Institut für Tierwissenschaften

Rheinische Friedrich-Wilhelms-Universität Bonn

Evaluation of pangola grass as forage for ruminants

Inaugural-Dissertation

zur

Erlangung des Grades

Doktor der Agrarwissenschaften

(Dr. agr.)

der

Landwirtschaftlichen Fakultät

der

Rheinischen Friedrich-Wilhelms-Universität Bonn

vorgelegt im März 2014

von

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Tag der mündlichen Prüfung:	**13.06.2014**
Erscheinungsjahr:	**2014**

This study was financially supported by Institute of Animal Science, University of Bonn, Japan International Research Center for Agricultural Sciences (JIRCAS) and National Science and Technology Development Agency (Northern Network)-Thailand.

My Beloved Family

SUMMARY

Evaluation of pangola grass as forage for ruminants

Pangola grass (*Digitaria eriantha* Steud., synonym D. *decumbens*) is a high quality tropical grass and widely grown as pastures. It is utilized extensively for grazing, hay or silage making. The purpose of this study was to evaluate pangola grass in fresh, hay and silage form compared with fresh Napier grass (*Pennisetum purpureum*) and Ruzi grass (*Brachiaria ruziziensis*) as forage for ruminants.

The aim of the first part of the study was to review pangola grass as forage for ruminant animals. According to the review, pangola grass has the potential to provide high quality feed for ruminant animals in tropical countries. Results obtained when pangola grass (in fresh, hay or silage form) was fed to ruminant animals as sole feed or supplement showed better performances in body weight gain, feed conversion ratio, carcass yield, meat quality, milk yield and composition compared with other forage or tropical grasses.

The aim of the second part of the study was to assess its nutritive value and investigate nutrient digestibility, metabolisable energy and *in vitro* rumen fermentation kinetics in cross-bred native × Merino sheep (n = 16) fed pangola grass. Results showed that pangola silage (with addition of 5% molasses) was superior in terms of crude protein, crude fat, nutrient digestibility and metabolisable energy. *In vitro* gas production was highest (P<0.05) in pangola silage followed by – in that order – fresh pangola, pangola hay and Napier grass.

The third part of the study was carried out to estimate *in vitro* gas production and dry matter intake, apparent digestibility, metabolisable energy and average daily gain in Thai indigenous cattle fed pangola grass. It was shown that pangola grass in different forms (fresh, hay and silage) can serve as the main component in the diets of growing White Lamphun native bulls (n = 16). Bulls fed pangola silage (with addition of 5% sugarcane molasses) diets had higher average daily weight gain compared to other treatments (P<0.05). *In vitro* gas production was highest (P<0.05) in pangola silage followed by – in that order – fresh pangola, pangola hay and Ruzi grass.

Overall, results from these studies demonstrated that pangola grass is a feasible alternative as a good forage source and is regarded as high quality tropical grass and expected to be a valuable feed for ruminant animals. It can also be fed in conserved form as hay or silage to overcome feed shortage during dry season. The outcome of this study can be used as baseline data to introduce and promote pangola grass to smallholder farmers in order to improve animal productivity in Thailand and other tropical countries having similar environmental conditions and farming systems.

ZUSAMMENFASSUNG

Die Bewertung von Pangolagras als Grobfutter für Wiederkäuer

Pangolagras (*Digitaria eriantha*, synonym D. *decumbens*) ist ein weit verbreitetes tropisches Gras von hoher Qualität, welches umfangreich als Gras für die Beweidung sowie zur Herstellung von Heu und Silage genutzt wird. Das Ziel dieser Studie war die Bewertung von Pangolagras in frischer oder konservierter Form (Heu und Silage) als Futtermittel für Wiederkäuer im Vergleich zu Napiergras (*Pennisetum purpureum*) und Ruzigras (*Brachiaria ruziziensis*).

Im ersten Teil der Arbeit wird eine Literaturübersicht über die Einsatzmöglichkeiten von Pangolagras als Grobfuttermittel für Wiederkäuer gegeben; Pangolagras ist aufgrund seiner hohen Qualität ein vielversprechendes Futtergras für die Verwendung in tropischen Ländern. In Fütterungsversuchen mit Wiederkäuern, in denen Pangolagras als Ergänzungs- oder Alleinfuttermittel in frischer oder konservierter Form eingesetzt wurde, zeigten sich gegenüber anderen Grobfuttermitteln zum Teil deutliche Verbesserungen hinsichtlich Tageszunahmen, Futteraufwand, Schlachtausbeute, Fleischqualität sowie Milchmenge und -zusammensetzung.

Ziel des zweiten Teils dieser Studie war es, in Fütterungsversuchen mit Kreuzungsschafen (Nativ x Merino; n = 16) den Futterwert von Pangolagras, die Verdaulichkeiten der Rohnährstoffe, die Gehalte an umsetzbarer Energie sowie *in vitro* die ruminale Abbaukinetik zu bestimmen. Die Ergebnisse zeigten, dass die Pangolagras-Silage (mit Zusatz von 5% Melasse) die höchsten Konzentrationen an Rohprotein, Rohfett und umsetzbarer Energie sowie höhere Nährstoffverdaulichkeiten aufwies. Die *in vitro*-Gasproduktion war hier ebenfalls am höchsten ($P<0,05$), gefolgt von frischem Pangolagras und -heu sowie Napiergras.

Der dritte Teil dieser Studie verfolgte das Ziel, die *in vitro*-Gasproduktion und scheinbare Verdaulichkeit sowie im Fütterungsversuch die Trockenmasseaufnahme, die Tageszunahmen, die Gehalte an umsetzbarer Energie sowie an in Thailand beheimateten und mit Pangolagras gefütterten Rindern (16 Lamphun-Bullen) zu untersuchen. Die Resultate dieser Experimente zeigten, dass Pangolagras frisch oder in konservierter Form als Hauptkomponente in Rationen wachsender Rinder eingesetzt werden kann. Bei den mit Pangolagras-Silage (mit Zusatz von 5 % Melasse) gefütterten Tieren wurden dabei im Vergleich zu anderen Behandlungen höhere Tageszunahmen gemessen ($P<0,05$). Die *in vitro*-Gasproduktion war bei Pangolagras-Silage am höchsten ($P<0,05$), gefolgt von frischem Pangolagras, -heu und Ruzigras.

Die Resultate belegen, dass Pangolagras als ein hochwertiges, tropisches Gras eine mögliche Alternative als eine Grobfutterquelle für Wiederkäuer darstellt; der Einsatz auch in konservierter Form kann besonders in Perioden von Futtermittelknappheit empfohlen werden. Die Ergebnisse dieser Studie können als Grundlage dienen, um den Anbau von Pangolagras durch Kleinbauern zu verbreiten und zu fördern und damit einen Beitrag zur Verbesserung der Tierproduktion in Thailand und anderen tropischen Ländern mit ähnlichen Produktionsbedingungen zu leisten.

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ABBREVIATIONS

ADF	Acid detergent fibre
ADFom	Acid detergent fibre expressed exclusive residual ash
ADG	Average daily gain
ADL	Acid detergent lignin
BW	Body weight
CL	Crude lipids
CP	Crude protein
DM	Dry matter
DMI	Dry matter intake
DOM	Digestible organic matter
EE	Ether extract
GP	Gas production in 24 hours from 200 mg (DM) substrate
IVOMD	*In vitro* digestible organic matter
MCP	Microbial CP
ME	Metabolisable energy
mg	Milligram
MJ	Megajoule
mL	Milliliter
NDF	Neutral detergent fibre
NH_3-N	Ammonia-Nitrogen
OM	Organic matter
SD	Standard deviation
SEM	Standard error of mean

CHAPTER 1

General introduction

The livestock sector is one of the fastest growing sectors in agriculture especially in developing countries. As demand for meat and dairy products continues to increase, questions arise as to how this demand will be met and by whom. Access to a permanent forage base is a physiological priority for ruminants and an economic priority for farmers (Dunière et al., 2013). Ruminant livestock, namely goat, sheep, beef cattle, native cattle, dairy cattle and buffalo are widespread in the tropical zones and are important for the subsistence, economic and social livelihoods of a large human population in these areas.

Low quality and inadequacy of feeds are considered to be major constraints of livestock production in Southeast Asia in general and in Thailand in particular. This is particularly important during the dry season where availability and quality of forage often become severely limited. The most promising forage grasses in Southeast Asia are pangola (*Digitaria eriantha* Steud., synonym D. *decumbens*), Napier (*Pennisetum purpureum*), Ruzi (*Brachiaria ruziziensis*), Para (*Brachiaria mutica*), Purple guinea (*Panicum maximum* TD 58), Atratum (*Paspalum atratum*), Mulato (*Brachiaria hybrido* cv. Mulato) and Nile (*Acroceras macrum*) grasses.

Pangola is native to South Africa and is widely distributed in many humid subtropical and tropical areas. Optimal growth conditions are annual precipitations ranging from 700 to 4000 mm/year, temperatures from 15.9 to 27.8°C and soil pH from 4.3 to 8.5 (Duke, 1983). Pangola grass is one of the higher quality tropical grasses (Cook et al., 2005). It is usually used for hay production but can also withstand very heavy grazing (FAO, 2009). When pangola grass is utilized for grazing (fresh) or preserved as hay or silage (Figure 1), grass production is higher with nitrogen fertilization rather than when gfrown with a companion legume (Meeske et al., 1999).

Figure 1. Fresh pangola, pangola hay and pangola silage (Source: The author, 2010).

Nutrition is very important for livestock production, especially protein and energy sources are being considered. Crude protein (N×6.25) contents of pangola grass are commonly in the range of 5 to 14% of dry matter (DM) and may exceed 15% of DM with young regrowths under intensive fertilization (Heuzé et al., 2011).

Pangola grass has already been used as ruminant feed for long time. However, pangola grass grown at the same location under identical conditions, harvested at the same day of regrowth and utilized in different forms (fresh or preserved as hay or silage) for ruminants has not yet been investigated. Therefore, the present study was carried out to evaluate *in vitro* rumen fermentation kinetics and the nutritive value, digestibility, metabolisable energy concentration and growth performance in sheep and cattle of fresh or preserved (hay, silage) forms of pangola grass cut at the same day after 45 days of growth.

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CHAPTER 2

Scope of the thesis

The scope of this thesis was to evaluate pangola grass as fresh or preserved (hay, silage) forage for ruminants. This study was conducted in order to:

1. Give an overview of pangola grass as forage for ruminants.
2. Analyze the nutritive values and evaluate the metabolisable energy content of pangola grass using an *in vitro* gas production method.
3. Investigate nutrient digestibility and metabolisable energy content of pangola grass in cross-bred native × Merino sheep and Thai indigenous cattle.
4. Assess the performance in terms of body weight gain of Thai indigenous cattle (White Lamphun native bulls) fed diets based on pangola grass.

This is a cumulative thesis composed of three chapters;

Chapter three of this thesis is a review of pangola grass as forage for ruminant animals. The review focuses on pangola grass with regards to its origin and distribution, on historical highlights in Thailand and on chemical composition, nutritive value and utilization by ruminants.

Chapter four focuses on *in vitro* rumen fermentation kinetics and nutrient digestibility and metabolisable energy content in sheep fed pangola grass either fresh or as hay or silage.

Chapter five concentrates on the feeding value of pangola grass for Thai indigenous cattle. For this puropose, *in vitro* gas production kinetics, *in vivo* digestibility and growth performance of cattle were measured.

Chapters three to five are formatted according to the regulations of the journal chosen for submission or publication.

CHAPTER 3

Pangola grass as forage for ruminant animals: a review

Tikam, K., Phatsara, C., Mikled, C., Vearasilp, T., Phunphiphat, W., Chobtang, J., Cherdthong, A. and Südekum, K.-H., 2013. Pangola grass as forage for ruminant animals: a review. SpringerPlus, 2, 604, 6 pp.

Abstract

This review focuses on the introduction and investigation of pangola grass as a tropical forage species especially in Thailand. Pangola grass (*Digitaria eriantha* Steud., synonym *D. decumbens*) is one of recent examples of grasses that have been successfully introduced to Southeast Asia and is often considered as one of the highest quality tropical grasses popularly grown as pasture. Pangola grass is utilized extensively as grass for animal grazing, hay and silage making. Its crude protein content is commonly in the order of 5 to 14% of dry matter and may exceed 15% of dry matter with young regrowth under high fertilization. It has been documented that the type and number of ruminants receiving pangola grass can determine the success of its use. Results obtained when pangola grass in fresh, hay or silage form was fed to ruminant animals as supplements showed better performances in body weight gain, feed conversion ratio, carcass yield, meat quality, and milk yield and composition. In conclusion, pangola grass is a promising forage and a source of high quality feed for ruminant animals in tropical countries.

Keywords: Pangola grass; Tropical forage; Ruminants; Thailand

Introduction

In several developing countries, ruminant animals are the major contributors to draught power and are increasingly important as a source of meat, milk, and other livestock products. Livestock contribute 10 to 45% to the gross domestic product (GDP) in the developing world, and this contribution is higher if the value of draught power is included in the calculation. It is one of the fastest growing sub-sectors in agriculture (World Bank 2009). Indonesia, Myanmar and Thailand have the largest ruminant populations in Southeast Asia. The livestock numbers continue to increase throughout Southeast Asia despite the increasing human population density in these regions.

Thailand, which lies between 5°30' and 20°30'N and 98° and 105°E, has approximately 0.6 million dairy cattle, 6.5 million beef cattle and 1.2 million buffalo; about 3.4 million families raise these animals on 184,400 ha of forage (Department of Livestock Development Thailand 2011), mostly on natural pastures and crop residues.

The common problem of the farmers is the scarcity of good quality forage and the sometimes very high prices during the dry season. Grass and legume pastures are generally sources of green forage for beef cattle during wet or rainy seasons. During the dry season, grasses and legumes stop growing so the farmers need to find alternative roughages for their animals. One way to overcome this problem and to maintain the continuity of feed supply is to conserve surplus forage or crops as hay or silage for later use when feed is in short supply.

Pangola (*Digitaria eriantha* Steud., synonym *D. decumbens*; family: *Poaceae* (alternatively *Gramineae*), subfamily: *Panicoideae*, tribe: *Paniceae*) is one of the highest quality tropical grasses (Cook et al. 2005). It is utilized extensively for grazing, hay or silage making (Meeske et al. 1999), mostly with nitrogen fertilization rather than a companion legume. Therefore, this review focuses on pangola grass with regard to description of its origin and distribution, historical highlights in Thailand, chemical composition, nutritive values and utilization by ruminant animals.

Description of pangola

Common names for pangola are pangola grass (American and Australian English and Thai), finger grass, digit grass, woolly finger grass (English), digitaria (French), pangolagras (German), pasto pangola (Spanish), pangola digit grass (Florida). Pangola is a stoloniferous perennial and when established, it spreads rapidly by stolons. It does not produce viable seeds. Stems are up to 120 cm high. The leaves are linear-lanceolate to linear, 10 to 25 cm long and 2 to 7 mm wide. The inflorescence has one to two whorls with 5 to 10 spikes that are up to 13 cm long each, with many spikelets 2.70 to 3.00 mm long (Bogdan 1977). Optimal growth conditions are annual precipitations ranging from 700 to 4000 mm, temperatures from 15.9 to 27.8°C and soil pH from 4.30 to 8.50 (Duke 1983), indicating adaptability to a wide range of environmental conditions.

Origin and distribution of pangola

Pangola is a native of tropical South Africa, thought to originate in the Pongola River in the eastern Transvaal in South Africa or in the adjacent Zululand districts. Pangola is thus thought to be an alteration of the river's name. The grass was introduced into the United States in 1935 and released for cultivation in 1940. By 1955 there were 202,343 hectares established in Florida, all derived by vegetative reproduction from the two or three plants introduced in 1935. Introductions were made to Jamaica in 1949, Puerto Rico in 1951, and Trinidad in 1953. Since that time it has been introduced widely to Central- and South-America, Australia, West Africa, the Pacific Islands and tropical Asia (Nestel et al. 1962). Pangola is recommended for the poorly drained soils in Malaysia and the Philippines and is tolerant of flooding (Hacker 1992).

Historical highlights of pangola in Thailand

Pangola was adapted from the Philippines to areas of Thailand by the Animal Nutrition Division in 1983, and released for cultivation at Pakchong Animal Nutrition Center (which later changed its name to Nakhonratchasima Animal Nutrition Research and Development Center) and redistributed to all areas in Thailand. Until 1992, Dr. T. Yu (at that time at Charoen Pokphand Foods PCL-Crop Integration Business CP Group) imported pangola grass type 254A from Taiwan and cultivated it at Kamphaeng Phet province (Northern Thailand) to produce pangola hay for sale in Thailand and abroad. Pangola grass was introduced to the farmers not until 1999 (Animal Nutrition Division 2006).

In 2002, the Thai government promoted forage production and supported farmers who produced hay and silage instead of rice and other regular cash crops. Pangola grass cultivation replaced rice cultivation in the lowland and was called “Paddy pasture”. The project was called the “Na Yaa” project in Thai. Pangola grass cultivation has now been introduced into all regions in Thailand. Farmers are now planting and using pangola widely as a crop for raising animals. Pangola is being promoted as a high quality fresh grass cash crop for cultivation on former rice lands (Khemsawat and Phonbumrung 2002).

Chemical composition and nutritive value of pangola

Pangola grass, Para (*Brachiaria mutica*), Ruzi (*Brachiaria ruziziensis*), Purple guinea (*Panicum maximum* TD 58), Napier (*Pennisetum purpureum*), Atratum (*Paspalum atratum)*, Mulato (*Brachiaria hybrido* cv. Mulato), Hamata stylo (*Stylosanthes hamata* cv.Verano), Stylo 184 (*Stylosanthes guianensis* CIAT 184), Cavalcade centurion (*Centrosema pascuorum* cv. Cavalcade), Leuceana (*Leuceana leucocephala)* and Desmanthus (*Desmanthus virgatus*) have been the most successful grass and legume species and are commonly found in Southeast Asia, especially in Thailand. In the Philippines and Indonesia, Leucaena (*Leuceana leucocephala)* was widely promoted as a livestock feed. Although these grass and legume species are competing with each other, direct comparisons of both agronomic performance and feeding value are missing and are thus encouraged.

Chemical composition

Crude protein (CP) values of pangola grass are commonly in the range of 5 to 12% of dry matter (DM; Table 1) but may exceed 15% of DM with young regrowth age and intensive fertilization (Heuzé et al. 2011). Common to all tropical grasses, nutritional value and chemical composition of pangola vary with several factors such as differences in stage of cutting, fertilizer, location, climate and environment. The average CP content of pangola (7.9%) is low compared to those of *Pennisetum purpureum* cv. Mott, *P. purpureum*, *Brachiaria humidicola* and *Panicum maximum* cv. Common (Animal Nutrition Division 2004).

Many studies have been made on the chemical composition of pangola utilized fresh or preserved as hay or silage (Table 1). If only studies from Thailand are considered, the CP content varied from 5.3 - 7.9, 3.1 - 10.5 and 7.1 - 13.4% of DM, respectively, for fresh, dried (hay) and ensiled pangola. Archimède et al. (2000) have shown that it was mainly the CP content of pangola grass that decreased with maturity. The decrease in CP content between 14 and 28 days of growth represent 70% of the general decrease observed between 14 and 56 days. Moreover, Assoumaya et al. (2007) reported that the 56-day old grasses were characterised by lower CP and higher fibre contents as compared to 21-day old grasses. The CP values of pangola therefore depend on the stage of growth. In Taiwan, Yeh (1990) reported that the average CP content of pangola varied depending on the regrowth interval length – from 10.5% with cutting at 4-week intervals to 8.9% with cutting at 6-week intervals and 8.0% with cutting at 8-week intervals. An attempt was made to assign the observed variation in chemical composition and particularly CP concentration of pangola to specific sources but this attempt failed as most studies lacked sufficient information on factors such as amount of applied nitrogen fertilizer or soil type and fertility. For this reason, a quantitative evaluation of factors contributing to variation in chemical composition of pangola was not possible.

Table 1 Chemical composition of pangola grass

Pangola form and reference	Cutting age (days)	DM (%)	CP	EE	NDF % DM	ADF	ADL
Fresh							
Archiméde et al. (2000)	42	-	7.2	-	79.0	44.2	7.8
Lee et al. (2000)	45	39.7	6.7	2.1	-	42.8	-
Animal Nutrition Division, Thailand (2004)	45	31.8	7.9	2.0	63.3	35.7	4.0
Chaichaum et al. (2007)	40-50	21.5	8.1	2.6	61.2	34.1	-
Assoumaya et al. (2007)	42	-	10.7	-	72.5	35.7	6.4
Angthong et al. (2008)	45	24.8	9.5	1.7	66.4	39.8	4.9
Eugéne et al. (2010)	42	-	12.0	-	71.6	35.0	-
Chaiwang et al. (2011)	40-45	22.8	5.3	3.4	73.0	37.7	7.3
Fanchone et al. (2012)	35	-	12.0	-	75.6	38.2	-
SD[1]		7.6	2.4	0.7	6.1	3.5	1.6
Hay							
Lee et al. (2000)	70	87.1	3.0	2.0	-	46.6	-
Suzuki et al. (2008)	45	90.1	9.5	1.5	74.6	42.3	5.0
Suksathit et al. (2011)	45	85.4	3.1	3.8	71.7	41.7	4.1
Chobtang et al. (2012)	45	88.7	7.0	1.4	69.5	36.6	4.2
Kaewkunya et al. (2013)	84	89.5	4.3	0.8	69.5	35.1	9.9
SD		2.4	2.8	1.1	2.4	4.6	2.8
Silage							
Esperance et al. (1980)	42	20.6	8.0	-	-	-	-
Phunphipat (2004)	45	34.1	13.4	-	-	-	-
Chaichaum et al. (2007)	45	25.0	7.1	2.5	5.9	39.5	-
SD		6.9	3.4	-	-	-	-

[1]Standard deviation. DM, dry matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, Acid detergent lignin;

Nutritive value of pangola and utilization by ruminants

Leng and Preston (1976) suggested that ruminant feeding systems based on poor quality tropical forages, crop residues or agro-industrial by-products, in which protein is one of the first limiting factors, may require additional protein to maintain an efficient rumen ecosystem that will stimulate nutrient intake and improve animal performance. Several authors subsequently showed that pangola could efficiently serve as a protein supplement to such diets. If used as a supplement to low-CP forage or mixed diets based on, e.g., straw, CP concentrations above 15% of DM (see previous section) can be accepted as the greater proportion of non-protein-nitrogen in the CP of intensively fertilized forage can be effectively converted by rumen microbes into microbial amino acids, and finally, microbial protein (review by Leng 1990).

Results of studies involving pangola varied widely depending on the form of its presentation and species of animal. The general conclusion is that supplementation of pangola grass in fresh or preserved (hay and silage) forms to ruminant animals showed beneficial results. Ranchers in Central and South Florida have been well served for many years by 'pangola' and other cultivars of digit grass. Pangola is a very palatable grass that is readily consumed by livestock (beef, dairy cattle and horses) as grazed pasture or hay (Vendramini at al., 2012). In the following paragraphs, results are summarized from studies involving *in vivo* and *in vitro* measurements and these are separately presented.

In vitro data were only reported by Regan (2000) and Juárez Reyes et al. (2009). Regan (2000) reported that in northern Australia bale silage was prepared from wilted pasture with pangola grass (*Digitaria eriantha* subsp. e*riantha*) and two legumes, namely cavalcade centurion (*Centrosema pascuorum*) and wynn cassia (*Chamaecrista rotundifolia*). The DM content of the silages made from the wilted plants ranged from 42–57%, the *in vitro* digestibility from 55.0-58.0% and the estimated metabolizable energy concentration from 8.5-9.0 MJ/kg DM. Juárez Reyes et al. (2009) reported higher *in vitro* gas production ($P<0.05$) for pangola grass, compared with 30% less gas in other grasses (Guinea, Bermuda and Tanzania grasses). They also reported greater ($P<0.05$) *in vitro* gas production and insoluble but slowly degradable (b) fraction of pangola grass, as well as lower b fraction in Guinea and Bermuda grasses.

Although a reasonable number of *in vivo* studies have been published, they vary largely in terms of animal species or category within species, research methods and, even more important, response variables studied. This extreme heterogeneity, which left only few and sometimes one single number for a given variable related to the nutritive value of pangola, precluded a quantitative analysis of data. It became obvious that more systematic and comparative studies are needed before this goal can be achieved.

Lee et al. (1991) indicated that the digestibility of DM and DM constituents and hence the energy value of pangola and Napier grasses were higher at the earlier stages of growth and decreased as the plant approached maturity. More specifically, Archimede et al. (2000) reported that OM digestibility decreased curvilinearly with age. Seventy-one percent of the total decrease occurred between 14 and 28 days with the corresponding values for neutral detergent fibre and acid detergent fibre of 75 and 69%. More recent studies on in vivo digestibility of pangola fed in different forms are summarized in Table 2. This data again suggest a considerable variation even for pangola harvested after similar or the same length of the growth period but, as already stated for chemical composition, data do not allow to clearly identifying the reason for this variation. Panjaitan et al. (2010) fed Spear and Mitchell grass hays (low quality tropical forage) to steers and observed lower microbial CP (MCP) production (80 and 170 g MCP/day, respectively) and efficiency of MCP production (78 and 79 g MCP/kg digestible organic matter (DOM), respectively) than when steers were fed pangola grass (328 g MCP/day; 102 g MCP/kg DOM) and ryegrass (627 g MCP/day; 135 g MCP/kg DOM) hays, which was directly related to the supply of DOM and rumen-degradable CP.

Table 2 *In vivo* nutrient digestibility of pangola grass

Pangola form and reference	Cutting age (days)	Type of animal	DM (%)	OM	CP % DM	NDF	ADF
Fresh							
Lee et al. (2000)	45	Dairy goats (n=6)	79.8	-	61.9	-	-
Mullik et al. (2009)	-	Brahman steers (n=4)	59.7	68.6	52.3	69.9	-
Eugéne et al. (2010)	42	Black Belly rams (n=16)	-	64.8	73.7	74.9	-
SD[1]					10.7		-
Hay							
Lee et al. (2000)	70	Dairy goats (n=6)	54.1	-	34.0	-	-
Angthong et al. (2006)	45	Brahman cattle (n=4)	61.0	64.0	62.0	67.9	64.8
Pitaksinsuk et al. (2007)	45	Brahman cattle (n=4)	60.3	62.6	57.2	71.4	63.4
Suzuki et al. (2008)	45	Brahman steers (n=4)	58.1	60.7	53.7	68.0	66.3
Suksathit et al. (2011)	45	Thai native cattle (n=4)	74.5	76.7	78.9	66.2	54.6
Chobtang et al. (2012)	45	Brahman cattle (n=4)	55.6	58.5	45.4	56.0	49.9
Kaewkunya et al. (2013)	84	Crossbred lambs (n=16)	78.5	-	66.2	79.5	73.2
SD			9.5	7.1	14.5	7.6	8.4

[1]Standard deviation. DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre.

Some authors studied effects of pangola on growth of ruminants. In Taiwan, Hsieh (1990) used four tropical grasses (pangola, Guinea, dwarf elephant and South African pigeon grass) which were grazed by seven Holstein steers during the first year and 60 Nubian-native goat hybrids during the second year. Pangola gave the highest average daily gain (ADG) for cattle, while Guinea grass was the second highest. At Parada in North Queensland, Australia, a body weight gain of 2,990 kg/(ha x year) was obtained from grazing irrigated pangola grass fertilized with 672 kg N/(ha x year; Ebersohn and Lee 1972). In Jamaica, Creek and Nestel (1965) found that pangola grazed at 32-day intervals produced more DM and more body weight gain than when grazed at 40-day intervals.

In Thailand, the quality of beef from cattle fed with pangola in terms of chemical composition, collagen content, cholesterol, triglyceride and water holding capacity showed different values between White Lamphun and Brahman crossbred cattle (Chaiwang et al. 2011). However, pangola can be used for rearing native cattle and could be an alternative feed for farmers. Moreover, Tuikampee et al. (2006) reported that the average milk yield of cows fed pangola grass-based diets was approximately 16 kg/day; the milk had 3.51 - 3.61% fat, 2.93 - 2.94% protein, 5.02 - 5.04% lactose and 11.97 - 12.00% total solids. Moreover, Chobtang et al. (2012) reported that methane emissions from bulls that received good quality pangola hay (28-day growth period) were significantly lower ($P<0.05$) than those of bulls fed medium quality hay (45-day growth period). These authors postulated that the use of good quality hay can contribute not only to improving nutrient supply to the animal but also to reducing greenhouse gas emission to the atmosphere when compared with lower quality hay.

Ruminal disorder or toxicity was not found in sheep, goat, beef cattle and dairy cattle. However, in horse grazing pangola pastures, cases of bighead disease (nutritional secondary hyperparathyroidism caused by interference of oxalate in pangola grass with mineral utilization in horses) have been recorded (Stewart et al., 2010). In suitable environments, pangola grass – through improved intake and digestibility – can support better ruminant performance in terms, milk yield and composition, body weight gain, feed conversion ratio and meat quality than most other introduced pasture grasses in the Tropics.

Conclusions

The future of pangola grass as basal roughage or supplement in the diets of ruminant animals seems to be very promising but requires long term plans. Pangola grass is a good source of forage and can be fed fresh or preserved as hay or silage. Thus, pangola is regarded as one of the most digestible and highest quality tropical grasses and expected to be good feed for ruminant animals.

Acknowledgements

The authors would like to thank all members of Bureau of Animal Nutrition Division, Department of Livestock Development, Ministry of Agriculture and Cooperatives Thailand for all of their help, advice and information provided for this review. This study was financially supported by the Institute of Animal Science, University of Bonn. Dr. Y. Anele is acknowledged for language editing.

Competing interest

The authors declare that they have no competing interests.

Authors' contribution

All authors read and commented on drafts prepared by the first author and finally approved the manuscript.

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CHAPTER 4

In vitro gas production, nutrient digestibilities, and metabolisable energy concentrations for sheep of fresh and conserved pangola grass

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Submitted for publication

A B S T R A C T

In vitro gas production, nutrient digestibilities and metabolisable energy (ME) values of fresh and conserved pangola grass (*Digitaria eriantha* Steud., synonym *D. decumbens*) were studied in 16 cross-bred (Thai native × Merino) sheep. The study was designed as a completely randomized design with Napier grass (*Pennisetum purpureum*) as control and pangola grass in fresh, hay and silage form with the same cutting age (45 days growth) as treatments. Chemical composition of forages and faeces were determined and used to estimate nutrient digestibility. *In vitro* gas production was recorded at 3, 6, 8, 12, 24, 48, 72, 84 and 96 hours of incubation and used to estimate the kinetics of gas production. Likely due to the addition of 5% sugarcane molasses before ensiling, pangola grass silage had more ($P<0.05$) crude protein and crude fat (82.6 and 25.7 g/kg dry matter) than the other treatments. Nutrient digestibilities and ME concentrations of the silage were also greater ($P<0.05$) than those of the other forages when estimated from *in vivo* digestibility and *in vitro* gas production. Gas production was highest ($P<0.05$) in pangola silage followed by fresh pangola, pangola hay and Napier grass, in that order. In conclusion, pangola grass in fresh or conserved forms has a high potential to deliver energy and protein through forage and can be recommended as a nutrient source for small ruminants.

Keywords: Chemical composition, Forage conservation, Small ruminant, Thailand, Tropical grass

1. Introduction

Ruminant livestock in the tropics and sub-tropics cover most of their dietary requirements from native pastures and crop residues. However, these feed resources are low in nutrient quality, e.g. they contain little crude protein (CP) and much fibre which is often of low digestibility. The most common problem facing smallholder farmers is the scarcity of good quality forages. These feed resources are either not available or attract very high prices during the dry season. One way to overcome this problem and to maintain adequate feed supply is to conserve surplus forage or crops during the rainy season as hay or silage for later use when the feed is in short supply.

Pangola grass (*Digitaria eriantha* Steud., synonym *D. decumbens*) is a high quality tropical grass (Cook et al., 2005) reputed with potentials to fill this gap. It is popularly grown in Thailand as pasture and utilized extensively for animal grazing, hay and silage making, mostly with N fertilization instead of using legumes as companion crops (Meeske et al., 1999). Its CP concentration ranges from 5 to 14% of dry matter (DM) and may exceed 15% of DM for young regrowths under intensive fertilization (Heuzé et al., 2011).

Pangola grass has already been used as ruminant feed for long time (review by Tikam et al., 2013), however, evaluation of pangola grass in different forms (fresh, hay, or silage) at the same cutting age and harvested at the same location has not yet been investigated. Therefore, our objective was to evaluate *in vitro* gas production and nutrient digestibilities, and metabolisable energy (ME) values for sheep of pangola and Napier grasses (*Pennisetum purpureum*) harvested at the same regrowth age (45 days). The outcome of the present study could be used as baseline data to introduce and promote pangola grass in different forms to smallholder farmers in the near future.

2. Materials and methods

2.1. Experimental site

This study was carried out at the experimental farm of the Department of Animal and Aquatic Science, Faculty of Agriculture, Chiang Mai University, Chiang Mai Province, Thailand (latitude 18°47'N and longitude 98°59'E). The average daily temperature during the study (in the dry season; October 2008 to January 2009) was 15°C and the average daily relative humidity was 64%.

The chemical analyses were conducted at the Department of Animal and Aquatic Science, Chiang Mai University, Thailand and the Institute of Animal Science, University of Bonn, Germany.

2.2. Forage management and harvest

Pangola grass and Napier grass were harvested from the same location at the same regrowth age at cutting (45 days) and were used to produce four forage treatments, namely Napier grass, fresh pangola, pangola hay and pangola silage. Pangola in Thailand typically contains 10% CP, 29% crude fibre and 59% total digestible nutrients (Animal Nutrition Division, 2002). For fresh pangola and Napier grasses, their fields were divided into different plots already for the previous growth period so that their maturity could be controlled by cutting at different days in order to obtain fresh grass of 45 days regrowth duration and thus, similar quality, throughout the digestibility trial carried out in the following weeks. Grasses were cut early every morning and chopped before feeding. For pangola hay, fresh pangola was harvested and sun-dried on the field for 2-3 days, then small square bales (0.9 m x 0.45 m x 0.35 m and weighing between 20 and 30 kg) were made and stored indoor. For pangola silage, grasses were chopped into pieces of 2 to 3 cm length, after which 5 kg sugarcane molasses per 100 kg fresh pangola were added. Molasses is the by-product of sugar production from sugarcane and contains on average 72.4% DM and 2.2% CP (Animal Nutrition Division, 2004). The material was then homogenized and filled in six 120-l plastic barrels (60 kg/barrel), compacted, sealed and ensiled for a minimum of 21 days. Each barrel was weighed before and after ensiling to determine the DM loss. At opening, silages were checked by sensory evaluation (organoleptic quality) and each barrel was sampled for determination of pH, ammonia-N and lactic, acetic and butyric acids. The barrels were opened one after the other during the digestibility trial where each was completely consumed within 3 to 4 days.

As ensiling of pangola is difficult to achieve without an additive providing, e.g., extra water-soluble carbohydrate, promoting a strong lactic acid fermentation, the supplementation of a fermentable carbohydrate source like molasses is seen as a practical solution to the problem of delayed fermentation or malfermentation in tropical silages (Tjandraatmadja et al., 1994). It was assumed that the inclusion of molasses represents a standard type of pangola silage and therefore, this forage type was simply referred to as pangola silage hereafter.

Forages (fresh Napier and pangola grass, pangola hay and pangola silage) were sampled twice every morning before being fed to the animals during the 7-day collection period (n = 14 for each forage) for chemical analyses.

2.3. Animals and in vivo digestibility trials

Sixteen cross-bred sheep (native Thai x Merino; 18.5 ± 1.21 kg body weight) were placed individually in metabolism cages where faeces could be collected quantitatively. They were randomly assigned to four treatment groups comprising of Napier grass (control), fresh pangola, pangola hay and pangola silage with four animals per treatment. The sheep were fed twice daily at 08:30 and 16:30. Fresh water was available continuously during the whole experiment. The total experimental period was 21 days. The sheep were fed diets for *ad libitum* consumption during a 14-day adaptation period, followed by a 7-day collection period, during which each animal was fed 550 g DM/day divided into two equal portions. Forages, feed refusals and faeces of each animal were collected daily, weighed fresh and dried in an oven at 60°C until constant weight was achieved.

2.4. Chemical analyses

Sensory silage quality (odour, colour and texture) was evaluated by an organoleptic test (Gross, 1982; score: 20-16 = very good-good; 15-10 = fair-good; 9-5 = fair; and < 5 = poor). The silage pH was determined as follows: Approximately 50 g of duplicate samples were diluted with deionized water to 200 g in a blender jar. Samples were macerated for 30 s, macerated samples were filtered through two layers of cheesecloth, and pH was measured using a glass electrode pH meter (Bal et al., 1997). The concentrations of lactic, acetic and butyric acids were analyzed by distillation procedures as described by Zimmer (1966). Fermentation quality of the silages was assessed with the DLG scheme (DLG, 2006), based on the concentrations of acetic acid, butyric acid and the pH. Ammonia-N concentration was determined by distillation using Tecator Auto-Kjeldahl analyzer according to Chen et al. (1994).

Feed samples (fresh, hay and silage), feed refusals and faeces samples were weighed and oven-dried at 60 ^{o}C and then successively ground in mills with 1-mm sieves for use in chemical analyses. The DM content of samples was determined by oven-drying at 100^{o}C for 24 h. Crude protein (method ID 976.06), ash (method ID 942.05) and ether extract (hereafter denoted crude fat, method ID 920.39) analyses were carried out as described by AOAC (2000). Crude fibre, neutral detergent fibre (NDF) and acid detergent lignin (ADL) were determined according to the method of Van Soest et al. (1991). Acid detergent fibre expressed exclusive residual ash (ADFom) was analyzed using method 6.5.2 of the German Handbook of Agricultural Experimental and Analytical Methods (VDLUFA, 2007).

2.5. In vitro gas production measurement

In vitro gas production was determined according to Menke and Steingass (1988). The gas volume was recorded after 0, 3, 6, 8, 12, 24, 48, 72, 84 and 96 hours of incubation. Data were fitted to an exponential model given by McDonald (1981):

$$y = B\,(1-e^{-c(t-lag)})$$

where ‘y’ is the cumulative volume of gas produced at time ‘t’ (h), ‘B’ the asymptotic gas volume, ‘c’ the rate constant and ‘lag’ is the time (h) between inoculation and commencement of gas production.

2.6. Calculations and statistical analyses

The *in vivo* digestibilities (%) were calculated as follows:

((Nutrient consumed in feed [g/day] – nutrient excreted in faeces [g/day])/nutrient consumed in feed [g/day]) x 100.

The *in vivo* ME values were calculated from *in vivo* digestibility values as follows (GfE, 1995; all variables expressed per kg DM):

$ME_{in\ vivo}$ (MJ) = 0.0312 × digestible crude fat (g) + 0.0136 × digestible crude fibre (g) + 0.0147 × (digestible organic matter – digestible crude fat – digestible crude fibre) (g) + 0.00234 × CP (g).

This equation is based on *in vivo* digestibilities that were calibrated against a large number of measured ME values (92 diets) using respiration chambers.

Gas production at 24 and 48 h of incubation, together with the concentrations of chemical components, was used to predict concentrations of *in vitro* digestible organic matter (IVOMD24 and IVDOMD48, respectively) as follows:

IVOMD24 or IVDOMD48 (%) = 15.38 + 0.8453 × GP + 0.0595 × CP + 0.0675 × ash

where GP is *in vitro* gas production (mL/200 mg DM) at the respective incubation time, CP and ash are given as g/kg DM (Menke and Steingass, 1988).

The ME values based on GP and chemical composition were calculated using the following equation (GfE, 2008):

ME (MJ/kg DM) = 7.81 + 0.07559 × GP – 0.00384 × ash + 0.00565 × CP + 0.01898 × crude fat – 0.00831 × ADFom where GP is *in vitro* gas production at 24 h (mL/200 mg DM) and ash, CP, crude fat and ADFom are expressed in g/kg DM.

The experimental setup was a completely randomized design (CRD) and data were subjected to analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS (2002). Means were compared using Duncan's new multiple range test (Steel and Torrie, 1980). All statistical analyses were performed using SAS version 9.1 (SAS, 2002.)

3. Results

3.1. Pangola silage characteristics

The DM loss during ensiling, sensory characteristics, pH and concentrations of NH_3 and organic acids of pangola silages are summarised in Table 3. At opening, the colour of the silage was yellowish to green and there were no visible moulds. The average pH of the silage was 4.2.

3.2. Chemical composition

Data on chemical composition and nutrient digestibility are shown in Table 4. Pangola silage had the highest (P<0.05) CP and crude fat contents (82.6 and 25.7 g/kg DM, respectively), whereas pangola hay contained more (P<0.05) NDF, ADFom and ADL than the other forages.

3.3. Nutrient digestibility and metabolisable energy

Pangola silage had higher (P<0.05*) in vivo* digestibilties of DM, OM, CP and crude fat than the other forage types (Table 4). The IVDOMD48 values for the pangola forages ranged from 66.1 for pangola hay to 74.9% for pangola silage (Table 5). The ME of pangola silage both from *in vivo* digestibility and *in vitro* gas production methods was higher (P<0.05) than those of fresh pangola, pangola hay and Napier grass.

Table 3

Dry matter (DM) loss, organoleptic quality, pH and concentrations of NH_3 and organic acids of pangola silage (n=6) at opening of the silos

Items	Pangola silage	SEM[1]
$DM_{before\ ensiling}$ (g/kg)	283.2	0.29
$DM_{after\ ensiling}$ (g/kg)	258.3	0.18
DM loss (%)[2]	11.1	0.11
Organoleptic quality[3]	18	0.26
pH	4.2	0.12
NH_3-N(g/kg of total N)	110	2.1
Organic acids (g/kg DM)		
Lactic acid	50	0.8
Accetic acid	1	0.3
Butyric acid	0.4	0.12
Fermentation quality[4]	95	0.22

[1] Standard error of the mean.

[2] DM loss (%) = $$\left\{\frac{(DM \times weight/100)_{before\ ensiling} - (DM \times weight/100)_{after\ ensiling}}{(DM \times weight/100)_{before\ ensiling}}\right\} \times 100$$

[3]Organoleptic quality (odour, colour and texture), score: 20-16 = very good-good; 15-10 = fair-good; 9-5 = fair; and < 5 = poor (Gross, 1982).

[4]Fermentation quality, score: 100-90 = very well, 89-72 = well, 71-52 = in need for improvement, 51-30 = bad, < 30 = bad (DLG, 2006).

Table 4

Chemical composition, nutrient digestibilities and energy value of forages.

Item	Napier grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]
DM (g/kg)	227.2	225.5	852.1	219.9	6.10
Chemical composition (g/kg DM)					
OM	895.5	892.6	915.4	866.9	0.20
CP	76.5	81.2	80.5	82.6	0.05
Crude fat	23.6	24.9	19.2	25.7	0.10
Ash	104.5	107.4	84.6	133.0	0.59
NDF	595.6	625.8	634.6	612.9	0.13
ADFom	330.7	359.8	369.0	345.4	0.10
ADL	41.4	43.4	49.2	42.6	0.16
Nutrient digestibility (%)					
DM	50.2^{d}	53.1^{b}	51.8^{c}	55.4^{a}	0.15
OM	60.5^{c}	62.2^{b}	57.9^{d}	65.2^{a}	0.17
CP	49.1^{b}	51.4^{b}	50.2^{b}	57.8^{a}	0.25
Crude fat	30.3^{c}	34.4^{b}	28.8^{d}	50.9^{a}	1.59
NDF	50.5^{c}	52.5^{b}	54.3^{a}	52.9^{b}	0.11
ADFom	48.1^{c}	50.2^{b}	52.2^{a}	50.0^{b}	0.15
Energy value					
ME (MJ/kg DM)	8.0^{ab}	8.2^{ab}	7.8^{b}	8.5^{a}	0.06

[1] Standard error of the mean. Means with different letters within rows differ *($P<0.05$)*.

DM, dry matter; OM, organice matter; CP, crude protein; NDF, neutral detergent fibre; ADFom, acid detergent fibre expressed exclusive residual ash; ADL, acid detergent lignin; ME, metabolisable energy.

3.4. In vitro gas production characteristics

The gas production curves are given in Fig. 2 and the parameters of the exponential model are presented in Table 5. The cumulative gas volume at each sampling time was affected by type of forage. There were differences in the asymptotic *(b)* gas production with greater values noted for pangola silage (58.5 mL) *versus* fresh pangola grass, pangola hay and Napier grass (53.9, 50.6, and 47.3 mL, respectively). The rate constant *(c)* did not differ among the treatments (P>0.05). The lag time was highest for pangola hay (P<0.05) followed by Napier grass, fresh pangola and pangola silage.

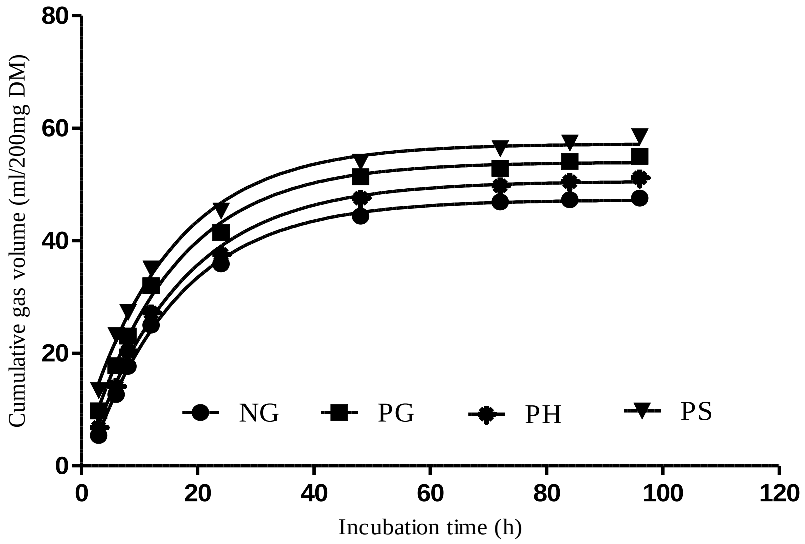

Fig. 2. *In vitro* gas production profiles of the forages. Gas production profiles have been fitted to curves using the equation $y = B\ (1-e^{-c(t-lag)})$; NG, Napier grass; PG, fresh pangola; PH, pangola hay; PS, pangola silage).

Table 5

Cumulative gas produced at different times of incubation for forages and parameters of gas production estimated with the exponential model, metabolisable energy (ME) and *in vitro* organic matter digestibility.

Item	Napier grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]
Cumulative gas (mL) produced at					
12h	25.0	32.0	27.2	35.0	0.44
24h	35.9	41.5	37.6	45.3	0.37
48h	44.4	51.4	47.6	54.0	0.32
96h	47.6	55.0	51.2	58.5	0.33
Parameters of exponential model					
B, mL	47.3[d]	53.9[b]	50.6[c]	58.5[a]	0.33
c, mL/h	0.0648	0.0666	0.0627	0.0664	0.003
LAG, h	1.012[b]	-0.187[c]	0.465[a]	-1.466[d]	0.85
In vitro organic matter digestibility (%)					
IVOMD24	57.3	62.5	57.7	67.6	0.34
IVOMD48	64.5	70.9	66.1	74.9	0.26
Energy value					
ME (MJ/kg DM)	8.3	8.5	8.1	8.8	0.05

[1] Standard error of the mean. Means with different letters within rows differ *($P<0.05$)*.

B the asymptotic gas volume, *c* the rate constant, *LAG* is the time (h) between inoculation and commencement of gas production, *IVOMD in vitro* organic matter digestibility, *ME* metabolisable energy

4. Discussion

4.1. Characteristics of Napier and pangola grasses

Napier grass is widely planted in the tropical and subtropical regions of the world (William and Hanna, 1995). The importance of Napier grass can be seen from the role it plays as the major livestock feed in smallholder ruminant production systems in Thailand. Unfortunately, it shows a low digestibility, low CP content and low herbage production in the dry season (Yunus et al., 2000) which was also found in our study where Napier grass ranked lowest for CP concentration and DM digestibility. Characteristics of Napier grass in this study, especially its CP content were similar to values reported by Tamada et al. (1999) and Rahman et al. (2009).

Characteristics of fresh pangola grass in this study indicated a high forage quality when compared with previous reports (Chaiwang et al., 2011; Chaichaum et al., 2007; Animal Nutrition Division, 2006; Lee et al., 2000) and a similar trend was noted for pangola hay. The quality of pangola silage as evaluated by the organoleptic test was good to very good. Although the precision of this test method may be variable due to the experience and the sensitivity of test panels, it is practical and popular since it needs no equipment (Angthong et al., 2007). Based on this evaluation, the pangola silages were classified as well fermented. This is supported by the results of the DLG scheme (DLG, 2006), which objectively assesses silage fermentation quality by means of contents of butyric acid, acetic acid and pH using a points-based system. According to that scheme, fermentation quality was ranked as “very well” for pangola silages in this study with a low variance between barrels (SEM 0.22). The ensiling process was dominated by lactic fermentation and signs of malfermentation which are often found in tropical silages (Tjandraatmadja et al., 1994), did not occur. This is possibly due to the addition of fermentable carbohydrates in form of molasses, resulting in lactic acid being the major organic acid (65.6%), moderate concentrations of acetic acid, only trace amounts of butyric acid and relatively low NH_3-N concentrations. Similar improvements were achieved by the addition of molasses to clover-grass silages (McDonald et al., 1991) and to Napier grass silages (Yunus et al., 2000).

The DM losses during ensiling averaged 11% which is relatively high when comparing with well-fermented maize and grass silages (Köhler et al., 2013). Increasing the density in the silo (130 kg DM/m³ in this study) or wilting the forages above 30% DM could help to reduce these losses.

4.2. Chemical composition

The CP content of the Napier grass used in the present study (76.5 g/kg DM) was lower than given by Manaye et al. (2009) (120 g/kg DM). This might be due to the differences in stage of cutting, location, climate and environment. Rahman et al. (2009) reported that the CP content of Napier grass varies with many factors, such as plant maturity and nitrogen fertilization.

The CP content of fresh pangola (81.2 g/kg DM) was lower than the average of 100 g/kg DM reported by Animal Nutrition Division (2002) but similar to values reported by Chaichaum et al. (2007; 81 g/kg DM) and greater than 79, 63 and 53 g/kg DM reported by Animal Nutrition Division (2006), Mullik et al. (2009) and Chaiwang et al. (2011), respectively. Moreover, Assoumaya et al. (2007) who harvested fresh pangola after 14, 28, 42 and 56 days of growth reported that the CP concentration of fresh pangola sharply declined during this period. The CP contents were 130, 79, 72 and 57 g/kg DM, respectively for the four harvest dates.

The differences in chemical composition among fresh pangola, pangola hay and pangola silage could be due to the several reasons. Pangola silage was ensiled with 5 kg molasses/100 kg fresh pangola which added some nutrients and improved the nutritional value. When compared with fresh pangola, the silage had slightly increased concentrations of crude fat and decreased concentrations of NDF. Both might be a relative change due to the addition of molasses, decreased NDF values could also be a result of the fermentation process which attributes to the hydrolysis of the cell wall of plant materials providing monosaccharides as additional substrate for lactic acid production during fermentation (Huisden et al., 2009). The lower values of CP and crude fat in pangola hay compared to fresh pangola were probably caused by the drying process which could result in (mechanical) field losses, especially of leave-rich material (McDonald et al., 2002).

4.3. Nutrient digestibility and metabolisable energy

The nutrient digestibility and ME of the forages in this study were affected by the conservation method and the forage type.

4.3.1. In vivo

The OM and CP digestibilities (60.5 and 49.1%) of Napier grass in the present study were similar to previous report of 59.5 and 52.7% by Rahman et al. (2013). The digestibility of most of the nutrients in pangola hay in the present study was higher than that reported by

Lee et al. (2000). This could be due to the fact that in the latter study pangola grass was harvested on day 70 and was relatively mature, with lignified cell walls thereby lowering digestibility. Digestibility of DM, OM and NDF were comparable to values also measured in sheep published by Tomkins et al. (1991).

One of the main goals of the present study was to estimate the energy value of the forages. The ME value was lowest ($P<0.05$) in pangola hay followed by Napier, fresh pangola and pangola silage. However, the ME value of pangola hay in this study (7.8 MJ/kg DM) was still greater than the values of 6.4 and 7.3 MJ/kg DM reported by Nitipot et al. (2009) and Chaokaur et al. (2008), respectively. This indicates that the pangola forage used in this study was in general of good quality in terms of energy value for sheep.

4.3.2. In vitro

Due to its ability to simulate the process of digestion in ruminant animals in a much better way than pure chemical methods, *in vitro* methods have been successfully used for prediction of IVOMD and ME content of ruminant diets. In the present study, IVOMD24 and ME contents (67.6% and 8.8 MJ/kg DM) were greater in pangola silage than in the other forage types. Regan (2000) reported that in northern Australia bale silage was prepared from wilted pasture with pangola grass (*D. eriantha* subsp. e*riantha*) and two legumes, namely cavalcade centurion (*Centrosema pascuorum*) and wynn cassia (*Chamaecrista rotundifolia*). The *in vitro* digestibility of the silages made from the wilted plants (42-57% DM) ranged from 55-58% and the ME values ranged from 8.5-9.0 MJ kg/DM. The fermentation profile depended on wilting degree, and the haylage contained less lactic and volatile fermentation products, as expected. Estimation of ME based on both *in vivo* and *in vitro* data resulted in comparable results with values between 8.1 and 8.8 for *in vitro* and 7.8 and 8.5 MJ ME/kg DM for *in vivo*, with the same ranking of forages, starting with pangola silage having the highest ME concentration, followed by fresh pangola, Napier grass and pangola hay.

4.4. In vitro gas production characteristics

The *in vitro* gas production technique has the potential to indicate the *in vivo* total-tract digestibility of feeds for ruminants. On the other hand, the *in vitro* gas production technique has been used as a measure of ruminal degradation of feeds (Menke and Steingass, 1988; Getachew et al., 1998). In the present study, the highest values of gas production parameters with the exception of the rate of gas production were found in pangola silage, probably caused by the lower fibre (cell wall) contents, which are at least partly caused by the addition of rapidly fermentable carbohydrate in molasses, and higher degradability of insoluble fraction.

In a previous study, Juárez Reyes et al. (2009) reported higher (P<0.05) *in vitro* gas production for pangola grass, and it was some 30% less in other grasses (Guinea, Bermuda and Tanzania grasses) and they also reported greater (P<0.05) gas production from the insoluble fraction in pangola grass *versus* Guinea and Bermuda grasses.

The amount of gas produced after 24 h for pangola hay was higher (37.6 mL/200 mg DM) than those reported by Thiputen and Sommart (2012) (20.7 mL/200 mg DM), which may also be caused by differences in maturity. It underlines the possibility of conserving pangola grass in high quality, especially when using grasses early in regrowth.

5. Conclusions

Pangola grass is a promising forage with good potential as feeding resource for ruminant animals based on its chemical composition and energy value as estimated from *in vivo* measurements in sheep and also *in vitro* incubations using ruminal fluid. It can be well preserved as silage – provided an appropriate additive is used, e.g., molasses as in this study – and hay for dry season feeding in tropical countries. Likely due to the addition of 5% molasses, in the present study pangola silage ranked higher than its fresh and hay forms as well as Napier grass which was the control. The outcome of this study provides baseline data which can be used to introduce and promote pangola grass to smallholder farmers in order to improve animal productivity in Thailand and other tropical countries having similar environmental conditions and farm structures.

Acknowledgements

This study was funded by the Institute of Animal Science, University of Bonn and by Japan International Research Center for Agricultural Sciences (JIRCAS). The authors would like to thank Her Majesty the Queen's Initiated Projects, Thailand for support in acquisition and maintenance of experimental animals. Dr. Uchenna Young Anele is acknowledged for editing an earlier version of the manuscript.

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CHAPTER 5

In vitro gas production and nutrient digestibility and growth performance of Thai indigenous cattle fed fresh and conserved pangola grass

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To be submitted for publication

Abstract Fresh and conserved pangola grass (*Digitaria eriantha* Steud., synonym *D. decumbens*) were compared in terms of *in vitro* gas production and nutrient digestibilities, metabolisable energy (ME) values and average daily gain (ADG) of Thai indigenous cattle. The study was designed as a completely randomized design with Ruzi grass (*Brachiaria ruziziensis*) as control and pangola grass in fresh, hay or silage form at the same age at harvest (45-days regrowth) as treatments. The dry matter (DM) intake of forages supplemented with concentrate and a protein block was not significantly different *(P>0.05)* among treatments. Pangola silage, to which 5% sugarcane molasses was added at ensiling to minimize the risk of bad fermentation, produced more gas *in vitro* after 96 hours incubation and had greater *(P<0.05) in vivo* DM, organic matter and crude protein apparent digestibilities and ME contents and resulted in higher ADG of cattle. In conclusion, the form of pangola grass had a direct effect on digestibility, ME and ADG of Thai indigenous cattle. Pangola silage ranked higher than its fresh and hay forms as well as Ruzi grass which was the control.

Keywords Nutrient digestibility • Metabolisable energy • Average daily gain • *In vitro* gas production • Thai indigenous cattle

Introduction

Ruminant livestock play a key role as an integral part of farming and rural life in tropical countries by providing food, family income and employment (Pezo and Devendra 2002). Most developing countries are located in the tropical area, including Thailand. White Lamphun and the mountain cattle are the most prominent native cattle breeds in northern Thailand. They are fertile animals, tolerant to poor feed quality and also towards internal and external parasites and adapt well to hot and humid climate (Rattanaronchart 1998).

Feeding of cattle in the tropics is often difficult because of seasonal decline in feed supply, in both quality and quantity (Wanapat and Devendra 1992). The main cattle feed is grass, either from natural or cultivated pasture. The common problems that farmers face are cattle losing weight and lack of quality feed resources during dry season. Hay and silage making as reserve for feeding during periods of feed limitation are one possibility to overcome these problems. In Thailand, ensiling is one of the fodder conservation methods to avoid feed shortage in dry season and silage has been produced for many years by government research and field extension stations and distributed to farmers, mostly dairy farmers (Poathong and Phaikaew 2001).

Ruzi grass is one of the most important forage species planted in the tropics. For almost 30 years, Ruzi has been the grass most commonly planted on upland soils in Thailand because of the availability of relatively cheap seed (Hare et al. 2005) despite poor dry season forage production (Hare et al. 2009).

Pangola grass (*Digitaria eriantha* Steud., synonym *D. decumbens*) is a commonly grown, high quality tropical grass (Cook et al. 2005). It is recommended for the poorly drained soil in Malaysia and the Philippines (Hacker 1992) and utilized extensively for animal grazing, hay or silage making (Meeske et al. 1999). Pangola grass has already been used as animal feed for long time (see review by Tikam et al. 2013), and has shown its potential as nutrient source for sheep in both fresh and preserved forms (Tikam et al. submitted). However, evaluation of pangola grass, grown under identical conditions at the same location, harvested at the same regrowth age and then utilized in fresh and conserved (hay, silage) forms in cattle has not yet been investigated. Therefore, the aim of this study was to evaluate *in vitro* gas production and nutrient digestibilities, metabolisable energy (ME) and average daily gain (ADG) of Thai indigenous cattle fed fresh and conserved pangola grass and fresh Ruzi grass.

Materials and methods

Study site

This study was carried out at the farm of Lampang Animal Nutrition Research and Development Centre, located in Lampang province, Thailand (latitude 18°16'N and longitude 98°32'E). The climate is tropical monsoon, with a wet season from May to October and a dry season from November to April. The experiment was conducted during the months of May to October 2009. The average daily temperature during the study was 27°C and the average daily relative humidity was 84%.

Forage and management

Pangola grass and Ruzi grass were harvested from the same location at the same regrowth age at cutting (45 days) and were used to produce four forage treatments, namely Ruzi grass, fresh pangola, pangola hay and pangola silage. For fresh pangola and Ruzi grasses, their fields were divided into different plots already for the previous growth period so that their maturity could be controlled by cutting at different days in order to obtain fresh grass of 45 days regrowth duration and thus, similar quality, throughout the feeding and digestibility trial carried out in the following weeks. Grasses were cut early every morning and chopped before feeding. For pangola hay, fresh pangola was harvested and sun-dried on the field for 2-3 days, then small square hay bales (0.9 m x 0.45 m x 0.35 m and a weight between 20 and 30 kg) were made and stored indoor. For pangola silage, grasses were chopped into pieces of 2 to 3 cm length, after which 5 kg sugarcane molasses per 100 kg fresh pangola were added. Molasses is the by-product of sugar production from sugarcane and contains 72.4% DM and 2.2% CP (Animal Nutrition Division 2004). The material was then homogenized and filled in sixty 120-l plastic barrels (100 kg/barrel), compacted, sealed and ensiled for a minimum of 21 days. The barrels were opened one after the other during the feeding and digestibility trial where each was completely consumed within two days.

As ensiling of pangola with a dominant lactic acid fermentation is difficult to achieve without an additive providing, e.g., extra water-soluble carbohydrates, the supplementation of a fermentable carbohydrate source like molasses is seen as a practical solution to the problem of delayed fermentation or malfermentation in tropical silages (Tjandraatmadja et al. 1994). It was assumed that the inclusion of molasses represents a standard type of pangola silage and therefore, this forage type was simply referred to as pangola silage hereafter.

Forages as well as the concentrate and the protein block used as supplement in the feeding trial were sampled for chemical analyses four times (n=4) before being fed to the animals during 111 days of the experiment.

In vitro gas production measurement

In vitro gas production of forages was determined according to Menke and Steingass (1988). The gas volume was recorded after 0, 3, 6, 8, 12, 24, 48, 72, 84 and 96 hours of incubation. Data were fitted to an exponential model given by McDonald (1981):

$$y = B\,(1 - e^{-c(t - lag)})$$

where ‘y’ is the cumulative volume of gas produced at time ‘t’ (h), ‘B’ the asymptotic gas volume, ‘c’ the rate constant and ‘lag’ is the time (h) between inoculation and commencement of gas production.

Animals and experimental design

Sixteen native White Lamphun bulls at around 8-9 months of age with a body weight (BW) of 124 ± 16.9 kg (mean ± standard deviation) at the beginning of the experiment were used. Animals were randomly assigned to four treatment groups comprising of Ruzi grass (control), fresh pangola, pangola hay and pangola silage at four animals per treatment. Before starting the experiment, the cattle were drenched with Ivermectin 1% sterile solution (1 mL/50 kg BW) and vaccinated against foot and mouth disease. The experiment lasted for 111 days including adaptation and digestibility period (14 days for adaptation, 90 days for the feeding trial and 7 days for digestibility period). The feeds were offered twice per day at 08:00 and 16:00 h in two equal portions. Each animal was fed a diet consisting of forage and a commercial concentrate at 2.0 and 0.5% (DM basis) of BW, respectively. Protein blocks (5 kg solidified mixture of 40% soybean, 35% sugarcane molasses, 13% cement, 8% urea, 2% salt and 2% dicalcium phosphate; Mikled et al. 2008) and fresh water were offered for ad libitum consumption separately in each cage during the whole experimental period. Intake of the protein block was determined by dividing its total weight by the number of days the animals needed to consume it completely. The BW of the cattle were taken at the beginning, every two weeks and at the end of the feeding experiment. The amount of feed offered to the animals was adjusted according to these measurements. The digestibility trial was conducted in the last 7 days of this study. Forages and feed refusals of each animal were collected daily, weighed fresh and dried in an oven at 60°C until constant weight was achieved. Faeces collected were weighed and recorded daily. Five percent of the faeces voided daily were sampled and stored at -20°C and then pooled for each animal over the collection period.

Chemical analyses

Feed samples, feed refusals and faeces samples were oven-dried and then successively ground in mills with 3- and 1-mm sieves for use in chemical analyses. The DM content of samples was determined by oven-drying at 100oC for 24 h. Crude protein (method ID 976.06), ash (method ID 942.05) and ether extract (hereafter denoted crude fat, method ID 920.39) analyses were carried out as described by AOAC (2000). Crude fibre, neutral detergent fibre (NDF) and acid detergent lignin (ADL) were determined according to the method of Van Soest et al. (1991). Acid detergent fibre expressed exclusive residual ash (ADFom) was analyzed using method 6.5.2 of the German Handbook of Agricultural Experimental and Analytical Methods (VDLUFA 2007).

Calculations and statistical analyses

The *in vivo* digestibilities (%) of diets were calculated as follows:

((Nutrient consumed in feed [g/day] – nutrient excreted in faeces [g/day])/nutrient consumed in feed [g/day]) x 100.

The *in vivo* ME values of diets were calculated from *in vivo* digestibility values as follows (GfE 1995; all variables expressed per kg DM):

$ME_{in\ vivo}$ (MJ) = 0.0312 × digestible crude fat (g) + 0.0136 × digestible crude fibre (g) + 0.0147 × (digestible organic matter – digestible crude fat – digestible crude fibre) (g) + 0.00234 × CP (g).

This equation is based on *in vivo* digestibilities that were calibrated against a large number of measured ME values (92 diets) using respiration chambers.

Gas production at 24 and 48 h of incubation, together with the concentrations of chemical components, was used to predict concentrations of *in vitro* digestible organic matter (IVOMD24 and IVDOMD48, respectively) of forages as follows:

IVOMD24 or IVDOMD48 (%) = 15.38 + 0.8453 × GP + 0.0595 × CP + 0.0675 × ash

where GP is *in vitro* gas production (mL/200 mg DM) at the respective incubation time, CP and ash are given as g/kg DM (Menke and Steingass 1988).

The ME values of forages based on GP and chemical composition were calculated using the following equation (GfE 2008): ME (MJ/kg DM) = 7.81 + 0.07559 × GP – 0.00384 × ash + 0.00565 × CP + 0.01898 × crude fat – 0.00831 × ADFom

where GP is *in vitro* gas production at 24 h (mL/200 mg DM) and ash, CP, crude fat and ADFom are expressed in g/kg DM.

The experimental setup was a completely randomized design (CRD) and data were subjected to analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS (2002). Means were compared using Duncan's new multiple range test (Steel and Torrie 1980). All statistical analyses were performed using SAS version 9.1 (SAS 2002.)

Results and discussion

In vitro gas production and substrate degradability are commonly used to determine the nutritive value of forages (Blümmel et al. 1997; Getachew et al. 1998) and due to its ability to simulate the process of digestion in ruminant animals in a much better way than pure chemical methods, *in vitro* methods have been successfully used for prediction of IVOMD and ME content of ruminant diets. In this study, IVOMD24 values for the pangola forages ranged from 59.9 to 70.5% (Table 6). As in the *in vivo* measurements of OM digestibility, pangola silage showed the highest values for both IVOMD24 and IVOMD48.

The gas production curves are given in Figure 3 and the parameters of the exponential model are presented in Table 6. The cumulative gas volume at each sampling time was affected by type of forage. There were differences in the asymptotic (b) gas production with greater values noted for pangola silage (60.6 mL) versus fresh pangola grass, pangola hay and Ruzi grasses (56.4, 54.2 and 51.3 mL, respectively).

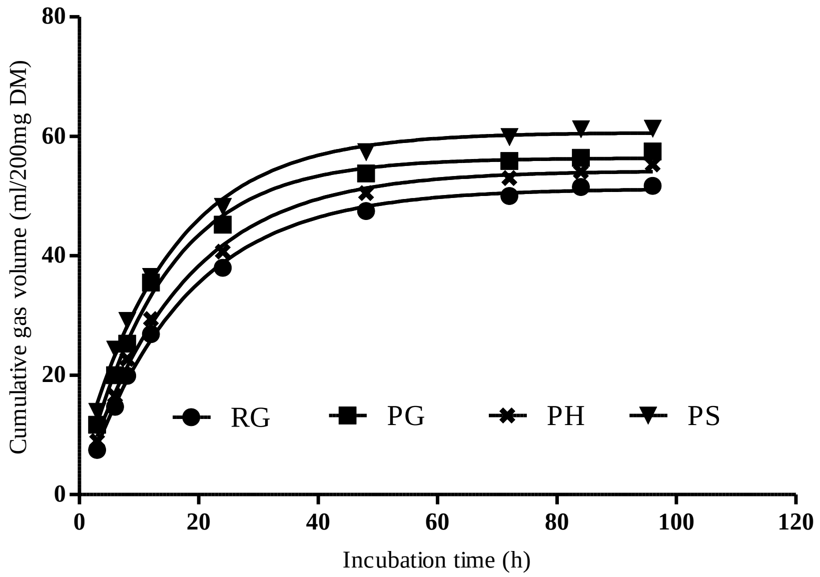

Figure 3 *In vitro* gas production profiles of the forages. Gas production profiles have been fitted to curves using the equation $y = B\,(1-e^{-c(t-lag)})$; *RG* Ruzi grass, *PG* fresh pangola grass, *PH* pangola hay, *PS* pangola silage

Table 6 Cumulative gas produced at different times of incubation for forages and parameters of gas production estimated with the exponential model, *in vitro* organic matter digestibility and metabolisable energy

Item	Ruzi grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]
Cumulative gas (mL) produced at					
12 h	26.9	35.5	29.4	36.5	0.65
24 h	38.0	45.2	40.7	48.2	0.56
48 h	47.5	53.8	50.5	57.4	0.45
96 h	51.7	57.7	55.3	61.3	0.33
Parameters of exponential model					
B, mL	51.3 ^{d}	56.4 ^{b}	54.2 ^{c}	60.6 ^{a}	0.29
c, ml/h	0.059	0.073	0.061	0.067	0.0256
LAG, h	0.116 ^{a}	-0.253 ^{b}	-0.263 ^{b}	-1.323 ^{c}	1.1526
In vitro organic matter digestibility (%)					
IVOMD24	59.2 ^{c}	66.1 ^{b}	59.9 ^{c}	70.5 ^{a}	0.48
IVOMD48	67.5 ^{c}	73.4 ^{b}	68.2 ^{c}	78.3 ^{a}	0.32
ME (MJ/kg DM)	8.5 ^{b}	9.1 ^{ab}	8.8 ^{b}	9.6 ^{a}	0.11

[1] Standard error of the mean. Means with different letters within rows differ *($P<0.05$)*

B the asymptotic gas volume, *c* the rate constant, *LAG* is the time (h) between inoculation and commencement of gas production, *IVOMD in vitro* organic matter digestibility, *ME* metabolisable energy

The rate constant (c) did not differ among the treatments (*P>0.05*). The highest values of gas production parameters with the exception of the rate of gas production in pangola silage, probably caused by the lower fibre (cell wall) contents, which are at least partly caused by the addition of rapidly fermentable carbohydrate in molasses, and higher degradability of insoluble fraction. Hemicelluloses might have been partly degraded during the ensiling process (McDonald et al. 1991). In a previous study, Juárez Reyes et al. (2009) reported higher (*P<0.05*) *in vitro* gas production for pangola grass, and it was some 30% less in other grasses (Guinea, Bermuda and Tanzania grasses) and they also reported greater (*P<0.05*) gas production from the insoluble fraction in pangola grass versus Guinea and Bermuda grasses. The amount of gas produced after 24 h for pangola hay was higher (40.7 mL/200 mg DM) than those reported by Thiputen and Sommart (2012) (20.7 mL/200 mg DM), which may also be caused by differences in maturity. It underlines the possibility of conserving pangola grass in high quality, especially when using grasses early in regrowth.

The chemical compositions of the forages and the supplements (concentrate and protein block) are shown in Table 7. Pangola silage had the highest (*P<0.05*) CP and crude fat concentrations (98 and 28 g/kg DM, respectively) which might be due to the fact that it was ensiled with 5% sugarcane molasses which added some nutrients and improved the nutritional value. Pangola hay contained more (*P<0.05*) NDF, ADFom and ADL than the other forages. The lower values of CP and crude fat in pangola hay compared to fresh pangola were probably caused by the drying process which could result in (mechanical) field losses, especially of leave-rich material (McDonald et al. 2002). All forms of pangola ranked higher in CP concentrations than Ruzi grass. As CP concentration in pangola grass sharply declines with advancing maturity (Ventura et al. 1975), even higher values could be reached by an earlier age at cutting.

Data on *in vivo* digestibility and ME values of the diets are given in Table 8. The pangola silage diet had higher (*P<0.05*) *in vivo* digestibilities of DM, CP and crude fat which resulted in the highest ME concentration in comparison with the other forage diets. Higher CP concentrations might have improved ruminal energy supply of microbes and the improvement in microbial activity resulted in greater DM and CP digestibility. The pangola hay in this study had a lower (*P<0.05*) OM digestibility (61.2%) than other forage types. However, previous studies have shown that in Thailand, the OM digestibility of pangola hay varied from 58.5-76.7% when fed as sole feed (Suzuki et al. 2008; Chobtang et al. 2012) or in forage based diets (Suksathit et al. 2011) and is strongly affected by stage of maturity

(Ventura et al. 1975). All diets based on fresh or preserved forms of Pangola grass showed higher (*P<0.05*) NDF and ADFom digestibilities than the control diet.

Table 7 The chemical composition of the forages and the concentrate and protein block fed for supplementation

Item	Ruzi grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]	Concentrate	Protein block
Dry matter (g/kg)	235.5	229.0	835.8	215.5	5.54	889.6	706.0
Nutrient composition (g/kg dry matter)							
Organic matter	898.6	896.5	932.8	872.4	0.21	915.7	841.0
Crude protein	81.8	93.5	94.4	97.6	0.16	119.2	405.5
Crude fat	25.8	26.7	21.3	27.5	0.34	31.9	18.6
Ash	101.4	103.5	67.2	127.6	0.45	84.3	159.0
NDF	687.7	694.5	722.9	695.3	0.11	337.2	-
ADFom	362.6	379.2	393.5	373.5	0.24	-	-
ADL	41.1	45.3	49.9	43.5	0.34	-	-

[1] Standard error of the mean,

NDF neutral detergent fibre, *ADFom* acid detergent fibre expressed exclusive of residual ash, *ADL* Acid detergent lignin

Table 8 The *in vivo* nutrient digestibility (%) and concentration of metabolisable energy (ME) of the difference diets (forages supplemented with concentrate and protein block)

	Diet				
Item	Ruzi grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]
Dry matter	59.5 [c]	60.7 [c]	62.7 [b]	64.5 [a]	0.15
Organic matter	61.5 [c]	65.7 [b]	61.2 [c]	69.2 [a]	0.35
Crude protein	50.3 [c]	55.7 [b]	56.3 [b]	58.0 [a]	0.29
Crude fat	43.5 [c]	44.4 [b]	42.1 [d]	49.9 [a]	0.45
NDF	70.6 [c]	73.2 [b]	74.9 [a]	73.6 [b]	0.15
ADFom	56.7 [c]	58.6 [b]	60.6 [a]	58.7 [b]	0.14
ME (MJ/kg DM)	8.3 [b]	8.8 [ab]	8.5 [b]	9.1 [a]	0.09

[1] Standard error of the mean. Means with different letters within rows differ *(P<0.05)*

NDF neutral detergent fibre, *ADFom* acid detergent fibre expressed exclusive of residual ash, *ME* metabolisable energy

Estimation of ME based on both *in vivo* and *in vitro* data resulted in the same ranking of forages, starting with pangola silage having the highest ME concentration, followed by fresh pangola, pangola hay and Ruzi grass.

The DMI, BW gain and ADG are shown in Table 9. The DMI in this study was not significantly different among treatments ($P>0.05$).

Table 9 Dry matter intake, body weight gain and average daily gain of native White Lamphun bulls fed on diets with different forages supplemented with concentrate and protein block

	Diet				
Item	Ruzi grass	Fresh pangola	Pangola hay	Pangola silage	SEM[1]
Dry matter intake (kg/day)	2.84	2.85	2.88	2.90	0.014
-Forage	2.22	2.25	2.27	2.24	0.013
-Concentrate	0.52	0.51	0.51	0.54	0.019
-Protein block	0.10	0.09	0.10	0.12	0.039
Initial body weight (kg)	123.5	123.4	123.5	123.6	1.81
Final body weight (kg)	151.3	167.0	159.5	171.5	0.56
Body weight gain (kg)	27.8 ^{d}	43.6 ^{b}	36.0 ^{c}	47.9 ^{a}	0.98
Average daily gain (kg/day)	0.30 ^{d}	0.48 ^{b}	0.40 ^{c}	0.53 ^{a}	0.112

[1] Standard error of the means. Means with different superscripts (a-d) within rows differ *($P<0.05$)*

The ADG of the White Lamphun native bulls were normal and in agreement with Mikled et al. (1991). However, there were differences in BW gain and ADG ($P<0.05$), with cattle fed pangola silage having higher ($P<0.05$) values than other treatments. It shows the possibility of achieving moderate to good weight gains with indigenous cattle fed forage-based diets also during the dry season. By adding molasses, both a stable fermentation and conservation of the forage as well as increases in nutrient digestibilities and ME concentration could be achieved. Higher digestibility and ruminal fermentation activities due to feeding pangola silage probably resulted in the observed increased body weight gain and ADG. Feeding diets higher in protein and energy improved the feedlot performance of growing animals (Sultan et al. 1991). Also Preston and Leng (2009) reported that improved nutrition requires increasing the energy density of the diet, ensuring efficient rumen function and providing a complimentary source of bypass protein. The lower BW gain in the Ruzi, fresh pangola and pangola hay treatments in comparison with pangola silage indicate that supplementation with protein and energy source would potentially improve growth performance of growing bulls fed these forages. Also an adequate amount of fertilizer (nitrogen and sulphur) can help to improve DM and OM digestibility as well as voluntary intake of pangola grass in different forms (Minson 1973, Rees et al. 1974). With a good forage management and supplementation of concentrate pangola grass in both fresh and conserved forms can be used to achieve animal performances of indigenous cattle comparable or even superior to Ruzi grass.

Conclusion

Results from the present study showed that pangola grass is a feasible alternative as forage source for cattle in tropical countries. It could be well preserved as silage and hay. Pangola silage ensiled with molasses increased organic matter digestibility and thus, ME concentration, body weight gain and ADG of Thai indigenous cattle fed forage-based diets and can thus be recommended as a grass species for feeding especially during dry season in tropical countries.

Acknowledgements This study was financially supported by Institute of Animal Science, University of Bonn, Japan International Research Center for Agricultural Sciences (JIRCAS) and National Science and Technology Development Agency (Northern Network)-Thailand. Dr. Uchenna Young Anele is acknowledged for editing an earlier version of the manuscript.

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CHAPTER 6

General conclusions

The goal of this thesis was to investigate the effect of pangola grass on nutrient digestibility, *in vitro* gas production and growth performance in ruminants. Pangola grass has already been used as ruminant feed for long time, however, to our knowledge, this study is the first report of evaluation of pangola grass in difference forms (fresh, hay or silage) at the same cutting age and harvested at the same location on chemical compositions, nutrient digestibilities, *in vitro* gas production, metabolisable energy and growth performance in sheep and native bulls.

Based on the review of pangola grass as forage for ruminants (Chapter 3) it can be emphasized that, given the prevailing technical, economic and climatic conditions in many tropical zones and in Thailand particularly, the chemical composition and nutritive value of pangola grass vary with several factors like age of regrowth at harvest, season, fertilizer and genotype. The age of the regrowth at harvest is the main source of variation for chemical compositions and overall feeding values. In addition, pangola can be fed fresh or preserved as hay or silage, provided proper harvest and conservation management is applied. Several authors showed beneficial results when fed pangola grass in fresh or preserved (hay and silage) forms to ruminants. Thus, pangola is regarded as one of the highest quality tropical grasses and expected to be good feed for ruminant animals.

In this study, characteristics of forages used in both sheep and native bull experiments indicated a high forage quality. The nutritional compositions of the forages were higher than values available in the literature from many previous studies (Animal Nutrition Division, 2004; Chaichaum et al., 2007; Rahman et al., 2009; Chaiwang et al., 2011 and Chobtang et al., 2012) respectively, for Napier, Ruzi, pangola, pangola hay and pangola silage. The pangola silages in this study were preserved with the addition of 5% sugarcane molasses to ensure good fermentation quality. Based on evaluation with the DLG scheme (DLG, 2006), which objectively assesses silage fermentation quality by means of contents of butyric acid, acetic acid and pH using a points-based system, the pangola silages were classified as very well fermented. Previous studies reported that molasses has been widely used as an additive to forages for supporting the fermentation process due to its high sucrose content (Umaña et al., 1991; Rezaei et al., 2009; Lima et al., 2010). In most studies, addition of molasses especially to forages poor in fermentable substrate improved fermentation and avoided malfermentation e.g. caused by clostridia. This suggests that the quality of pangola silage can be improved by the addition of sugarcane molasses. As pangola grass typically contains only low concentrations of watersoluble carbohydrates, it should be recommended to include additional fermentable substrate (like molasses) for improving the ensiling process, especially in unwilted grasses like in this study. Other low quality tropical grasses used as feeds for ruminants could be significantly improved by ensiling with additives like small amounts of molasses and with high-protein tree leaves. In Thailand, Khuamangkorn et al. (2006) studied the quality of pangola, ensiled with molasses at four levels (2, 4, 6 and 8% of fresh pangola) and with rice bran at four levels (5, 10, 15 and 20%) and without additives. The result indicated that all of the tested additives can improve the quality of pangola. The best quality of pangola silage was found in the additives of rice bran at 20%. Pangola grass can be ensiled however the quality of silage obtained depends on fresh grass quality, the ensiling process and use of additives.

One of the main goals of this study was to evaluate *in vitro* gas production of forages. It was observed that highest values for parameters of gas production were found in pangola silage. The difference in nutrient availability could have resulted in increased microbial growth and activity at the beginning of incubation for pangola silage samples, which resulted in more fermentation and increased gas production.

For use in the feeding trials, pangola was successfully supplemented with concentrate and a protein block. All forms of pangola improved CP digestibility, final body weight and ADG compared to the control. White Lamphun native bulls (Chapter 5) gained more body weight when fed pangola silage diets in comparison to the other treatments. It is hypothesized that efficient N and energy coupling helped to achieve higher productivity. In agreement with previous research (Sultan et al., 1991), feeding high protein and energy diets improve the feedlot performance of growing animals and potential benefit of feeding diets varying in protein and energy. With a good forage management and supplementation of concentrate, pangola grass in both fresh and conserved form can be used to accomplish high animal performances of indigenous cattle. In contrast to diets containing low quality forages like straw, the amount of concentrate needed to achieve moderate to good animal performances might therefore be reduced when feeding pangola in fresh or conserved form.

Based on the estimates of ME, for both *in vivo* and *in vitro* methods, the ME values were low in forages or diets having high fibre and low protein contents. The ME values of pangola ranged of from 8.1-9.6 MJ/kg DM for *in vitro* and 7.8-9.1 MJ/kg DM for *in vivo*, starting with pangola silage having the highest ME concentration, followed by fresh pangola and pangola hay, with the same order of forages for both methods. As expected, a higher gas production was associated with an increase in the values of ME in *in vitro* method.

Common to all tropical grasses, nutritional value and chemical composition of pangola depend on several factor such as differences in stage of cutting, fertilizer, location, soil fertility, climate, environment and management factors. In our study, fresh pangola contained 81 g/kg DM (Chapter 4) and 94 g/kg DM (Chapter 5) CP, when harvested at 45 days. It is well known that forage nutritive value declines with advancing plant maturity. Assoumaya et al. (2007) who harvested fresh pangola after 14, 28, 42 and 56 days of growth reported that the CP concentration of fresh pangola sharply declined during this period. The CP contents were 130, 79, 72 and 57 g/kg DM, respectively for the four harvest dates. In Taiwan, Yeh (1990) reported that the average CP content of pangola varied depending on the regrowth interval length – from 10.5% with cutting at 4-week intervals to 8.9% with cutting at 6-week intervals and 8.0% with cutting at 8-week intervals. Therefore, harvesting interval affects the quantity as well as quality of forage (Elessesser, 2004). In terms of the recommendations relating to cutting age of pangola grasses, 45-day cutting interval at 5-10 cm height above ground level could be the optimal level for harvesting pangola grass in Thailand or other tropical countries to achieve high quantities of pangola with good nutritional value.

Pangola is very responsive to N applications. In the present study, a fertilizer program similar to the following recommended by Animal Nutrition Division (2006) was applied; a 15-15-15 fertilizer (15% N, 15% Phosphorus, 15% Potassium) at a rate of 50-100 kg/rai (0.16 ha) before planting; in each round of cutting two times (10 kg/rai/time) urea (46-0-0) with the first time urea directly after the first cutting and the second time 10-15 days later. Tudsri et al. (1999) found that the different rates (0, 14, 18 and 24 kg N/rai) of N fertilizer significantly increased the DM yield, CP levels and N recovery. The split applications of N at the rate of 12 kg N/rai was recommended for improving the CP concentration of mature pasture. Moreover, Hendy (1972) reported that CP concentration and CP production per acre increased with increasing levels of N fertilizer over the whole growing season. Based on the above findings, it may be suggested that age at cutting and amount of fertilizer can help to improve the nutritive value of pangola grasses. In addition, the adequate amount of fertilizer (N and sulphur) can help to improve DM and OM digestibility as well as voluntary intake of pangola grass in different forms (Minson, 1973; Rees et al., 1974).

Pangola is a palatable and highly digestible tropical grass, but both digestibility and CP content fall dramatically as it matures in the dry season. However, the dry season standing feed value of pangola grass is still higher than that of native grasses and most other introduced tropical grasses such as Napier (Yunus et al., 2000) and Ruzi grasses (Hare et al., 2009) which was also found in our study where Napier and Ruzi grasses ranked lowest for CP concentration and digestibility.

Pangola grass can be grown pure or in mixtures with other grasses and legumes. Under suitable conditions for its own development, pangola grass dominates all other species (Skermann and Riveros, 1990). It combines well with the legume Lotononis bainesii (Bryan and Evans, 1971), as both stand heavy grazing. It can also grow with Centrosema pubescens. In Florida, Kretschmer (1965) has grown it satisfactorily with Stylosanthes humilis and Macroptilium atropurpureum where addition of nitrogenous fertilizer was low.

Based on the literature review and own results on chemical composition, nutrient digestibility, metabolisable energy concentration and *in vitro* gas production this study clearly shows that fresh and conserved pangola grass has a potential for use in ruminant diets. Moreover, pangola hay or silage could be used as sources of high quality forage when feed is scarce for example during the dry season or when natural forages are of very low quality. In conclusion, the potential of pangola as a strategic forage in temperate as well as tropical regions of the world is demonstrated. Its productivity and feeding value make pangola grass an important forage in its area of adaptation, mainly in tropical and sub-tropical areas.

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ACKNOWLEDGMENTS

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study. I would like to thank all those people who made this thesis possible and an unforgettable experience for me.

First of all, I would like to thank my supervisors, Professor Karl-Heinz Südekum and Professor Choke Mikled, for providing me with this opportunity and supporting me during these past many years. Professor Karl-Heinz Südekum is someone you will instantly love and never forget once you meet him. He is a great advisor and one of the smartest people I know. I hope that I could be as lively, enthusiastic, and energetic as him and to someday be able to command an audience as well as he can. Professor Choke Mikled, this work would not have been possible without his advice, guidance, support and encouragement from the very early stage of this research as well as giving me extraordinary experiences throughout the work. Under his guidance I successfully overcame many difficulties and learned a lot. I can’t forget his hard times. Sir, I am grateful in every possible way.

I would like to express my very sincere gratitude to Professor Therdchai Vearasilp and Dr. Chirawath Phatsara for their support and many motivating discussions. I also wish to appreciate PD Dr. Jürgen Schellberg for being in my examination committee.

A huge thanks to Dr. Uchenna Young Anele and Dr. Katrin Gerlach for their help, proofreading, correcting the manuscripts and this thesis. Special thanks to Professor Jürgen Hummel, Dr. Rustam Mundegar, Dr. Moses Arigbede, Petra Jacquemien, my colleagues at University of Bonn, Chiang Mai University and all members of the Bureau of Animal Nutrition Development, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand for their continued friendship, support, advice, helps, laughs and smiles. My special regards go to Helga Koknat for her help to solve any problems in my real life in Germany.

I would like to thank Mr.Wirapon Phunphiphat, Lampang Animal Nutrition Research and Development Centre, Thailand for his support, kindness, work, cooperation and always take good care of me. “Uncle Jee” I know you are up in heaven now and looking my successfully. Cheers!

I take this opportunity to sincerely acknowledge Deutschmann family (Gitty, Bernd, Andy, Chris) and Tuschl family (Barbara, Michael, Marcel) for their love and encouragement. And, thank them for their support when I have needed it the most. They really let me feel like “Kleiner Engel”.

Finally, my utmost gratitude goes to my beloved family especially my dad, mom, sister, auntie and grandmothers who I cannot thank enough for their infinite support throughout everything. I love them so much. Thank you with all my heart!

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Tikam, K., Phatsara, C., Mikled, C., Vearasilp, T., Phunphiphat, W., Chobtang, J., Cherdthong, A., Südekum, K.-H., 2013. Pangola grass as forage for ruminant animals: a review. SpringerPlus 2, 604, 6 pp.

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