intake by ruminants was low. The CWC of rice straw is lower in the leaves than in the sheaths and stem. Also legumes have a lower CWC than grasses with temperate grasses(C_3) lower than tropical(C_4) species. The chemical composition of rice straw from various locations is shown in Table 1.

Table 1 Chemical composition of rice straw (% dry matter basis)

constituent	Sources 1	2	3	4
Dry matter	93.2	90.0	-	93.30
Crude protein	2.0-2.3	3.1	-	3.06
Ether extract	-	2.2	-	1.70
Crude fiber	-	42.3	-	34.93
Ash	-	16.4	-	13.52
NFE	-	35.9	-	46.79
Organic matter	-	-	81.7	-
NDF	76.3	-	75.9	83.89
ADF	55.2	-	56.7	53.95
Cellulose	-	-	51.5	48.38
Hemicellulose	-	-	19.2	29.96
ADL	-	-	5.1	5.15

Sources: 1. Tinnimit (1992)
2. Promma *et al.*(1985)
3. Cheva-Isarakul and Potikanond (1985)
4. Anil Kumar *et al.*(1995)

Remarks: NFE = nitrogen-free extract
NDF = neutral-detergent fiber
ADF = acid-detergent fiber
ADL = acid-detergent lignin

2.2 Improvement of the Nutritive Value of Rice Straw

In general, rice straw is of low nutritive value. It is low in nitrogen but high in fiber content and is poorly digested with low voluntary intake. Rice straw needs to be upgraded by treatments or appropriate supplementation of concentrates. Doyle *et al.*(1986) and El-Shobokshy *et al.*(1989) indicated that many processes or pretreatments have been tested as the means to improve nutritive values of rice straw or fibrous feeds. These can be summarized as:

1. Physical treatment, which includes soaking and wetting, chopping, and steaming under pressure and gamma irradiation.

2. Chemical treatment, such as acid and alkali treatment.

3. Biological treatment, which includes ensiling, composting, and enzyme additions.

4. Physico-chemical treatment, such as chopping and treatment with chemical agents, reduction of particle size plus chemicals or steaming and chemical methods.

2.3 Urea Treatment to Improve Utilization of Rice Straw

Sundstol and Coxworth (1984) reported on the use of urea as a source of ammonia for straw treatment. A solution of urea was sprayed onto the

straw and left for some time to allow the urease enzyme to convert the urea to ammonia as shown below.

$$NH_2\text{-}\overset{\overset{O}{\|}}{C}\text{-}NH_2 + H_2O \xrightarrow[\text{UREASE}]{} 2NH_3 + CO_2$$

Fondevira *et al.*(1993) studied the effects of ammonia treatment of barley straw on rumen environmental conditions for fiber degradation in sheep. Two dietary treatments were applied: untreated barley straw or barley straw treated with anhydrous ammonia (30 g/kg straw). There was no significant difference between untreated and treated barley straw in rumen pH (6.56 vs 6.38), rumen ammonia nitrogen (NH_3-N)(159 vs 189 mg/l), and total volatile fatty acids (68.6 vs 57.6 mmol/l). Tinnimit(1992) reported that the DMD value of untreated rice straw was 48.4%, whereas rice straw treated with urea (6% w/w) had a DMD value of 56.0%. The neutral-detergent fiber (NDF) digestibility value increased from 76.3 to 78.0%, the acid-detergent fiber (ADF) digestibility value increased from 55.2 to 57.5%, but the digestibility of lignin showed little change.

A study was conducted by Wongsrikeaw and Wanapat (1985) on the effect of urea treatment of rice straw on its chemical composition and digestibility by comparing untreated rice straw with 3% urea-treated rice straw and 6% urea-treated rice straw. The diets were fed to unmated female buffaloes. The CP of the untreated rice

straw was 3.8%, with 56.4% ADF, 17.3% ash, and 43.2% DMD value. The comparative values for 3% and 6% urea-treated rice straw were as follows: 5.5 and 6.8% for CP, 59.5 and 60.6% for ADF, 16.9 and 14.6% for ash, and 52.7 and 55.4% for DMD values. Wanapat *et al.*(1985) reported that untreated barley straw has an *in vivo* digestibility of 51% compared to 42% for *in vitro* and 41% for *in sacco* methods. With urea treatment, the digestibility values were 56% for *in vivo*, 53% for *in vitro*, and 52% for the *in sacco* technique.

Sundstol and Coxworth (1984) found that if the treatment of straw was effective, *in vitro* organic matter digestibility (IVOMD) increases by 10 to 12%. Treatment of straw also has other advantages since weed seeds were killed and soil and water pollution was reduced. However, Mpofu and Ndlovu (1994) revealed that treatment of straw with ammonia or urea has a problem with poor palatability. An alternative approach to increase the utilization of structural carbohydrate by ruminants is through appropriate supplementation. These supplements can be grains, oil seeds, or microbial additives. Tinnimit(1992) found that cattle which ate only rice straw lost approximately 90-150 g/d of their body weight . Therefore, it is necessary to supplement rice straw with various materials such as concentrates, molasses, cassava leaves, or leucaena leaves, etc. Doyle *et al.*(1988) who supplemented lamb diets with oat grain and sunflower meal (2:1) at the rate of

330-370 g/d could increase weight gain by 21 g/d, whereas, unsupplemented lambs lost 63 g/d of their body weight. Bowman *et al.*(1993) reported that cattle lost body weight when forage CP was below 5.6%, but gained weight when CP was above this level.

2.4 The Utilization of Oil Palm By-Products in Animal Feed

The southern region of Thailand has placed emphasis on the production of oil palms. Cultivated areas and production in various provinces are shown in Table 2.

Table 2 Distribution of oil palm production in the southern region of Thailand, 1990/1991

Province	Planted Area (rai)	Production (ton)
Krabi	394,359	548,190
Surat Thani	280,627	424,788
Chumporn	84,132	74,148
Satun	46,407	58,899
Trang	39,584	58,302
Songkhla	7,263	8,212
Phang Nga	11,631	11,416
Ranong	3,209	4,368
Phuket	200	900
Nakhorn Si Thammarat	3,901	1,859

Source: Office of Agricultural Economics, Thai Ministry of Agriculture and Cooperatives, 1990/1991

Remarks: 6.25 rai = 1 hectare; 2.5 rai = 1 acre

Devendra and Muthurajah (1977) and Salunkhe and Desai (1986) reported that oil palm fruit consists of three parts:

1. The mesocarp (or exocarp) which is the fibrous outer part from which palm oil is extracted.

2. The shell of the kernel.

3. The kernel (or seed meat) from which palm kernel oil is obtained after the endosperm has been removed. The residue is PKC which is a by-product from extracting oil from the palm kernel. Generally, the composition of fresh ripe fruit is about 29% oil, 27% water, 8% residue, 30% shell, and 6% kernel. Chitmanee (1991) reported that the processing for oil palm production involves and yieldsproducts and by-products as shown in Figure 1.

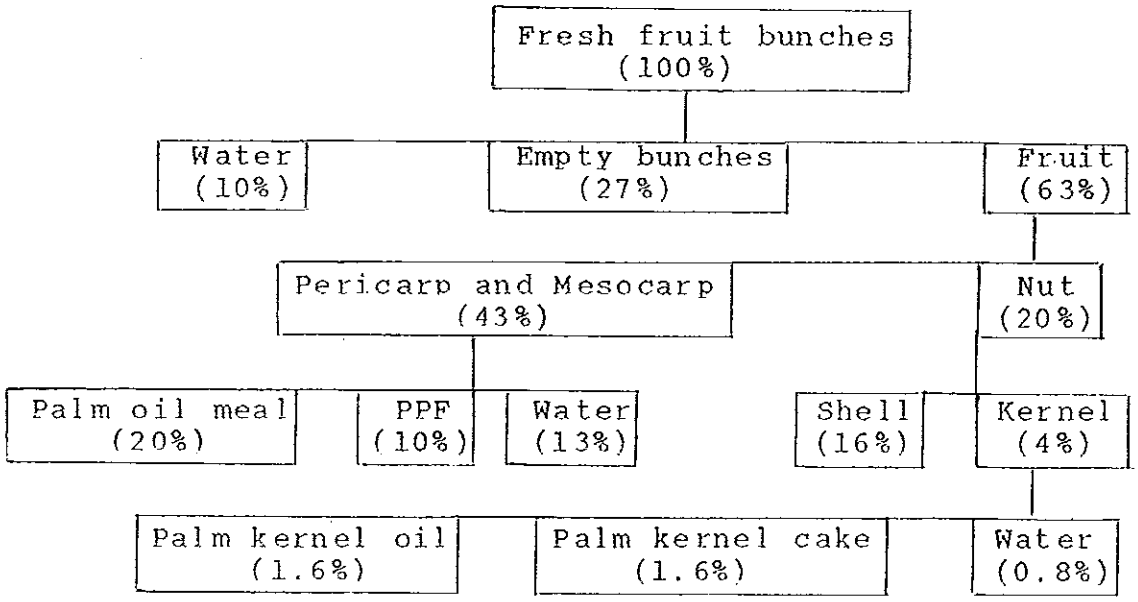


Figure 1: Products and by-products from palm oil processing

Source: Chitmanee (1991)

Remarks: PPF = palm press fiber

By-products from the processing of palm oil such as palm press fiber(PPF), palm kernel cake(PKC), palm oil sludge, and oil palm meal can be used as animal feed . Devendra and Muthurajar (1977) reported that PKC, like rice bran, is valuable in supplying both dietary energy and protein. One of the problems concerning such feed is its variable quality, partly due to the presence of shell content that makes it less suitable as feed for non-ruminants. This kind of

feed is more commonly fed to ruminants. Kuprasert *et al.*(1987), Tinnimit(1992), Miyashige(1989), and Lakshmi and Krishna (1993) studied the chemical composition of oil palm by-products, and the results are shown in Table 3.

Table 3 Chemical composition of palm oil by-products (on dry matter basis)

constituent (%)	1*	2*	3*		4*	
	PKC	Oil palm meal	Oil palm meal	PKC (Expeller)	PKC (Solvent extract)	PPF
Dry matter	88.18	87	94.58	93.72	89	92
Crude protein	14.80	8	7.58	13.44	16	5
Ether extract	1.28	8	8.80	15.84	<1	3
Crude fiber	33.20	35	38.89	14.99	20	42
Ash	9.00	5	5.12	3.13	4	5
NFE	41.72	44	40.28	52.60	59	45
NDF	73.56	-	-	-	-	
ADF	38.55	-	-	-	-	-
Hemicellulose	35.01	-	-	-	-	-
Cellulose	18.39	-	-	-	-	-
Lignin	20.50	-	-	-	-	-
Gross energy (Kcal/kg)	4430	-	5050	5513	-	-

Sources : 1* Lakshmi and Krishna (1993)
2* Tinnimit(1992)
3* Kuprasert *et al.*(1987)
4* Miyashige(1989)

An experiment conducted by Miyashige (1989) showed that the values for apparent dry matter digestibility in Kedah-Kelantan cattle were 16 and 65% for palm press fiber and palm kernel cake, respectively.

2.5 The Utilization of Direct Fed Microbials (DFM)

The use of microbial feed additives in diets has a long history. The main objectives in manipulation are to preserve and increase the nutritive value of feedstuffs. Miles (1993) reported that The United States Food and Drug Administration (FDA) defines direct fed microbials (DFM) as "a source of live (viable) naturally-occurring microorganisms." The microorganisms used in DFM fall into the category of generally being recognized as safe according to FDA and American Association of Feed Control Officials. Soqaard and Suhr-Jessen, cited by Miles (1993), reported that DFM were used basically to control and promote the proper environmental conditions for the establishment of an ideal microbial population in an animal's digestive tract. Fuller (1989) defined probiotics as "a live microbial feed supplement which beneficially affects a host animal by improving its intestinal microbial balance". He also emphasized the importance of live cells as an essential component of an effective probiotic.

Williams and Newbold (1990) and Bolsen *et al.*(1992) suggested that microbial cultures can be used in feed preservation, restoring gut function in stressed livestock and enhancing feed utilization. The various species of DFM or probioticsare shown in Table 4.

Table 4 Direct fed microbials (DFM) generally recognized as safe

Genus	Species
Aspergillus	*niger*
	oryzae
Bacillus	*coagulans*
	lentus
	lincheniformis
	subtilis
Bacteroides	*amylophilus*
	capillosus
	ruminococcus
Bifidobacterium	*adolescentis*
	bifidum
	infantis
	thermophilum
Lactobacillus	*acidophilus*
	bulgaricus
	casei
	lactis
	cellobiosus
	plantarum
Leuconostoc	*mesenteroides*
Pediococcus	*acidilacticii*
	pentosaceus
Propionibacterium	*freudenreichii*
	shermanii
Saccharomyces	*cerevisiae*
Streptococcus	*cremoris*
	lactis
	faecium
	thermophilum

Sources: Fuller (1989) and Miles (1993)

2.6 Cellulose Degradation by Microorganisms

In general, rice straw contains a high proportion of cellulosic materials. Therefore, microorganisms such as cellulolytic bacteria play an important role in the fermentation process to break down and enhance the digestibility of straw. Enari(1983), Coughlan (1990), and Stutzenberger (1990) reported that during fermentation, cellulolytic enzymes are formed by a large number of microorganisms. Cellulolytic bacteria are found among gliding bacteria and actinomycetes, as well as among both gram-negative and gram-positive true bacteria. They include aerobic species such as myxobacteria (*Cytophaga,Sporocytophaga*), *Actinomycetes* and *Pseudomonas*, facultative and anaerobes such as *Bacillus* and *Cellulomonas*, and finally strict anaerobes like *Clostridium* and *Bacteroides*. The ability to produce cellulolytic enzymes is also widespread among fungi such as *Trichoderma reesei*. (formerly designated as *Trichoderma viride.*), *Trichoderma koningii*, *Penicillium funiculosum*, *Penicillium pinophilum*, *Fusarium solani*, *Aspergillus terreus*, *Aspergillus niger*, *Talaromyces emersonii*, *Thermoascus aurantiacus* and others. Movillon (1989) and Tancongco *et al.*(1990) reported that the numbers of the fungal genus *Trichoderma* are important sources of commercial cellulase which is used to enhance the making of compost from industrial and agricultural waste materials like rice straw, coconut coir dust, weeds and natural agents of decomposition.

2.7 Properties and Modes of Action of Cellulases

Chitmanee (1992), Verma *et al.*(1982), Enari (1983), and White (1982) reported that there were three major types of cellulolytic enzymes:

1. Endoglucanase or endo 1-4 β glucanase which hydrolyses β- 1,4 - glycosidic bond of cellulose randomly.

2. Cellobiohydrolase or exoglucanase which acts on cellulose by splitting-off cellobiose units from the non-reducing end of the chain.

3. Cellobiase or β- glucosidase which hydrolyses cellobiose and cello-oligosaccharide to glucose.

The model of enzymatic hydrolysis of cellulose is shown in Figure 2.

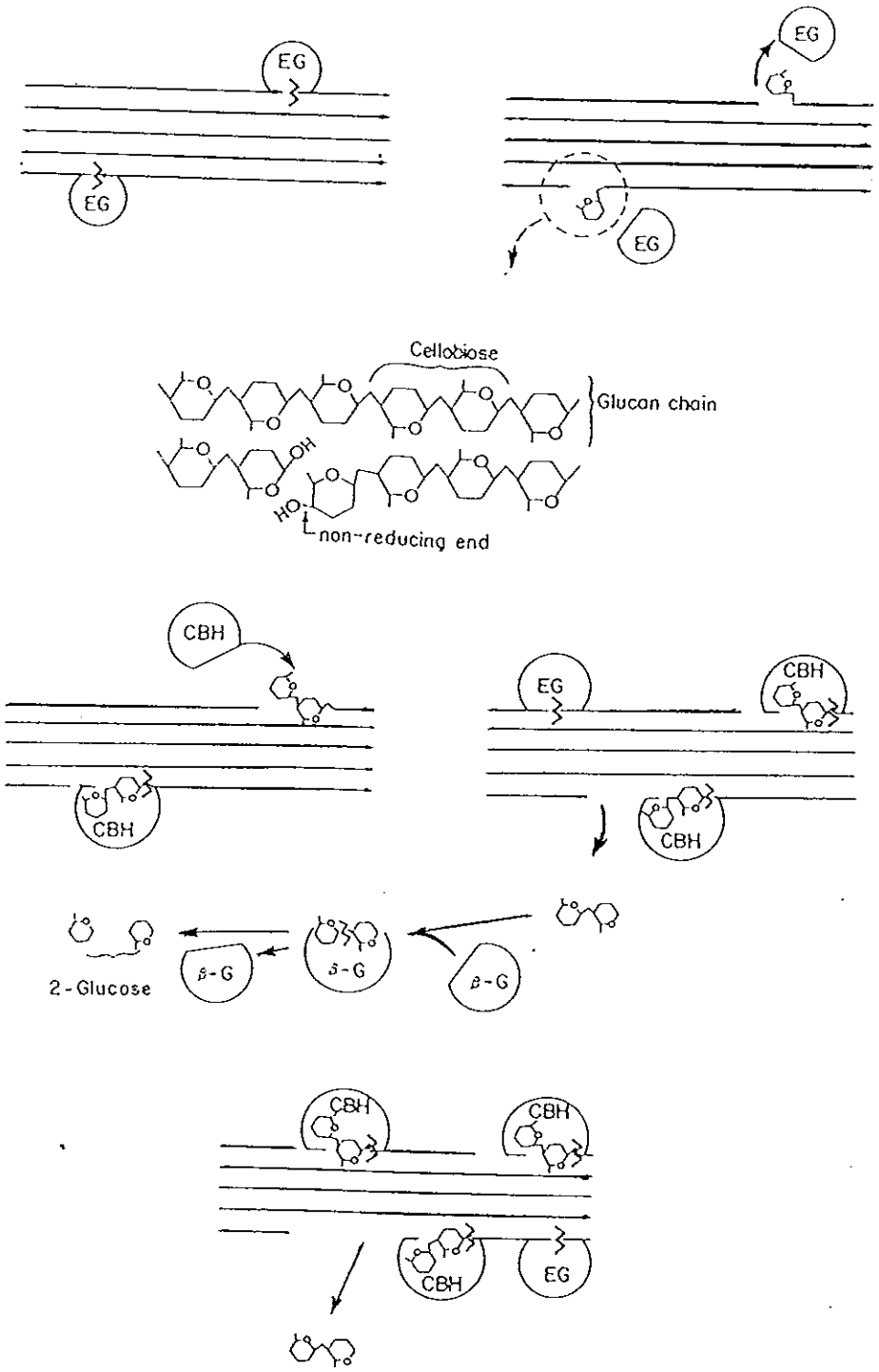


Figure 2: A schematic representation of cellulase action.

Source: White (1982)

Remarks: The cellulase enzyme system consists of three major enzymes: endoglucanase(EG), cellobiohydrolase,(CBH),and β-glucosidase (β-G)

The degradation of feedstuffs by rumen microbes causes the production of various gasses. According to Yokoyama and Johnson (1988), the composition of the gas mixture in the rumen is about 65% CO_2, 27% CH_4, 7% N_2, 0.6% O_2 , 0.2% H_2, and 0.01% H_2S. Rumen temperature remains relatively constant at 38-42°C, and rumen pH is usually between 6-7. Under any circumstances, extraneous microbes never exert a significant influence on fermentation because they cannot compete successfully with those microbes which have been selected under the conditions of the rumen environment. Orpin and Joblin (1988), Stewart and Bryant(1988), and Yokoyama and Johnson(1988) reported that preliminary classification of rumen bacteria has largely followed a system based on the type of substrates as shown in Table 5.

Table 5 Groupings of rumen bacterial species according to the type of substrates fermented

Cellulolytic species	
	Bacteroides succinogenes
	Ruminococcus flavefaciens
	Ruminococcus albus
	Butyrivibrio fibrisolvens
Hemicellulolytic species	
	Bytyrivibrio fibrisolvens
	Bacteroides ruminocola
	Ruminococcus sp.
Pectinolytic species	
	Bytyrivibrio fibrisolvens
	Bacteroides ruminocola
	Lachnospira multiparus
	Succinivibrio dextrinospolvens
	Treponema bryantii
	Streptococcus bovis
Amylolytic species	
	Bacteroides amylophilus
	Streptococcus bovis
	Succinomonas amylolytica
	Bacteroides ruminocola
Ureolytic species	
	Succinivibrio dextrinosolvens
	Selenomonas sp.
	Bacteroides ruminocola
	Ruminococcus bromii
	Butyrivibrio sp.
Methane-producing species	
	Methanobrevibacter ruminantium
	Methanobacterium formicicum
	Methanomicrobium mobile

(to be continued)

Table 5 (continued)

Sugar-utilizing species	
	Treponema bryantii
	Lactobacillus vitulinus
	Lactobacillus ruminus
Acid-utilizing species	
	Megasphaera elsdenii
	Selenomonas ruminantium
Proteolytic species	
	Bacteroides amylophilus
	Bacteroides ruminocola
	Butyrivibrio fibrisolvens
	Streptococcus bovis
Amino-producing species	
	Bacteroides ruminocola
	Megasphaera elsdenii
	Selenomonas ruminantium
Lipid-utilizing species	
	Anaerovibrio lipolytica
	Butyrivibrio fibrisolvens
	Treponema bryantii
	Eubacterium sp.
	Micrococcus sp.

Sources: Orpin and Joblin (1988) and Yokoyama and Johnson (1988)

2.8 Characteristics and Properties of Cellulose

Hall *et al.*(1978), Goodwin and Mercer (1983), and Coughlan (1990) reported that cellulose is the most abundant organic macromolecule found on the earth. Usually, most of them contain more than 90% cellulose which is made up of glucose. The glucan

portion of extracted cellulose is made up of β(1→4) glycosidic linkages (Figure 3). Most authorities estimate a value within the range 2,000-14,000 glucose units for a chain of natural cellulose with a chain length of 1-7 μ and a molecular weight approaching 1 million or more. β(1→4) linkages give rise to relatively rigid linear molecules which are able to align closely with their neighbours, and the free hydroxyl groups of carbons at positions 2, 3, and 6 probably form hydrogen bonds with neighbour chains which bind the molecules together. In this way, the glucan chains are thought to be packed and known as microfibrils. Possibly up to 100 glucan chains are packed together in these microfibrils giving rise to a flattened, thread like structure.

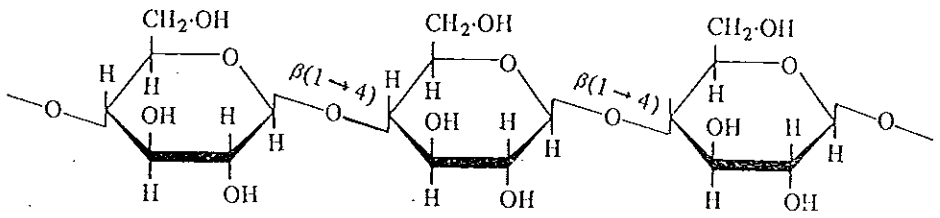


Figure 3: Structure of cellulose made up of β(1→4) glycosidic linkages between glucose units

Source: Hall *et al.* (1978)

The hemicellulose in monocot cell walls is composed basically of long chains of β(1→4) linked xylose units (Figure 4) to which are attached, through C-2 or C-3, by short carbohydrate side chains often of a single arabinose residue or a uronic acid. The dicot hemicellulose is, if any, more complex in structure, including xylans, glucomannans, galactoglucomannans, and arabinogalactans.

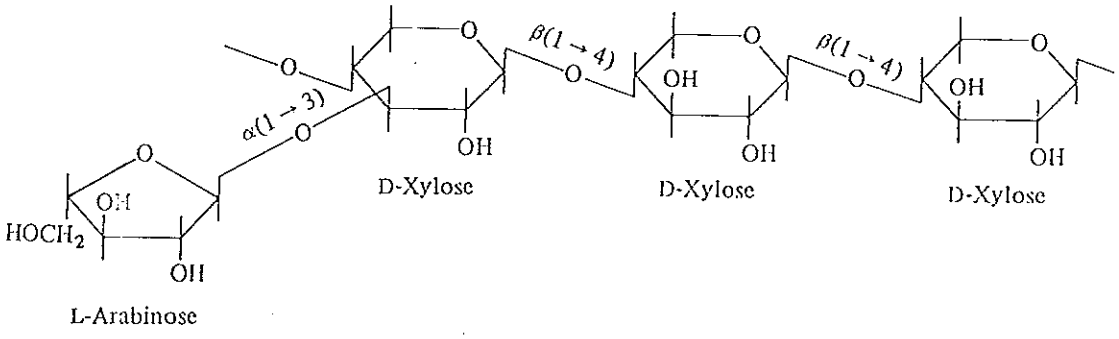
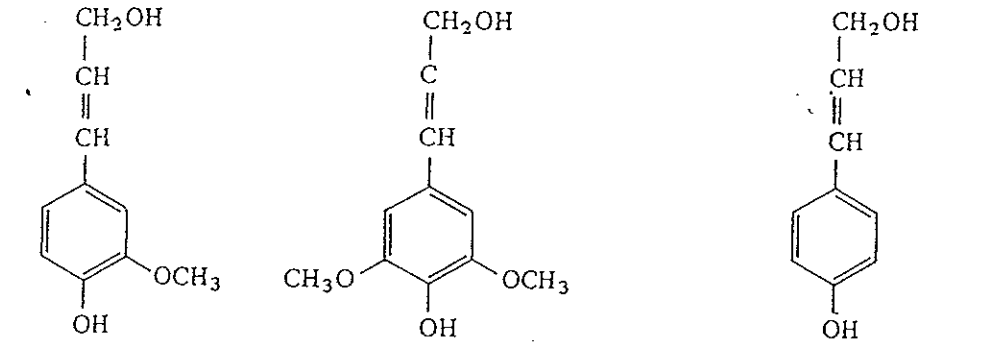


Figure 4: Partial structure of hemicellulose in part of arabinoxylan
Source: Goodwin and Mercer (1983)

Lignin is always found in cell walls and is closely associated with cellulose or some other carbohydrate. Whole lignin molecules are comprised of many phenylpropanoid units. Various kinds of phenylpropanoid units are presented in Figure 5. These are usually methoxylated on the aromatic ring.



(*a*) Coniferyl alcohol (Guaiacyl) (*b*) Sinapyl alcohol (Syringyl) (*c*) *p*-Hydroxycinnamyl alcohol

Figure 5: Various structures of phenylpropanoid units that are precursors of lignin

Source: Goodwin and Mercer (1983)

Lignification appears to fulfil two main functions. It cements and anchors cellulose fibrils together and, because of its hardness, it stiffens the cell wall and prevents chemical and physical damage to the cell. A complex polymer of lignin is shown in Figure 6.

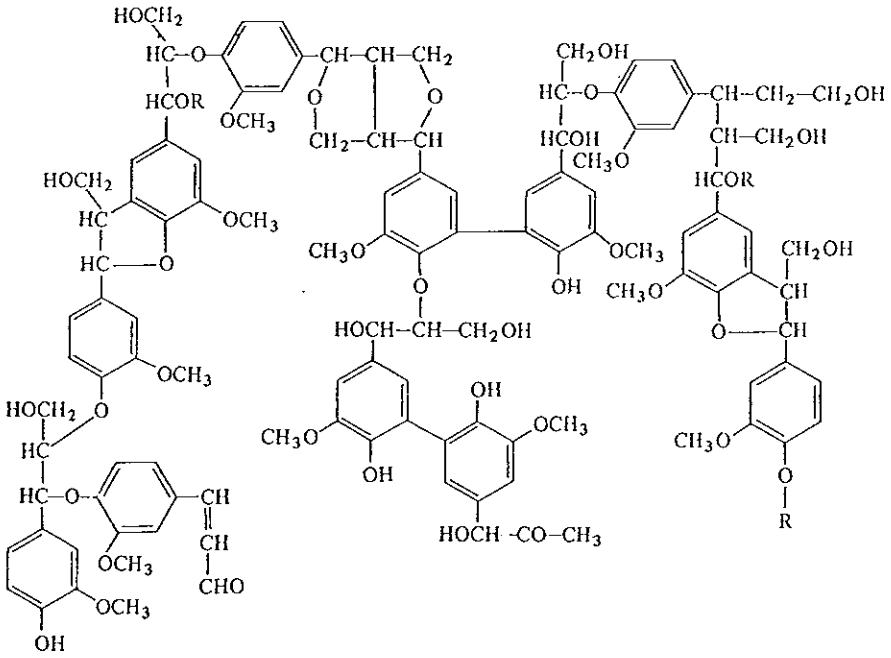


Figure 6: The complex structure of a lignin polymer

Source: Goodwin and Mercer (1983)

2.9 Digestion of Plant Cell Walls by Rumen Microorganisms

Bauchop (1979) and Chesson and Forsberg (1983) suggested that bacteria, fungi, and protozoa colonise practically all plant materials that enter the rumen. The major route of invasion appears to be via epidermal lesions. Colonisation by entering through stomatae is comparatively unimportant with stem fragments of forages, but it can be of greater importance for colonisation of leaves. Microorganisms exhibit a tight adhesion, frequently conforming to the

surface of the material being digested as shown in Figure 7.

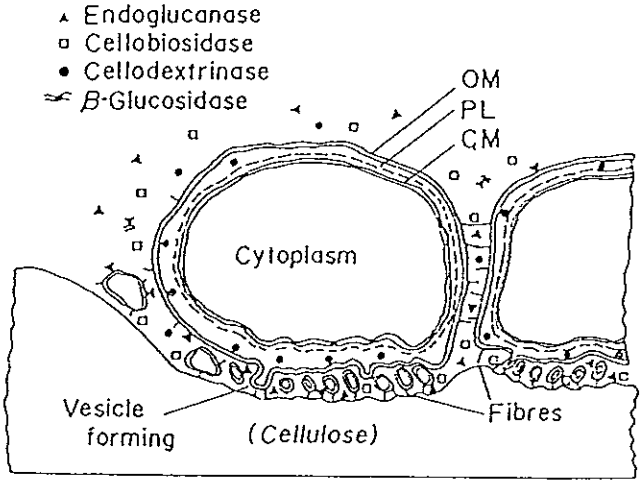


Figure 7: Sketch of a transverse section of microorganisms growing on cellulose, showing the locations of the enzymes of the cellulase complex

Source: Chesson and Forsberg (1983)

Remarks: OM = outer membrane

PL = plasma lemma

CM = cytoplasmic membrane

3 Objectives

The study aimed to achieve the following objectives:

1 To improve the nutritive value of rice straw by producing haylage supplemented with palm kernel cake and urea and/or microbial inoculants in a partially mixed ration.

2 To evaluate the nutritive values and digestibility of rice straw supplemented with palm kernel cake and ensiled with urea and/or microbial inoculants.

CHAPTER 2

MATERIALS AND METHODS

1. Experimentation Program

This study consisted of three experiments:

Experiment 1 investigated the effect of the addition of PKC, molasses, Effective Microorganisms (EM), and urea to rice straw on the dry matter intake (DMI) and digestibility of various nutrients in rice straw.

Experiment 2 evaluated the influence of different levels of urea on the dry matter intake and dry matter digestibility of rice straw supplemented with microbial inoculants (Poh-Doh 1), PKC, and molasses.

Experiment 3 studied the influence of different levels of microbial inoculants (Poh-Doh 1) on the dry matter intake and dry matter digestibility of rice straw supplemented with urea, PKC, and molasses.

2. Experiment 1

Digestion trials were conducted to evaluate the effect of EM microbes and urea supplementation to rice straw plus molasses and PKC on dry matter intake and nutrient digestibility in mature male goats.

This experiment was conducted at the Small Ruminant Section, and the Animal Nutrition Laboratory, Department of Animal Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, during October 1995 through February 1996.

2.1 Source of Rice Straw

Rice straw was collected from a private farm in Phathalung province, southern Thailand. The straw was machine-harvested by cutting the plant at 20-30 cm from the ground and baled after grain harvest.

2.2 Source of Palm Kernel Cake

Palm kernel cake in this study was commercially processed by expeller extraction. The cake from the same palm oil factory was used in all experiments.

2.3 Type of Microbial Inoculants

EM microbes were used in this study. The technology of EM microbes was developed by Dr. Teruo Higa, a Professor at the College of Agriculture of the University of Ryukyu in Okinawa, Japan. EM microbes are a mixed microbial culture of selected species of microorganisms with predominant numbers of lactic acid bacteria, yeasts, actinomycetes, and photosynthetic bacteria. All of these microorganisms are mutually compatible with one another and can coexist in a molasses liquid culture (Higa, 1993).

2.4 Dietary Treatments

Rice straw was cut to approximately ½-1 inch in length. The proportions of materials used in this experiment were 5 kg rice straw (air dry basis), 5 kg water, 500 g (10% of rice straw, w/w) palm kernel cake, 25 ml molasses, 25 ml(total plate count of 1 x 10^4cfu/ml) EM microbes, 300g (6% of rice straw, w/w) urea (N = 46%) with the same proportions as those described by Wanapat *et al.*(1985).

The following four treatments were used:

Treatment 1 = rice straw + water + palm kernel cake + molasses

Treatment 2 = rice straw + water + palm kernel cake + molasses + EM microbes

Treatment 3 = rice straw + water + palm kernel cake + molasses + urea

Treatment 4 = rice straw + water + palm kernel cake + molasses + EM microbes + urea

For all treatments the following procedures were performed. Chopped rice straw was spread uniformly over a plastic sheet and wet by applying 3 kg or 60% of water. Another 40% of water was mixed with molasses and EM microbes or urea or EM microbes and urea then sprayed onto the rice straw using a watering can. The palm kernel cake

was then added to the mixture. All ingredients were thoroughly mixed on a plastic sheet before being placed in a black plastic bag. The contents were pressed down and the air was removed before tieing the bag firmly with a piece of nylon string. The bag of haylage was kept on a shelf for 21 days. The contents were sampled for chemical analyses and then offered to experimental animals to determine the dry matter intake and nutrient digestibility.

2.5 Experimental Animals

2.5.1. Animals used for digestion trial

Four mature male goats with an average live weight of 40 kg were treated for internal and external parasites and placed in individual stalls, each fitted with a feed trough and waterer.

2.5.2. Animals used for nylon bag technique

Four Anglo-Nubian crossbred mature male goats (average live weight of 42 kg) fitted with rumen cannulas were used in this experiment.

2.6 Feeding and Management

2.6.1 Procedures used in the digestion trial

Goats were fed solely with straw haylage *ad libitum* during a 10 day preliminary period to determine voluntary feed intake. Four days before the collection period started, the amount of feed offered was adjusted to

90% of *ad libitum* intake. The collection period lasted for seven days. Feeding was done twice daily at 7.30 and 16.30 hours. Feces were collected directly into a blue net tray placed under the pen. Daily aliquot feed (1%) and feces (10%) samples were collected. The samples were bulked and stored in a freezer at -18 °C for subsequent analyses. After each period of the digestion trial, all samples were thawed, and the representative samples of the 7-day collection period were thoroughly mixed. Samples of offered straw haylage and feces were dried, ground through a 1 mm screen, and stored for chemical analysis.

2.6.2 Procedures used in the nylon bag technique

Goats were housed and fed individually in a barn in 3x3 m pens. The animals were fed equal diets twice daily (8.30 h and 16.30 h) with 1% (DM basis) of body weight as roughage, 600 g concentrate per day, and free access to water.

2.7 Methods of Analysis

The digestibility of various rice straw haylages was evaluated by three methods: *in vivo* technique, the nylon bag techniques (*in sacco*), and the pepsin cellulase technique (*in vitro*). Details of each method are described as follows:

2.7.1 *In vivo* digestibility

Two duplicate samples from four periods for each treatment of straw haylage and feces were analyzed for moisture, CP, EE, CF, total ash, and nitrogen-free extract (NFE) content by standard methods following the Association of Official Analytical Chemists (AOAC) Procedure (1984). NDF or cell wall (CW), acid-detergent fiber (ADF), acid-detergent lignin (ADL) and acid-insoluble ash (AIA) were determined according to the procedures of Goering and Van Soest (1970). Hemicellulose was calculated as the difference between NDF and ADF, and cellulose was calculated as the weight loss after treating ADF residue with 72% H_2SO_4.

From the chemical analysis data, the apparent digestion coefficient (Dig. Coef.) of DM, OM, CP, CF, NDF, ADF, and cellulose were computed as follows:

Total collection method

$$\text{Dig.Coef.of DM(\%)} = \frac{\text{kg(DM) feed intake} - \text{kg(DM) feces}}{\text{kg (DM) feed intake}} \times 100$$

$$\text{Dig.Coef.of CP(\%)} = \frac{\text{g CP intake} - \text{g CP in feces}}{\text{g CP intake}} \times 100$$

$$\text{Dig.Coef.of OM(\%)} = \frac{\text{g OM intake} - \text{g OM in feces}}{\text{g OM intake}} \times 100$$

$$\text{Dig.Coef.of CF(\%)} = \frac{\text{g CF intake} - \text{g CF in feces}}{\text{g CF intake}} \times 100$$

$$\text{Dig.Coef.of EE(\%)} = \frac{\text{g EE intake} - \text{g EE in feces}}{\text{g EE intake}} \times 100$$

$$\text{Dig.Coef.of NDF(\%)} = \frac{\text{g NDF intake - g NDF in feces}}{\text{g NDF intake}} \times 100$$

$$\text{Dig.Coef.of ADF(\%)} = \frac{\text{g ADF intake - g ADF in feces}}{\text{g ADF intake}} \times 100$$

$$\text{Dig.Coef.of C(\%)} = \frac{\text{g C intake - g C in feces}}{\text{g C intake}} \times 100$$

% TDN = % Dig. CP + (% Dig.EE × 2.25) + % Dig. CF
+ % Dig. NFE

2.7.2. Nylon bag technique (*in sacco* digestibility)

Four rumen fistulated mature male goats (Anglo-Nubian crossed with Thai native, with average live weight of 42 kg) were used in this experiment to determine the dry matter digestibility of straw haylage by the nylon bag technique. The nylon bag procedures were similar to those described by Ørskov *et al.*(1980) and Kempton (1983) with some modifications. Each bag (10 × 4 cm with a pore size of 45 μ) contained 2 gm of air dried sample of each treatment. Four bags for the four experimental diets were subsequently attached to 40 cm of nylon string. The bags were soaked in water for 5 min before being placed in the rumen. Duplicate nylon bags were incubated for 48 h. The bags were removed from the rumen and washed until the rinse fluid was clear. They were dried at 100 °C and weighed to calculate the decrease in dry matter.

2.7.3 Pepsin-cellulase *in vitro* digestibility

Duplicate samples of the four straw haylage samples were analyzed for pepsin-cellulase solubility by using a modification of the method of Goto and Minson (1977) and McLeod and Minson (1978). Samples of 0.5 g were incubated with 50 ml of 0.1 N hydrochloric acid containing 0.2% pepsin (Fluka Biochemical, from hog stomach, crystalline powder 0.26 unit/g) in 100 ml centrifuge tubes at 39 °C for 48 h to remove the cell contents. After centrifuging at 3,000 rpm for 10 min, the supernatant was removed. The cellulase solution used contained 2.5% cellulase extracted from *Aspergillus niger* (Fluka Biochemical, white powder 0.26 unit/mg)in acetate buffer (pH 4.6) containing 6.8 g sodium acetate ($CH_3COOHNa.3\ H_2O$) and 2.9 ml glacial acetic acid (CH_3COOH) per liter. Then 50 ml of cellulase solution were added, and the tubes were incubated for a further 48 h at 39 °C, during which they were shaken gently by hand twice a day. The tubes were then centrifuged at 3,000 rpm, the supernatant was discarded, and the residue was washed twice with water before being dried at 100 °C and weighed. The loss in weight was expressed as a percentage of the weight of the original sample.

$$\% \text{ IVDMD} = \frac{\text{g of original sample} - \text{g of residue} \times 100}{\text{g of original sample}}$$

2.8 Experimental Design and Statistical Analysis

2.8.1 Digestion trials

Goats were randomly allotted to the four treatments in a 4 × 4 Latin Square Design (LSD). The data of various values of nutrient digestibility were statistically analyzed using a Latin Square Design for four treatments by four replications.

2.8.2 Nylon bag technique

The data from *in sacco* disappearance (nylon bag technique) were statistically analyzed using a Randomized Complete Block Design (RCBD) with four replications for each treatment.

2.8.3 *In vitro* digestibility

The data from chemical composition and *in vitro* solubility of feeds were statistically analyzed using a Completely Randomized Design (CRD).

Significant differences among treatment means were detected using Duncan's Multiple Range Test (DMRT)(Steel and Torries, 1985). All analyses were done through the computer Statistic Analytical System (SAS,1985) programs. The relationship between the data from *in vivo* and *in vitro* DMD values were fitted with linear regression equation and statistically analyzed.

3. Experiment 2

The aim of this experiment was to evaluate the effects of different levels of urea in combination with one microbial inoculant (Poh Doh-1) on the DMI and DMD of rice straw haylage. Preparations of treatments (experimental diets) and animal management were similar to those described in Experiment 1. Four male goats from Experiment 1 were used. There were two replications or periods for each treatment and 2 different goats were randomly assigned to each of the four treatments. Data from this experiment were analyzed by using the mean from the two replications.

Four treatments of experimental straw haylage were prepared as shown:

Treatment 1 = rice straw + water + PKC + molasses + 25 g Poh Doh-1 microbes + 1.5% urea

Treatment 2 = rice straw + water + PKC + molasses + 25 g Poh Doh-1 microbes + 3.0% urea

Treatment 3 = rice straw + water + PKC + molasses + 25 g Poh Doh-1 microbes + 4.5% urea

Treatment 4 = rice straw + water + PKC + molasses + 25 g Poh Doh-1 microbes + 6.0% urea

Remarks: Poh Doh-1 microbes are a mixed culture of 3 genera and 10 species of various microorganisms that have been used to accelerate the making of compost or the

decomposition of organic wastes. The culture was obtained from the Department of Land Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

4. Experiment 3

This experiment was conducted to evaluate the influence of different levels of microbial inoculant (Poh Doh-1) in combination with urea on the DMI and DMD values of straw haylage. The microbial inoculant used in this study is the same as described in Experiment 2. The replications and animal management procedures for this experiment were the same as those in Experiment 2.

Four treatments of experimental straw haylage were prepared as shown:

Treatment 1 = rice straw + water + PKC + molasses + 3.0% urea

Treatment 2 = rice straw + water + PKC + molasses + 3.0% urea + 25 g Poh Doh-1 microbes

Treatment 3 = rice straw + water + PKC + molasses + 3.0% urea + 50 g Poh Doh-1 microbes

Treatment 4 = rice straw + water + PKC + molasses + 3.0% urea + 75 g Poh Doh-1 microbes

CHAPTER 3

RESULTS AND DISCUSSION

The research findings for Experiment 1 are presented on the following: the chemical composition of the experimental diets and feces; an evaluation of the *in vivo* digestibility of various nutrients, *in sacco* dry matter digestibility (nylon bag technique) and *in vitro* DMD values (pepsin-cellulase technique), and dry matter intake. The results of Experiments 2 and 3 are presented on *in vivo* dry matter digestibility and dry matter intake values.

1. Chemical Composition of Experimental Diets

The average chemical composition of the various straw haylages are presented in Table 6. The major constituents showed no significant differences among treatment means: dry matter (44.870 - 46.586%), organic matter (89.139 - 90.395%), crude fiber (36.396 - 37.158%), ether extract (1.972 -2.085%), and ash (9.605-10.861%). There was no significant difference in crude protein content between Treatments 3 and 4 (11.490 and 11.457%, respectively), but both were significantly higher than those for Treatments 1 and 2 due to the addition of 6% urea. These increases were similar to those reported by Promma *et al.*(1988), that a 6% urea treatment of rice straw increases crude protein by 5.5%. The NFE showed significant

differences among treatment means ($P < 0.05$). Treatment 1 had the highest NFE content (43.175%), followed by Treatments 2, 4, and 3 (42.265, 40.501, and 39.312%, respectively). There was no significant difference in NFE between Treatments 3 and 4, but the NFE of both treatments showed significant differences from Treatment 1. There were no significant differences in the NFE between Treatments 2 and 4 and between Treatments 1 and 2. Both Treatments 3 and 4, which contained urea, may stimulate microbial activities and rumen degradation of crude fiber at the expense of soluble carbohydrate (Promma *et al.*,(1988). Therefore, the NFE contents of these two treatments were lower than those of Treatments 1 and 2.

Table 6 Chemical composition of treatments (experimental diets) used in Experiment 1 (% on DM basis)

Constituent	Treatment			
	1	2	3	4
Dry matter	44.870	46.345	46.586	45.198
Organic matter	89.925	89.139	89.703	90.395
Crude protein	8.192[a]	7.975[a]	11.490[b]	11.457[b]
Crude fiber	36.585	36.831	37.158	36.396
Ether extract	1.972	2.007	2.085	2.042
Ash	10.075	10.861	10.297	9.605
Nitrogen-free extract	43.175[a]	42.265[ab]	39.312[c]	40.501[bc]

Remarks: Treatment 1 = rice straw + palm kernel cake + molasses + water

Treatment 2 = Treatment 1 + EM microbes

Treatment 3 = Treatment 1 + urea

Treatment 4 = Treatment 1 + EM microbes + urea

Means within any rows with different superscripts indicate significant differences ($P < 0.05$).

Fiber components of various straw haylages are given in Table 7. There was no significant difference among treatment means (P >0.05) in any of the cell wall contents. The NDF content ranged from 76.288 - 77.785%; ADF ranged from 54.161 -55.204%; cellulose ranged from 44.090 - 45.609%; hemicellulose ranged from 22.126 - 22.581%; ADL ranged from 5.180 - 6.156%; and AIA varied from 3.870 - 4.533%. These results indicate that rice straw treated with or without urea and/or EM microbes did not significantly change the quantity of all fiber components. However, the enhancement of fiber digestibility in the alimentary tract of ruminants was observed as shown from the data presented in Table 8.

Table 7 Fiber components of the various experimental diets (% on DM basis)

Constituent	Treatment			
	1	2	3	4
NDF	76.913	77.494	76.288	77.785
ADF	54.717	55.144	54.161	55.204
Cellulose	44.090	45.609	44.448	45.503
Hemicellulose	22.259	22.331	22.126	22.581
ADL	6.156	5.663	5.180	5.203
AIA	4.471	3.870	4.533	4.498

Remarks: Treatment 1 = Rice straw + palm kernel cake + molasses + water

Treatment 2 = Treatment 1 + EM microbes

Treatment 3 = Treatment 1 + urea

Treatment 4 = Treatment 1 + EM microbes + urea

NDF = neutral-detergent fiber , ADF = acid-detergent fiber,

ADL = acid-detergent lignin

AIA = acid-insoluble ash (by Van Soest method)

2. Digestibility of Nutrients in Experimental Diets

The results of nutrient digestibility coefficient from the digestion trials are given in Table 8.

2.1 Apparent Digestibility Coefficient for Dry Matter

Statistical analysis of the apparent digestibility coefficient for dry matter of various straw haylages showed highly significant differences among treatment means ($P < 0.01$). Treatment 3 (containing urea) showed the highest apparent digestibility coefficient for dry matter (58.753%), which was significantly higher than those for Treatments 1 and 2 (no urea). The lowest apparent digestibility coefficient for dry matter was observed in Treatment 1 (48.463%). There was no significant difference in the apparent digestibility coefficient for dry matter between Treatments 3 (containing urea) and 4 (containing EM microbes and urea), but both showed significantly higher ($P <0.01$) digestibility values than those for Treatments 1 and 2. The value for Treatment 2 was significantly higher ($P <0.05$) than for Treatment 1. The results of this study indicate that supplementation of urea and/or EM microbes to rice straw significantly improve the apparent digestibility coefficient for dry matter. Promma *et al.*(1985) and Dixon and Egan (1988) reported that the fibrous portion of crop residue is often compounded by high contents of lignin and silica which are resistant to microbial digestion in

Table 8 Percentage of *in vivo* nutrient digestibility of various straw haylages in Experiment 1 (on dry matter basis)

Nutrients	Treatment			
	1	2	3	4
Dry matter	48.463[a]	53.053[b]	58.753[c]	57.476[c]
Organic matter	54.699[a]	57.428[a]	63.677[b]	62.401[b]
Crude protein	70.410[a]	72.859[a]	76.748[b]	77.182[b]
Ether extract	64.849	66.841	71.788	72.883
Crude fiber	66.098[a]	70.944[b]	77.149[c]	76.722[c]
NFE	41.412	42.146	45.867	42.816
NDF	52.433[a]	58.599[b]	64.289[c]	65.487[c]
ADF	50.876[a]	56.657[b]	57.558[b]	56.910[b]
Cellulose	74.434[a]	81.778[b]	83.008[b]	82.227[b]
TDN	50.835[a]	52.930[a]	58.874[b]	57.715[b]

Remarks: Treatment 1 = rice straw + palm kernel cake + molasses + water

Treatment 2 = Treatment 1 + EM microbes

Treatment 3 = Treatment 1 + urea

Treatment 4 = Treatment 1 + EM microbes + urea

TDN = total digestible nutrients

Figures in any rows with different superscript indicate significant differences ($P < 0.01$)

herbivores, and the residue has low concentrations of protein and readily available carbohydrates. Treating rice straw with urea will increase the apparent digestibility coefficient for dry matter because ammonia from urea acts mainly on the linkages among cell wall components. Chesson and Forberg (1988) and Zorrilla-Rios *et al.*(1985) stated that when linkages are swollen and loose, it increases the accessibility by rumen microorganisms. In a similar manner, EM microbes which contain various groups of microorganisms, especially cellulolytic species such as *Trichoderma* and *Aspergillus,* can produce cellulolytic enzymes to digest the fiber substrates.

2.2 Apparent Digestibility Coefficient for Crude Protein.

The apparent digestibility coefficients for crude protein is shown in Table 8. There were significant differences ($P < 0.05$) in the apparent digestibility coefficient for crude protein among treatment means. Treatment 4 had the highest value (77.182%), followed by those of Treatments 3, 2, and 1. No significant difference was observed for Treatments 3 and 4 probably due to the inclusion of 6% urea during the ensiling process, and both were significantly higher than that for Treatments 1 and 2. No significant difference was observed between Treatment 2 and Treatment 1. These findings are in consonance with the report of

Klopfenstein (1978) that the advantage of urea and molasses mixed with rice straw may be due to increased microbial activity enhanced by nitrogen from urea and readily fermentable carbohydrate supplied by molasses. This result agrees with that of Schiere and Ibrahim (1985) and Virk *et al.*(1995) who reported that urea treatment of rice straw increases the intake and digestibility as well as the crude protein content.

2.3 Apparent Digestibility Coefficient for Crude Fiber.

The apparent digestibility coefficient for crude fiber is shown in Table 8. There were highly significant differences ($P < 0.01$) among treatment means. Treatment 3 (containing urea) had the highest apparent digestibility coefficient for crude fiber (77.149%). No significant difference was noted between Treatments 4 and 3, but both were significantly higher ($P < 0.05$) than those for Treatments 1 and 2. A significant difference in crude fiber digestibility was observed between Treatments 1 and 2. Promma *et al.*(1988) reported that the increase in crude fiber digestibility is presumably due to the breaking of lignocellulose bonds by the action of ammonium hydroxide formed after liberation of ammonia from urea. Ayala *et al.*(1992) found that both probiotics and urea-molasses supplement increases fiber digestibility and the number of ruminal microbes. This suggests that increases in fiber digestion could be associated with a

higher ruminal microbial population. Rush *et al.*(1990) performed studies on ruminal roughage digestion by placing a gelatin capsule of *Lactobacillus plantarum* in the rumen of fistulated cattle. However, that particular microbe did not improve the dry matter digestibility of roughage, probably because *Lactobacillus* is not a cellulolytic bacteria.

2.4 Apparent Digestibility Coefficient for neutral-detergent fiber (NDF)

The apparent digestibility coefficient for NDF showed significant differences ($P < 0.01$) among treatment means. Treatment 4 had the highest apparent digestibility coefficient for NDF (65.487%), but there was no significant difference from Treatment 3 (64.289%). Both were significantly higher ($P < 0.05$) than Treatments 1 and 2, whereas Treatment 2 was significantly higher ($P < 0.05$) than Treatment 1. Previous work (Tinnimit 1988, and Wanapat *et al.* 1984) has indicated that high fiber and ash contents are major factors limiting the utilization of rice straw by ruminants. Although the fiber and ash contents from these experimental diets were similar, rice straw treated with urea and/or EM microbes had higher NDF digestibility values than Treatments 1 and 2. Sharif (1984) reported that the microbial digestion of straw is limited by the masking effect of substances present in the cell wall which limit the contact of rumen microorganisms and enzymes with structural carbohydrates.

The cell walls have to be easily opened when chewed. Dixon (1986) reported that microbial digestion of fiber in the rumen was closely related to the rate of digestion and lag time before appreciable digestion could occur.

2.5 Apparent Digestibility Coefficient for acid-detergent fiber (ADF)

The apparent digestibility for ADF showed highly significant differences among treatment means ($P < 0.01$). While the ADF content showed no significant difference among Treatments 2,3 and 4 (56.657%, 57.558% and 56.910%, respectively), these values showed a high and significant difference ($P<0.01$) from Treatment 1 (50.876%). These results indicate that both EM microbes and urea increase the apparent digestibility coefficient for ADF. Wiedmeier *et al.*(1987) reported that although microbial cultures do not produce the enzymatic machinery to completely depolymerize structural carbohydrates to simple sugars, they produce enzymes that cause partial depolymerization and aid rumen cellulolytic bacteria in completing the depolymerization of cellulosic material to simple sugars. Wanapat *et al.*(1984) reported that the mechanisms by which alkaline increase microbial attacks have been attributed to its effect on the constitution of lignin; its ability to delignify the cell wall; and its ability to break bonds between lignin and hemicellulose or cellulose (lignocellulose bonds) without decreasing the lignin content. A number of reports citing the

mechanisms by which various chemical treatments will improve the potential digestibility of fibrous feedstuff can be found in the literature of Wanapat *et al.*(1985), and Tinnimit (1992).

2.6 Apparent Digestibility Coefficient for Organic Matter (ADCOM)

The ADCOM is shown in Table 8. There were significant differences ($P<0.01$) in the ADCOM among treatment means. Treatment 3 showed the highest ADCOM (63.677%), followed by Treatments 4, 2, and 1 (62.401, 57.428, and 54.699%, respectively). There was no significant difference in the ADCOM between Treatments 3 and 4, but both treatments showed significantly higher values than those for Treatments 1 and 2. The value for Treatment 2 was slightly higher than that for Treatment 1, but the difference was not significant. Promma *et al.*(1988) reported that the treatment of rice straw with 6% urea increases the organic matter digestibility by 8.0 percentage units.

2.7 Apparent Digestibility Coefficient for Cellulose (ADCC)

The result of ADCC is shown in Table 8. The differences for ADCC among treatment means were highly significant ($P <0.01$). Treatment 3 had the higest ADCC (83.008%), followed by Treatments 4, 2, and 1 (82.227, 81.778, and 74.434%, respectively). There were no

significant differences in the ADCC among Treatments 3, 4, and 2, but those values were significantly higher ($P < 0.01$) than that for Treatment 1. The ADCC values followed the same trend as those of NDF.

2.8 Total Digestible Nutrients (TDN)

Statistical analysis of the TDN from the various straw haylages showed highly significant differences ($P<0.01$) among treatment means. Treatment 3 had the highest TDN value (58.874%) and the lowest TDN value was observed in Treatment 1 (50.835%). There was no significant difference for TDN values between Treatments 3 and 4, but both treatments had significantly higher values than those for Treatments 1 and 2. The value for Treatment 2 was slightly higher than that for Treatment 1, but the difference was not significant.

The results showed that the apparent digestibilities of various nutrients from various straw haylages- DM, OM, CP, EE, CF, NDF, ADF, cellulose and TDN- are always similar between Treatments 3 and 4. These studies indicate that there is no potential synergism between urea and EM microbes in improving the apparent digestibility of the studied nutrients.

The apparent digestibility coefficient for CF, NDF, ADF, and cellulose in Treatment 2 was significantly higher than that for Treatment 1 primarily due to fungi, yeast, and bacteria of EM microbes (Higa, 1993). In the process of making haylage in this experiment, EM microbes

may have led to a shift in the pattern of fermentation. Although EM microbes do not produce sufficient enzymes to hydrolyse structural carbohydrates (cell wall contents) to the end products of digestion (simple sugars), they produce enzymes that cause partial digestion of structural carbohydrates. In addition, EM microbes have a stimulatory effect on the number of rumen bacteria, especially cellulolytic bacteria. Increases in the number of cellulolytic bacteria usually accompany the general bacteria stimulation. Improved CWC breakdown might therefore be expected to occur and lead to improved digestibility. There are several reports of experiments in which cell wall components were measured in ruminants with or without the addition of *Aspergillus oryzae* (AO) and *Saccharomyces cerevisiae* (SC). Beharka and Nagaraja (1993) reported that the addition of *Aspergillus oryzae* had no effect on *in vitro* NDF and ADF degradability of the pure cellulose of wheat straw and corn silage, but it increased NDF and ADF degradability of bromegrass hay and alfalfa hay. Wallace and Newbold (1993) suggested that microbial additives containing both components (yeast culture and AO) may have a broader spectrum of efficacy than those containing a single organism. Newbold *et al.* (1991) reported that both numbers of total bacteria and cellulolytic bacteria significantly increased by the addition of AO to the rumen from 1.17×10^9 to 2.27×10^9 cfu/ml, and 1.95×10^7 to 2.85×10^7 cfu/ml, respectively. Plata *et al.* (1994) found that the addition of yeast

culture with SC improved NDF disappearance in the rumen of Holstein steers at 48 h from 45.3%(no SC) to 52.5%. It also increased the ruminal protozoa population, which could partially explain the changes in NDF digestibility values. Grant *et al.* (1992) reported that fiber digestibility was inhibited when pH dropped from 6.9 to 6.0, and simultaneously the cellulolytic population fell from 10^6 to 10^3 cfu/ml. Rumen pH is depressed as a result of feeding large amounts of readily available carbohydrates. Dawson and Hopkin (1992) reported that the stimulatory effect of *Prevotella ruminicola* on cellulose digestion by *Ruminococcus albus* could have significant input on the rate and extent of cellulose degradation in cultures of cellulolytic ruminal bacteria. Dawson (1993) reported that concentrations of live yeast could influence the initial rate of cellulose degradation and metabolic activities of ruminal cellulose degraders. The lag time before the initiation of cellulose digestion is shorter in cultures containing yeast and cellulolytic bacteria (42.7 h) than in cultures containing only cellulose degraders (60.1 h). Alikhani *et al.*(1992) studied the effects of yeast supplementation in alfalfa silage or alfalfa hay. No difference was found in milk yield and milk fat from the yeast-supplemented silage or yeast-supplemented hay. However, when the yeast was combined in diets for lactating dairy cows fed on hay, these cows produced more milk than those fed silage alone (30.7 vs. 27.2 kg/d, respectively).

3. *In Sacco, In Vitro,* and *In Vivo* Digestibility of Dry Matter

In sacco, in vitro, and *in vivo* digestibility values of the various types of straw haylages are given in Table 9. DMD values showed the same trend for the various straw haylages, regardless of method. There were highly significant differences ($P < 0.01$) among treatment means. There were no significant difference in DMD values between Treatments 3 and 4: 53.344 and 53.106% *in sacco,* 28.896 and 29.602% *in vitro,* and 58.753 and 57.467% *in vivo,* respectively, but values for both treatments were significantly higher than those in Treatments 1 and 2. A significant difference ($P < 0.05$) was observed between Treatments 2 and 1: 49.743 vs 45.433% *in sacco,* 24.821 vs 20.402% *in vitro,* and 53.035 vs 48.463% *in vivo,* respectively. Haylages containing urea or EM microbes had higher DMD values than those without urea. Wanapat *et al.* (1985) found that urea treatment increases the digestibility of straw by 5 - 10%, while Promma *et al.* (1988) reported a smaller increase (3%). This increase is presumably due to the swelling and breaking of lignocellulose linkages by the action of ammonium hydroxide formed after liberation of ammonia from the urea.

Table 9 Percentage values for the DMD of the various rice straw haylages, as measured by *in sacco*, *in vitro*, and *in vivo* methods

Treatment	% DMD value		
	in sacco	*in vitro*	*in vivo*
Treatment 1 rice straw + PKC + molasses + water	45.433[a]	20.402[a]	48.463[a]
Treatment 2 rice straw + PKC + molasses + water + EM microbes	49.743[b]	24.821[b]	53.035[b]
Treatment 3 rice straw + PKC + molasses + water + urea	53.344[c]	28.896[c]	58.753[c]
Treatment 4 rice straw + PKC + molasses + water + EM microbes + urea	53.106[c]	29.602[c]	57.467[c]
SE	0.284	0.647	1.054

Remarks: *in sacco* = nylon bag technique, *in vitro* = pepsin-cellulase solubility

in vivo = DMD by goats

Significant differences ($P < 0.01$) between treatment means are indicated by dissimilar superscripts within columns.

4. Correlation Between *In Vivo* DMD and *In Vitro* Dry Matter Digestibility Values

A total of 16 samples of known *in vivo* digestibility by mature male goats have been examined by the *in vitro* technique of using pepsin and cellulase solubility. The results are shown in Figure 8. The linear regression equation, $Y = 27.296 + 1.046X$, has been fitted to the data, where Y = percent *in vivo* dry matter digestibility and X = percent *in vitro* DMD or solubility. The correlation coefficient (r) was 0.908. This means that *in vitro* solubility is highly correlated with *in vivo* dry matter digestibility. Therefore, the regression equation, $Y = 27.296 + 1.046X$, has been established. Consequently, *in vivo* dry matter digestibility values can be predicted from this equation, quickly and efficiently.

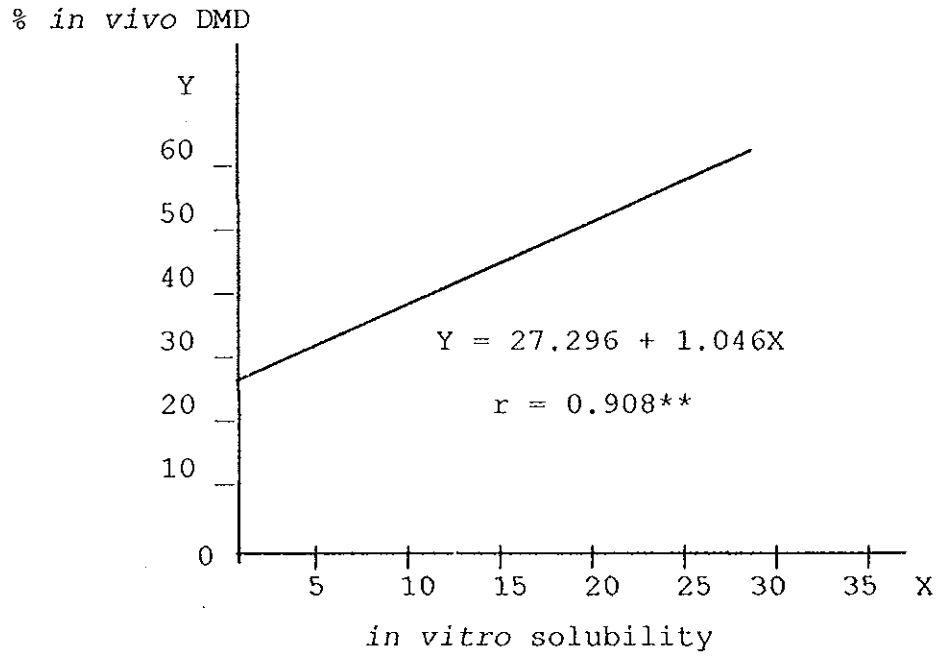


Figure 8. Relationship between *in vivo* dry matter digestibility (Y) and *in vitro* dry matter solubility (X) of 16 samples of straw haylages

5. Voluntary Dry Matter Intake (DMI) of Experimental Diets

The data on DMI of the various straw haylages are shown in Table 10. Statistical analysis showed highly significant differences among treatment means ($P < 0.01$). Treatment 4 had the highest DMI value (822.957 g/h/d or 50.110 g/kg$W^{0.75}$), which was significantly higher than those for Treatments 1 and 2. The lowest DMI value was observed in Treatment 1 (557.650 g/h/d or 34.640 g/kg$W^{0.75}$). There was no significant difference for DMI values between Treatments 4 and 3, but both were significantly higher than Treatment 1 because of the higher crude protein content in Treatments 3 and 4. The DMI value of Treatment 3 was slightly higher than that for Treatment 2, but the difference was not significant. The addition of EM microbes to the straw haylage (Treatment 2) increased the DMI when compared with Treatment 1, but this effect was not significant. These results indicate that the DMI of the groups fed urea-treated straw haylage were similar and relatively high, whereas the groups fed untreated straw haylage had similarly low DMI values. However, the haylage supplemented with EM microbes had a higher DMI value than the unsupplemented one. The results confirm that straw haylage treated with urea or EM microbes can increase DMI values as reported by Wanapat *et al.* (1985).

Bamualim (1986), Warmington *et al.*(1989), Tinnimit (1992) and Castrillo *et al.* (1995) reported that when roughages of low nitrogen content are given to ruminants, the supplementation of non-protein nitrogen such as urea and ammonia often results in an increase in voluntary DMI. This increase is interpreted as indicative of a deficiency in the availability of nitrogen to rumen microbes being rectified, thus increasing the rate of fermentation and removal of digesta. This agrees with Soetanto *et al.*(1988) who reported that the rate of feed digestion in the rumen was an important factor governing the intake of fibrous feed; the faster the digestion rate the higher the intake. Jamarun *et al.*(1988) stated that the critical level of crude protein in ruminant diets was approximately 7%, and amounts below this level would rapidly decrease voluntary feed intake. Cheva-Isarakul and Cheva-Isarakul (1984) indicated that the crude protein in pasture forage should be higher than 6.0-8.5%, otherwise voluntary intake would be limited by the nitrogen supply. Dixon (1986) reported that when rumen microbes utilized readily fermentable carbohydrates in concentrates, it would reduce the rate of rumen digestion of cell wall contents, and this might reduce roughage intake. Beauchemin *et al.* (1994) reported that DMI values decreases linearly as NDF concentrations increases. However, diets should be

Table 10 Dry matter intake of the various straw haylages (g/h/d) and (g/kg$W^{0.75}$/d)

Treatment	Dry matter intake (g/h/d)	Dry matter intake (g/kg$W^{0.75}$/d)
Treatment 1 rice straw + PKC + molasses + water	557.65[a]	34.64[a]
Treatment 2 rice straw + PKC + molasses + water + EM microbes	669.240[ab]	40.48[ab]
Treatment 3 rice straw + PKC + molasses + water + urea	724.188[bc]	44.312[bc]
Treatment 4 rice straw + PKC + molasses + water + EM microbes+ urea	822.957[c]	50.11[c]
SE	34.535	1.946

Remarks: Significant differences ($P < 0.01$) between treatment means are indicated by dissimilar superscripts within columns.

supplemented by an optimal dietary fiber to maintain proper rumen function and to avoid milk fat depression.

Promma *et al.*(1988) reported that crossbred dairy heifers fed with urea-treated rice straw require only 1.5 kg of concentrate, whereas groups fed untreated rice straw require 2.5 kg concentrate to maintain the same growth rate (480 and 493 g/d, respectively).

6. Properties and Characteristics of Straw Haylages

Properties and characteristics of the various experimental diets are shown in Table 11. The pH values of straw haylage in Treatments 1 and 2 were similar (5.377 and 5.332; respectively), whereas the pH values of Treatments 3 and 4 were 8.952 and 8.977, respectively. The higher pH value in Treatments 3 and 4 were due to the addition of urea in making haylage. Liberated ammonia combines with water to form ammonium hydroxide in this treatment process. The result agrees with Wanapat *et al.*(1984) who reported that the pH values of 6% urea-treated rice straw measured during the third week ranged from 8.7 to 9.0. All haylages in all four treatments were brown to dark brown in color. The haylage in Treatments 1 and 2 contained a small amount of mold, whereas Treatments 3 and 4 had no mold contamination. This agrees with Emanuele *et al.* (1992) who reported that urea can be used to prevent mold growth in high moisture haylage during storage. Jalc *et al.*(1994) reported that white rot

fungi, especially, *Poporus ciliatus,* and *Lentinus tigrinus,* can grow on mediums with an optimal pH value of 5.5. It is evident that urea is a good preservative for rice straw treatment.

Table 11 Properties and characteristics of the various straw haylages

Treatment	Properties and Characteristics			
	pH	Color	Odor	Mold
Treatment 1 rice straw + PKC + molasses + water	5.377±0.313	brown	acidic	minimal
Treatment 2 rice straw + PKC + molasses + water + EM microbes	5.332±0.142	brown	acidic	minimal
Treatment 3 rice straw + PKC + molasses + water + urea	8.952±0.117	dark brown	ammonia	none
Treatment 4 rice straw + PKC + molasses + water + EM microbes + urea	8.977±0.155	dark brown	ammonia	none

7. Results and Discussion of Experiment 2

Experiment 2 was conducted to determine the effect of four different levels of urea on the DMD and DMI values of straw haylage. The levels of urea were 1.5, 3.0, 4.5, and 6.0% for Treatments 1, 2, 3, and 4, respectively. The results of this study are shown in Table 12. The DMD values for Treatments 2, 3, and 4 were similar (55.210, 56.053 and 54.864%, respectively). However, these values were higher than that for Treatment 1 (52.554%). Similarly, the DMI values of straw haylage were 46.265, 48.593, and 47.995 $g/kgW^{0.75}$ for Treatments 2, 3, and 4, respectively. These results indicate that 3.0% urea is an optimal level for making haylage in combination with microbial inoculants.

Table 12 The DMD and DMI values of the various straw haylages in Experiment 2

Treatments	% DMD	DMI g/kg $W^{0.75}$/d
Treatment 1 rice straw + PKC + molasses + water + Poh Doh 1 microbes + 1.5 % urea	52.554±0.644	40.667±1.721
Treatment 2 rice straw + PKC + molasses + water + Poh Doh 1 microbes + 3.0 % urea	55.210±2.157	46.265±1.424
Treatment 3 rice straw + PKC + molasses + water + Poh Doh 1 microbes + 4.5 % urea	56.053±1.970	48.593±2.364
Treatment 4 rice straw + PKC + molasses + water + Poh Doh 1 microbes + 6.0 % urea	54.864±0.235	47.995±3.360

Remarks: Poh Doh-1 microbes are a mixed culture of various microorganisms and are recommended for use as compost accelerator by the Thai Department of Land Development.

8. Results and Discussion of Experiment 3

From the results of Experiment 2, it was found that 3% urea is an optimal level for rice straw treatment combined with microbes. Therefore, 3.0% urea was used in Experiment 3. The purpose of this experiment was to test the effect of four different levels of Poh Doh-1 microbes on the DMD and DMI values of straw haylages. The levels of Poh Doh-1 microbes were 0, 25, 50, and 75 g/5kg rice straw, and these were allocated for Treatments 1, 2, 3 and 4, respectively. The results of this experiment are given in Table 13. The DMD values of the straw haylages in Treatments 2, 3, and 4 were similar: 55.769, 55.213, and 56.017%, respectively. These were slightly higher than that for Treatment 1 (54.200%). The DMI values of the straw haylages in Treatments 3 and 4 were also similar (46.698 and 46.029 $g/kgW^{0.75}$, respectively), and both were higher than those for Treatments 1 and 2 (41.206 and 42.628 $g/kgW^{0.75}$, respectively). These results indicate that levels of 25-50 g Poh Doh-1/5kg rice straw might be optimal levels for making haylage in combination with 3% urea.

Table 13 The DMD and DMI values of the various straw haylages in Experiment 3

Treatments	%DMD	DMI $g/kgW^{0.75}/d$
Treatment 1 rice straw + PKC + molasses + water + 3.0 % urea	54.200±0.156	41.206±0.972
Treatment 2 rice straw + PKC + molasses + water + 3.0% urea + 25 g Poh Doh-1 microbes	55.769±0.835	42.628±0.279
Treatment 3 rice straw + PKC + molasses + water + 3.0% urea + 50 g Poh Doh-1 microbes	55.213±0.817	46.698±1.970
Treatment 4 rice straw + PKC + molasses + water + 3.0% urea + 75 g Poh Doh-1 microbes	56.017±0.672	46.029±1.136

CHAPTER 4

CONCLUSION

Rice straw treatment can be done by either physical, chemical, biological or physico-chemical methods. From the three experiments reported earlier, it was found that rice straw can be improved by chopping and ensiling with either urea, microorganisms, or a combination of both urea and microorganisms. The addition of urea, molasses, and palm kernel cake will increase feed intake and digestibility. When EM microbes were added to straw haylages containing PKC and molasses, digestibility increased by 9.40% over the control treatment. The addition of both EM microbes and urea to the above straw haylages increased the digestibility by 18.58%, whereas urea alone increased its digestibility by 21.16%. The production of straw haylage can be performed by ensiling the material with urea or microbial inoculants. In addition, urea plus microbial inoculants or urea alone can improve feed intake as compared to the control treatment or the control treatment plus microbial inoculants.

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APPENDICES

Appendix Table 1 ANOVA of crude protein content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	50.174	16.724	13.685**	3.49
Error	12	1.531	0.127		5.59
Total	15				

CV = 1.289 %

Treatment means ranking

Tr 3	Tr 4	Tr 1	Tr 2
11.490^{b}	11.457^{o}	8.192^{a}	7.975^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 2 ANOVA of crude fiber content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	1.297	0.432	0.435^{ns}	3.490
Error	12	11.903	0.991		3.950
Total	15	13.200			

CV = 2.709 %

Appendix Table 3 ANOVA of ether extract component of experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	0.032	0.010	0.192^{ns}	3.49
Error	12	0.625	0.052		5.95
Total	15				

CV = 11.156 %

Appendix Table 4 ANOVA of ash component from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	3.263	1.087	2.264^{ns}	3.49
Error	12	5.765	0.048		5.95
Total	15				

CV = 6.786 %

Appendix Table 5 ANOVA of dry matter from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	8.561	2.853	0.959^{ns}	3.49
Error	12	35.682	2.973		5.95
Total	15				

CV = 3.768 %

Appendix Table 6 ANOVA of NFE content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	37.654	12.551	4.729*	3.49
Error	12	31.848	2.654		5.95
Total	15				

CV = 3.943 %

Treatment means ranking

Tr 1	TR 2	Tr 4	Tr 3
43.175^{b}	42.265^{ab}	40.501^{ab}	39.312^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.05$)

Appendix table 7 ANOVA of NDF content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	5.245	1.748	0.845^{ns}	3.49
Error	12	24.819	2.068		5.59
Total	15				

CV = 1.864 %

Appendix Table 8 ANOVA of ADF content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	2.787	0.929	0.270^{ns}	3.49
Error	12	41.209	3.434		5.59
Total	15				

CV = 3.381 %

Appendix Table 9 ANOVA of ADL content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	0.803	0.267	0.558^{ns}	3.49
Error	12	5.756	0.479		5.95
Total	15				

CV = 5.303 %

Appendix Table 10 ANOVA of hemicellulose from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	0.437	0.145	0.028^{ns}	3.49
Error	12	61.954	5.162		5.59
Total	15				

CV = 10.177 %

Appendix Table 11 ANOVA of cellulose from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	9.081	3.027	0.641^{ns}	3.49
Error	12	56.621	4.781		5.95
Total	15				

CV = 1.450 %

Appendix Table 12 ANOVA of AIA content from experimental diets

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	1.200	0.400	1.481^{ns}	3.49
Error	12	3.242	0.270		5.95
Total	15				

CV = 11.962 %

Appendix Table 13 ANOVA of *in vivo* crude fiber digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	335.319	111.773	21.281**	4.76
Column	3	29.639	9.879	1.880	9.78
Row	3	4.687	1.562	0.297	
Error	6	31.516	5.252		
Total	15				

CV = 3.152 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
77.149^{c}	76.722^{c}	70.944^{b}	66.098^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 14 ANOVA of *in vivo* organic matter digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	209.402	69.800	23.459**	4.76
Column	3	11.047	3.682	1.757	9.78
Row	3	9.311	3.103	1.046	
Error	6	26.680	2.964		
Total	15				

CV = 2.889 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
63.677^{b}	62.401^{b}	57.428^{a}	54.699^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 15 ANOVA of *in vivo* NDF digestibility of straw haylages

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	430.281	143.427	65.016**	4.76
Column	3	24.566	8.188	3.711	9.78
Row	3	6.676	2.225	1.008	
Error	6	13.239	2.206		
Total	15				

CV = 2.466 %

Treatment means ranking

Tr4	Tr3	Tr2	Tr1
65.487^{c}	64.289^{c}	58.599^{b}	52.433^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 16 ANOVA of *in vivo* ADF digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	115.782	38.594	12.322**	4.78
Column	3	29.014	9.671	3.087	9.78
Row	3	56.392	18.797	4.950*	
Error	6	18.795	3.132		
total	15				

CV = 3.188 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
57.558^{b}	56.910^{b}	56.657^{b}	50.876^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 17 ANOVA of *in vivo* cellulose digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	190.487	63.495	10.201**	4.78
Column	3	4.283	1.427	0.299	9.78
Row	3	15.463	5.154	0.828	
Error	6	37.345	6.244		
Total	15				

CV = 3.104 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
83.008^{b}	82.227^{b}	81.778^{b}	74.434^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 18 ANOVA of *in vivo* crude protein digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	125.924	41.974	6.109*	4.78
Column	3	9.801	3.267	0.475	9.78
Row	3	25.717	8.572	1.870	
Error	6	41.225	6.870		
Total	15				

CV = 3.527 %

Treatment means ranking

Tr4	Tr3	Tr2	Tr1
77.182^{b}	76.748^{b}	72.859^{a}	70.410^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.05$)

Appendix Table 19 ANOVA of *in vivo* ether extract digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	204.115	68.051	3.736^{ns}	4.78
Column	3	150.376	50.125	2.752	9.78
Row	3	138.529	46.176	2.535	
Error	6	109.270	18.211		
Total	15				

CV = 6.244 %

Appendix Table 20 ANOVA of TDN

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	175.918	58.639	17.421**	4.78
Column	3	3.314	1.104	0.327	9.78
Row	3	10.841	3.613	1.073	
Error	6	20.200	3.366		
Total	15				

CV = 3.330 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
58.874^{b}	57.715^{b}	52.930^{a}	50.835^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 21 ANOVA of *in vivo* NFE digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	45.964	15.321	0.663^{ns}	4.78
Column	3	6.466	2.155	0.093	9.78
Row	3	99.651	33.217	1.439	
Error	6	134.479	23.079		
Total	15				

CV = 11.156 %

Appendix Table 22 ANOVA of *in vivo* DMD

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	217.203	90.401	20.342**	4.78
Column	3	32.657	10.885	2.449	9.78
Row	3	7.471	2.490	0.560	
Error	6	26.669	4.444		
Total	15				

CV = 3.872 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
58.753^{c}	57.476^{c}	53.053^{b}	48.463^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 23 ANOVA of DMI (g/h/d)

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	146976.06	48992.02	10.269**	4.78
Column	3	54915.94	18305.31	3.836	9.78
Row	3	2801.975	993.99	0.195	
Error	6	28624.48	4770.747		
Total	15				

CV = 9.95 %

Treatment means ranking

Tr4	Tr3	Tr2	Tr1
822.957^{c}	724.188^{bc}	669.240^{ab}	557.650^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 24 ANOVA of DMI ($g/kgW^{0.75}/d$)

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	555.546	168.515	11.123**	4.78
Column	3	83.904	29.968	1.978	9.78
Row	3	26.125	8.708	0.574	
Error	6	90.900	15.150		
Total	15				

CV = 3.104 %

Treatment means ranking

Tr4	Tr3	Tr2	Tr1
50.110^{c}	44.312^{bc}	40.480^{ab}	34.640^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 25 ANOVA of *in sacco* digestibility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	164.356	54.784	169.609**	3.86
Block	3	5.107	1.702	5.269	6.99
Error	9	2.929	0.323		
Total	15				

CV = 1.044 %

Treatment means ranking

Tr3	Tr4	Tr2	Tr1
53.344^{c}	53.106^{c}	49.743^{b}	45.433^{a}

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Appendix Table 26 ANOVA of *in vitro* pepsin-cellulase solubility

SOV	df	SS	MS	F-cal	F-tab
Treatment	3	216.256	72.085	43.034**	3.49
Error	12	20.101	1.675		5.95
Total	15				

CV = 4.991 %

Treatment means ranking

Tr4	Tr3	Tr2	Tr1
29.602[a]	28.896[a]	24.821[b]	20.402[b]

Treatment means with different superscripts indicate significant differences ($P < 0.01$)

Illustrations

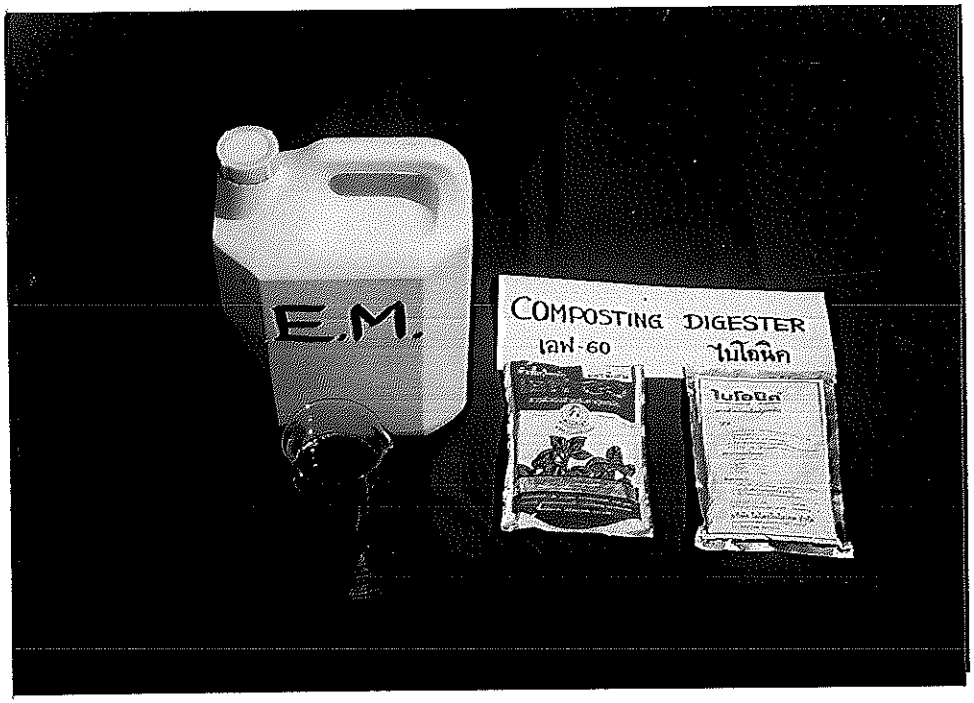

Figure 1. E.M.(Effective Microorganisms) and Poh Doh 1 microbes (in packages) used as microbial inoculants for haylage making

Figure 2 Chopped rice straw was being mixed with water, palm kernel cake, molasses, EM microbes or urea on a plastic sheet

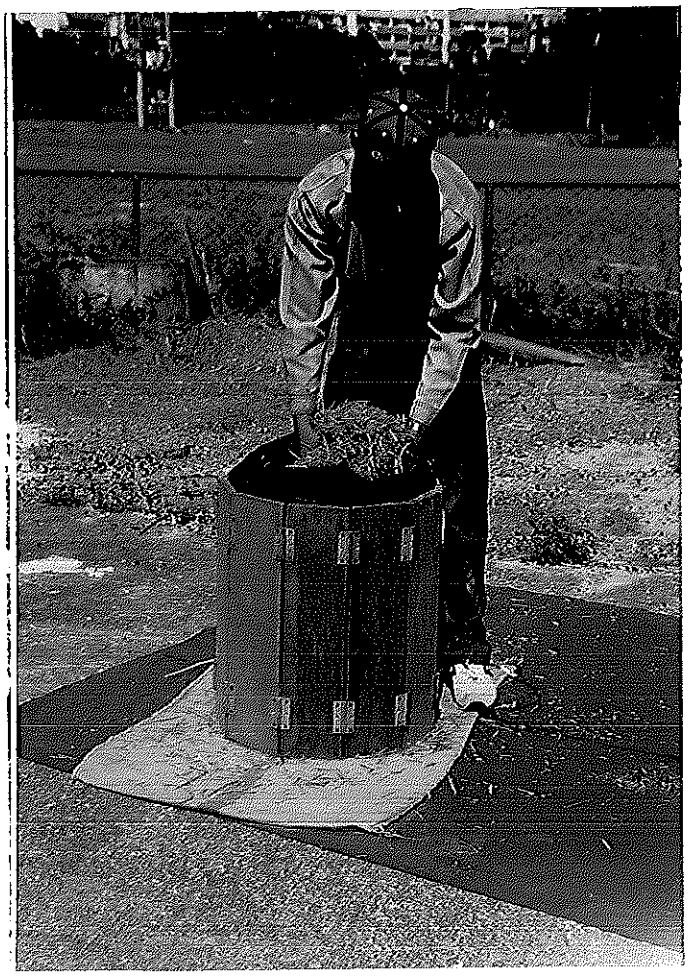

Figure 3
All ingredients were thoroughly mixed and placed into a black plastic bag in a wooden box

Figure 4 The bag was firmly tied and kept on a shelf for 21 days

Figure 5 Untreated or regular straw compared with urea treated straw or straw haylage

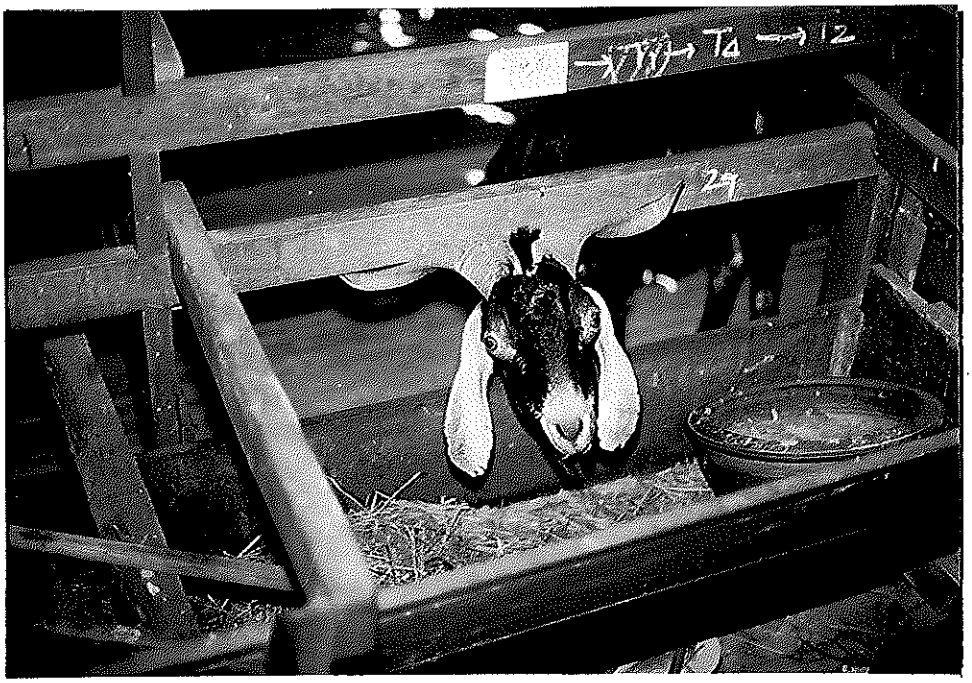

Figure 6 Crossbred male goats in an individual stall fitted with feed trough and water were used in digestion trial

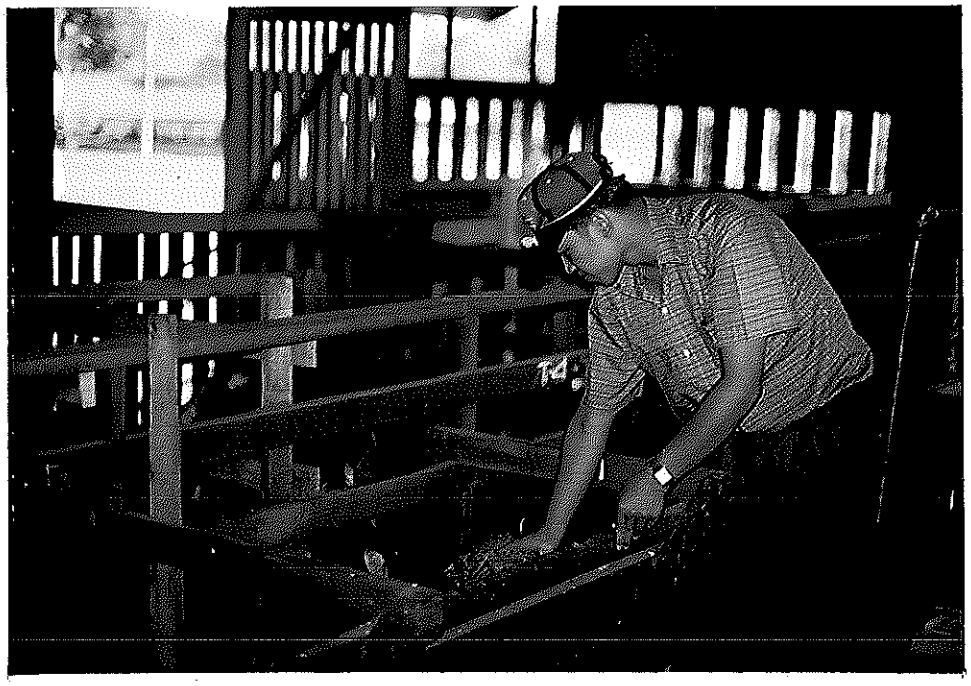

Figure 7 The researcher was giving straw haylage to the goat

Figure 8 The feces was collected into a blue net placed under the pen

VITAE

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