Determination of the Nutritive Value of Tropical Biomass Products as Dietary Ingredients for Monogastrics Using Rats: 1. Comparison of Eight Forage Species at Two Levels of Inclusion in Relation to a Casein Diet

Bui Huy Nhu Phuc[1], Jan Erik Lindberg*, Brian Ogle and Sigvard Thomke
Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management
P.O. Box 7024, SE-750 07 Uppsala, Sweden

ABSTRACT : In balance experiments with rats either 25 or 50% of the casein protein in the control diet was replaced with one of the following eight sun-dried tropical biomass products: water spinach plants (WS) (*Ipomoea aquatica Forsk*), leucaena leaves (LL) (*Leuceana leucocephala*), duckweed plants (DW) (*Lemma minor L.*), groundnut foliage (GF) (*Arachis hypogaea L.*), trichantera leaves (Tric) (*Trichantera gigantea*), indicago leaves (Ind) (*Indigofera hirsuta*), mungbean foliage (Mb) (*Phaseolus aureus*), and cassava leaves (CL) (*Manihot esculenta Crantz*). The experiment included 102 rats with six individuals per treatment group. In three of the 16 biomass treatment groups, feed intake and weight gain of the rats were unacceptably low, and therefore they were excluded from the statistical evaluation. The crude protein (CP) content of the biomass products varied between 20.9% (Tric) and 33.2% (DW), whereas the content of NDF varied between 18.5% (Ind) and 32.2% (DW) of dry matter (DM). The total content of essential amino acids (g/16 g N) was comparable with that of alfalfa meal, except for GF and Tric, which were inferior. Between plant species, differences in dietary digestibility of organic matter (dOM) and CP (dCP) were observed ($p<0.001$). Also, the replacement level negatively influenced dOM and dCP ($p<0.001$). The lowest values for dOM ($p<0.001$) were observed for diets including biomass products with the highest content of NDF (GF, Tric, Mb, LL). Digestibility of CP was negatively affected by level of protein replacement. Significant ($p<0.001$) differences were found in N-retention and biological value among diets with different biomass products. The most favourable overall results were obtained for DW, WS and CL. The main factors affecting the nutritive value of the diets tested were their NDF content, dCP and AA profile of the biomass. Also antinutritive component(s) may have influenced the process of digestion and metabolism of some of the biomass products. ***(Asian-Aust. J. Anim. Sci. 2001. Vol 14, No. 7 : 986-993)***

Key Words : Tropical Biomass, Nutrient Digestibility, Product Quality, Biological Value, Rats

INTRODUCTION

In view of the worldwide demand for additional sources of food, the exploitation of plants of low economic importance would be a step towards better resource utilization (Telek and Martin, 1983). The tropical zones hold the biggest genetic diversity of species and particularly of vascular plants of interest in this context. The non-conventional forage plants are an important example of this huge natural potential (Rosales et al., 1993). To be useful these plant species must be locally and readily available, cheap, and acceptable to animals.

In addition to multipurpose trees such as *Trichantera gigantea* (Rosales et al., 1993), *Leucaena leucocephala* (Göhl, 1998; Ekpenyong, 1986; Rosales et al., 1993; D'Mello, 1995; Phuc and Lindberg, 2000) and *Indicago hirsuta* (Göhl, 1998), by-products such as foliage of groundnut (*Arachis hypogaea*) (Göhl, 1998; Phuc and Lindberg, 2000) and mungbean (*Phaseolus aureus*) and cassava leaves (*Manihot esculenta Crantz*) (Ravindran, 1990, 1993; Phuc and Lindberg, 2000; Phuc et al., 2000) could also be of interest. Moreover, in lakes and waterways of tropical countries the tremendous growth potential of aquatic plants such as water spinach (*Ipomoea aquatica Forsk*) (Bruemmer and Roe, 1979; Jain et al., 1987) and duckweed (*Lemna minor*) (Dudley and Culley, 1978; Journey et al., 1991) should be considered in this context as alternative sources of amino acids in diets for monogastrics. Only limited information is available in the literature on the protein values of these plant species.

The green part of biomass is potentially the most abundant protein source (D'Mello, 1995). Due to their high potential of protein production per hectare, and as they are not directly used in human nutrition, these plant species could be a "non-competitive" protein source for monogastric animal species. However, the major problems, which preclude the use of these plants as protein sources for monogastrics, are their limited palatability and high levels of fibre, which may limit the feed intake and availability of nutrients (Cheeke et al., 1980; Rosales et al., 1993). Further, the possible occurrence of antinutritive and toxic substances (e.g. tannins, saponins, phenols, alkaloids, steroids) may also interfere with the exploitation of these materials (D'Mello, 1995; Makkar, 1993). For experimentation

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* Address reprint request to Jan Erik Lindberg. Tel: +46-18 -67 21 02, Fax: +46-18-67 29 95, E-mail: Jan-Eric.Lindberg @huv.slu.se.

[1] University of Agriculture and Forestry, Department of Animal Nutrition, Thu Duc, Ho Chi Minh City, Vietnam.

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purposes the rat seems to be a suitable model animal for the growing pig and this allows the determination of apparent protein digestibility, and is also a good and relatively inexpensive animal model to determine the quality of protein (Eggum, 1973; Knudsen et al., 1984; Knudsen, 1990; Donkoh et al., 1995).

The purpose of the present investigation was to study the protein quality of diets in which part of the casein of a semi-synthetic control diet was replaced with one of eight sun-dried biomass products, and to evaluate the effect of their chemical composition on animal performance. In a following paper, the effects of different means of preservation on the nutritive value as determined with rats will be reported.

MATERIALS AND METHODS

Experimental design

The digestibility and nitrogen utilization of diets with inclusion of tropical biomass products were studied in balance trials with rats. The experiment was a randomized complete block design and included three blocks of 34 rats in each, with two rats randomly allocated to each of the 17 experimental diets in each block. Thus, in total six rats were given each experimental diet. Each diet was given for a preliminary period of four days, followed by a balance period with quantitative and separate collection of urine and feces for five days. The different biomass products were tested at two levels of inclusion.

Biomass products tested

Sun-dried samples of the following species were investigated: water spinach plants (WS) (*Ipomoea aquatica Forsk*), leucaena leaves (LL) (*Leuceana leucocephala*), duckweed plants (DW) (*Lemna minor L.*), groundnut foliage (GF) (*Arachis hypogaea L.*), trichantera leaves (Tric) (*Trichantera gigantea*), indicago leaves (Ind) (*Indigofera hirusta*), mungbean foliage (Mb) (*Phaseolus aureus*) and cassava leaves (CL) (*Manihot esculenta Crantz*). The sun-drying of the biomass products was performed by spreading them on the ground under the sun until dry, which took one to two days. The leaves were ground in a Wiley mill to pass a 1 mm screen before mixing with the other dietary ingredients. The analyzed chemical composition of the biomass products is given in table 1.

Diets

The diets were composed of maize starch, sucrose, cellulose, minerals and vitamins, and a protein source (table 2). The calculated dietary content of metabolisable energy was balanced by admixing soybean oil. In each experiment a control diet with casein as the sole protein source was included. In the experimental diets either 0, 25 or 50% of the crude protein (CP) from the diet was replaced with the respective biomass product. These levels were selected as preliminary observations indicated a maximum replacement level of 50% for some of the biomass products, and the 25% level was included in order to determine whether changes observed were linear. The diets were calculated to be isocaloric and isonitrogenous (table 2). In the following the diets will be denoted with capital letter abbreviations and a subscript (25 or 50) for the replacement level.

Animals, housing and feeding

A total of 102 male Wistar rats were used in the experiment. The average initial body weight was 70 g (SD 5). The animals were kept individually in metabolic cages with wire net floors, in a temperature controlled room (23-24°C) with 12 h light/dark cycle. The daily allowance was 10 g air dry feed and 150 mg N, which was provided once daily (8:00 h). Water was available at *ad libitum*. The room humidity was controlled at 60-65%, giving similar conditions to those described by Eggum (1973). The animals were weighed at the beginning of the experiment as well as at the end of the collection period.

Collection of feces and urine

At termination of the experiment, feed refusals, if any, were collected and weighed. Urine was collected in 250 ml flasks containing 50 ml 5% H_2SO_4 and with a small piece of glass-wool in the funnel to avoid contamination by foreign materials. The fresh feces of the individual rats were collected 2 times per day at 8:00 h and at 15:00 h, and were kept in a freezer at -18°C.

Chemical analysis and calculations

Prior to analysis, the feces samples were freeze dried. All samples were ground in a Wiley mill to pass a 1 mm sieve. Dry matter (DM) was determined by drying at 105°C for two days to a constant weight. Crude protein (N×6.25), ether extract (EE) and ash content were determined according to AOAC (1995). Neutral detergent fibre (NDF) was analyzed according to Robertson and Van Soest (1977). Amino acids (AA) were analyzed according to Spackman et al. (1958) on an ion-exchange column using HPLC. Samples were hydrolyzed for 24 h at 110°C with 6 mol/L HCl containing 2 g/L reagent grade phenol and 500 nmol norleucine (internal standard) in evacuated and sealed ignition tubes. Methionine was determined as methionine sulphone with separate samples hydrolyzed for 24 h as described above following oxidation with performic acid overnight at 0°C (Moore, 1963). Cystine and tryptophan were not measured. Gross energy (GE) was determined using an adiabatic bomb calorimeter (dds CP 500; Digital Data Systems Ltd, Northcliff, South Africa). Digestibility of OM and CP were defined as the digestibility at fecal level

Table 1. Analyzed chemical composition, essential amino acid (EAA) and non-essential amino acid (NEAA) content and gross energy in the biomass products† investigated

	WS	LL	DW	GF	Tric	Ind	Mb	CL	Alfalfa ‡	Soybean‡
Chemical composition, % of DM										
Organic matter	88.8	92.0	80.1	91.9	73.6	90.4	86.8	92.8		
Crude protein	26.4	30.2	33.2	22.3	20.9	29.3	21.3	32.4	18.8	51.8
Ether extract	2.6	5.4	5.0	2.3	4.0	4.5	2.4	6.4		
NDF	22.9	34.4	32.2	38.7	33.0	18.5	28.4	27.5		
Essential amino acids, g/16 g N										
Arginine	6.0	5.2	6.7	4.8	5.3	6.1	7.7	6.3	4.1	7.4
Histidine	1.6	2.1	2.2	1.9	2.3	2.8	2.1	2.2	2.2	2.8
Isoleucine	3.8	3.8	4.0	3.6	4.2	4.5	4.1	4.1	4.0	4.6
Leucine	7.2	7.3	7.6	6.6	8.0	7.5	7.7	8.7	7.1	7.8
Lysine	4.2	5.0	4.2	3.6	3.7	4.1	4.1	5.1	4.3	6.3
Methionine	1.7	1.2	1.9	1.0	1.4	1.8	1.1	1.6	2.5 §	3.0 §
Phenylalanine	5.2	5.4	5.3	5.2	5.7	6.6	5.2	6.3	4.9	5.3
Threonine	4.1	3.9	4.2	3.7	4.3	4.4	4.3	4.4	4.1	4.0
Tyrosine	3.7	4.0	3.9	3.5	4.6	4.6	3.6	4.3	3.3	3.8
Valine	5.2	5.1	5.6	4.7	5.5	5.1	5.4	5.9	5.0	4.7
Σ EAA	42.8	43.1	45.5	38.6	44.9	47.5	45.4	48.9	41.5	49.7
Non-essential amino acids, g/16 g N										
Alanine	5.2	4.7	5.9	4.5	5.3	5.7	5.0	6.3	4.9	4.4
Aspartic acid	16.2	9.8	9.4	10.5	8.8	9.9	7.9	9.7	11.5	11.8
Glutamic acid	4.5	9.1	9.9	9.0	9.8	9.4	9.0	11.0	9.4	18.0
Glycine	4.3	3.9	4.1	3.8	4.2	3.9	3.9	4.5	4.9	4.4
Proline	3.3	3.7	4.0	5.6	3.9	4.5	3.9	3.8	4.9	5.2
Serine	4.1	4.0	4.5	3.7	4.6	4.0	4.1	3.4	4.3	5.2
Σ NEAA	37.6	35.3	37.8	37.1	36.6	37.5	33.9	38.8	39.9	49.0
Σ AA	80.4	78.4	83.2	75.8	81.5	85.0	79.3	87.8	81.4	98.7
Gross energy (MJ/kg DM)	18.2	21.8	17.8	17.4	18.4	19.9	17.1	21.3		

† Abbreviations: WS: water spinach plants; LL: leucaena spp leaves; DW: duckweed plants; GF: groundnut foliage; Tric: trichantera leaves; Ind.: Indicago leaves; Mb : mungbean foliage; CL: cassava leaf meal. ‡ Source: Degussa company 1996. §: Methionine= Cystine +Methionine.

of organic matter and CP, respectively, and biological value (BV) was calculated according to Eggum (1973). The dOM of each biomass product was calculated by the difference method using the average digestibility values for the two levels of inclusion, and by regression equation for dCP.

Statistical analysis

Analyses of variance were performed according to the following model:

$$Y_{ij} = \mu + T_i + P_j + e_{ij}$$

Where Y is a dependent variable, μ is the overall mean, T_i the treatment effect (i= 1,2,3….17), P_j the block effect (k= 1, 2, 3) and e_{ij} is the residual error.

The General Linear Models of Minitab Statistical Software Version 12 (1998) was used. Least-squares means (LSM) were compared statistically using the Tukey test ($p<0.05$). Linear regression analyses of the effect of dietary NDF content on the dOM and dCP were performed as well as of the level of CP replacement on dCP, nitrogen retention and BV. Stepwise regression analysis was used to investigate the effects of the AA lysine (Lys), methionine (Met) and threonine (Thr) on animal performance data.

RESULT

Chemical composition of the biomass products

The chemical analyses indicated some marked differences in composition among plant species (table 1). The content of OM varied from 73.6 to 92.8% of DM, with the highest content in CL, GF and LL and the lowest content in Tric and DW. The average CP content of the biomass material studied was 27% of DM, but varied between species, from 20.9 (Tric) to 33.2 (DW)% of DM. The EE content varied from 2.3 to 6.4% of DM, with the highest values in CL, LL and DW as compared with WS, GF and Mb foliages. The content of NDF varied from 18.5 to 38.7% of DM and averaged 29.5% of DM. The lowest NDF content was found for Ind and the highest for GF.

The highest content of Lys, at around 5% of CP, was found in LL and CL, whereas the Lys level in the other species was around 4% or lower. The content of Met was generally low and varied from 1.0 to 1.9% of CP with the highest values in WS, DW, Ind, and CL. The relative variation between species in their content of Thr was

Table 2. Ingredients and chemical composition, some limiting amino acids and metabolisable energy content of the experimental diets

	Control	WS		LL		DW		GF		Tric		Ind.		Mb		CL	
	0	25	50	25	50	25	50	25	50	25	50	25	50	25	50	25	50
Ingredients																	
Maize	62.6	68.6	61.5	68.9	62.2	69.8	64.5	64.9	54.5	65.0	54.2	70.0	64.5	65.4	55.4	70.2	64.6
Soya oil	7.0	2.8	3.9	3.6	5.5	3.2	4.5	4.8	7.7	4.4	7.3	2.2	2.8	3.8	5.8	2.8	4.1
Sucrose	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Cellulose	7.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Casein	10.0	7.5	5.0	7.5	5.0	7.5	5.0	7.5	5.0	5.0	5.0	7.5	5.0	7.5	5.0	7.5	5.0
Biomass products	0	8.0	16.6	7.0	14.3	6.5	13.0	9.8	19.8	10.2	20.5	7.3	14.7	10.3	20.8	6.5	13.3
Premix ‡	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Chemical composition, % of DM																	
Organic matter	95.1	95.5	94.1	96.3	95.2	96.0	93.3	95.9	95.1	92.8	90.3	96.0	95.4	95.1	93.7	96.0	95.2
Crude protein	9.3	9.3	9.4	9.3	9.4	9.4	9.3	9.4	9.3	9.3	9.3	9.4	9.3	9.4	9.4	9.3	9.4
NDF	7.4	1.8	3.8	2.4	4.9	2.1	4.2	3.8	7.7	3.3	6.8	1.3	2.7	2.9	5.9	1.8	3.7
Essential amino acids, g/16g N																	
Lysine	7.9	7.1	6.2	7.3	6.6	7.0	6.2	6.9	5.8	6.9	6.0	7.0	6.1	7.0	6.1	7.3	6.6
Methionine	3.2	2.9	2.5	2.7	2.3	2.9	2.6	2.7	2.1	2.8	2.4	2.9	2.6	2.7	2.2	2.8	2.5
Threonine	4.6	4.5	4.4	4.5	4.3	4.5	4.4	4.3	4.0	4.5	4.4	4.6	4.5	4.6	4.5	4.6	4.5
ME (MJ/kg DM)	15.1	15.1	15.0	15.1	15.0	15.1	15.0	15.1	15.0	15.1	15.0	15.1	15.0	15.1	15.0	15.1	15.0

† For abbreviations see footnote table 1.

‡ The supplement provided: Calcium: 3.5g/kg; Phosphorus: 0.93g/kg; Magnesium: 0.08g/kg, Sodium chloride: 4.6g/kg; mg/kg: Iodine: 1.04 mg/kg; Selenium: 0.16 mg/kg; Iron : 32 mg/kg; Cobalt: 0.32 mg/kg; Copper: 9.6 mg/kg; Manganese: 40 mg/kg; Zinc: 48 mg/kg, vit. A: 31 500 IU/kg; D_3: 3 152 IU/kg; E: 210 mg/kg; K_3: 40 mg/kg; B_1: 30 mg/kg; B_2: 24 mg/kg; B_6: 30 mg/kg; B_{12}: 0.08 mg/kg; Choline chloride: 200 mg/kg; Folic acid: 4 mg/kg; Calcium pantothenate: 30 mg/kg; niacin: 60 mg/kg; biotin: 0.40 mg/kg.

limited, with an average of 4.1% of CP. The sum of essential AA (EAA) as a percentage of CP varied between 38.6 and 48.9%, whereas for the non-essential AA (NEAA) the variation was smaller, i.e. 33.9 to 38.8% of CP (table 1). With increasing amounts of biomass in the diets, the NDF content increased, and there were plant species related differences in the NDF content of the diets (table 2). The average GE content of the biomass products was 19.0 MJ/kg DM, with the highest values found for CL and LL.

Feed intake and weight gain of the rats

Feed intake varied from 29 to 50 g/5 days (table 3). The observed feed consumption in the 25% replacement groups was higher ($p<0.001$) than for the 50% replacement groups. There were no differences in feed intake among the 25% groups and the control ($p>0.05$). For the 50% replacement diets based on Tric, LL and Ind the feed intake for five days was reduced to 29, 34 and 32 g, respectively, and differed significantly from the other treatment groups. As the very limited feed intake affected the growth performance of the rats, consequently these groups were excluded from the statistical analyses.

The weight gain of the rats on biomass treatments during the five day collection period averaged 8.4 g. There were significant differences in the weight gains between treatment groups ($p<0.001$), the lowest ($Tric_{50}$) being –0.8 g and the highest (control) being 15.2 g. Despite an acceptable feed intake $Tric_{25}$ resulted in a noticeably poor weight gain.

Digestibility and nitrogen utilization

There were significant inter-treatment differences in the dOM, dCP and N retention of the diets ($p<0.001$). The dOM of the treatment groups with acceptable feed intake varied from 89% (GF_{50} and Mb_{50}) to 96 % (CL_{25} and Ind_{25}). The values for dCP varied greatly (from 72 to 93%), the lowest in the WS_{50} and the highest in the control group. For the treatment groups with acceptable feed intake the variation in BV was relatively limited. However, a significant ($p<0.001$) inter-treatment effect was found, with the highest values of 88 to 90 for the control, WS_{25} and WS_{50}, $Tric_{25}$, and CL_{25} and CL_{50} groups, as compared with the lowest value of 80 for Ind_{25}.

Regression analyses

There were close relationships between dCP (Y_{CP}) and the protein replacement level for all diets with biomass products (table 4), implying a decrease in dCP with an increasing level of replacement. The same pattern was found for N retained of the N ingested (g/5 days) (Y_{Nu}). As

Table 3. Feed intake, and rat weight gain (g/5days), digestibility values of organic matter (dOM) and crude protein (dCP), nitrogen utilization (N_u; N retention as a percentage of N ingested) and BV (%) of the experimental diets

	Control	WS		LL		DW		GF		Tric		Ind.		Mb		CL		SEM	P
	0	25	50	25	50	25	50	25	50	25	50	25	50	25	50	25	50		
Intake	49.9^{a}	49.9^{a}	41.0^{b}	49.2^{a}	(34)	48.9^{a}	48.4^{a}	49.9^{a}	45.2^{c}	48.0^{ac}	(29)	48.8^{ac}	(32)	49.9^{a}	47.8^{ac}	49.9^{a}	49.9^{a}	0.80	.001
Weight gain	15.2^{a}	10.0^{b}	7.2^{bc}	9.3^{b}	(2.2)	12.2^{a}	10.8^{b}	10.1^{bd}	6.2^{c}	7.8^{bc}	(-0.8)	9.9^{b}	(2.7)	10.9^{d}	8.3^{bc}	11.0^{d}	10.0^{bd}	0.73	.001
dOM	91^{a}	95^{c}	91^{a}	94^{c}	(90)	95^{ce}	92^{bd}	93^{d}	89^{f}	93^{d}	(84)	96^{e}	(93)	94^{d}	89^{f}	96^{ce}	92^{bd}	0.02	.001
dCP	93^{a}	81^{c}	72^{b}	81^{c}	(72)	86^{e}	78^{d}	82^{c}	75^{d}	78^{d}	(63)	86^{e}	(79)	83^{fe}	76^{d}	85^{ef}	77^{d}	0.08	.001
N_u	71^{a}	59^{c}	50^{b}	58^{cd}	(45)	62^{c}	51^{b}	59^{c}	48^{b}	59^{c}	(38)	56^{c}	(41)	61^{c}	51^{b}	65^{e}	56^{c}	0.08	.001
BV	89^{a}	88^{a}	88^{a}	87^{a}	(85)	86^{a}	82^{b}	86^{ab}	82^{b}	90^{a}	(88)	80^{b}	(74)	87^{ac}	83^{bc}	89^{a}	88^{a}	0.80	.001

† For abbreviations see footnote table 1.

^{a,b,c,d} Means with different superscripts within rows are significantly different ($p<0.05$).

Table 4. Regression equations of the crude protein digestibility (dCP) and nitrogen utilization (N_u ; N retention as a percentage of N intake) and overall on protein replacement level (X, i.e. 0, 25 or 50 %) and organic matter digestibility coefficients (dOM) of the diets and overall on dietary NDF content (% of DM)

	WS	LL	DW	GF	Tric	Ind	Mb	CL	Overall
dCP									
Intercept	92.5	92.5	93.2	92.3	93.0	93.0	92.5	93.0	92.1
Slope	-0.42	-0.42	-0.30	-0.36	-0.60	-0.28	-0.34	-0.32	-0.36
R^2	0.98	0.98	0.99	0.98	0.96	0.98	0.99	0.98	0.80
N_u									
Intercept	70.5	71.0	71.3	70.5	72.7	71.2	71.0	71.5	71.8
Slope	-0.42	-0.52	-0.40	-0.50	-0.68	-0.62	-0.40	-0.30	-0.49
R^2	0.98	0.98	0.99	0.99	0.97	0.98	0.99	0.98	0.77
dOM									
Intercept	95.6	95.3	97.6	96.6	97	97.0	96.4	96.9	97.7
Slope	-0.77	-0.80	-0.90	-0.94	-1.37	0.96	-0.91	-0.88	-1.10
R^2	0.74	0.94	0.87	0.83	0.43	0.98	0.57	0.86	0.80

† For abbreviations see footnote table 1.

Table 5. Estimated digestible energy (DE, MJ/kg DM), digestibility (%) of organic matter (dOM) and crude protein (dCP) of biomass products investigated †

	WS	LL	DW	GF	Tric	Ind	Mb	CL
DE ‡	10.8	9.6	8.2	7.8	5.1	12.7	8.6	11.5
dOM	57	43	50	50	33	65	54	59
dCP	51	46	64	57	34	64	59	61

†For abbreviations see footnote table 1.

‡ DE (MJ/kg DM) calculated from digestibility of dry matter and gross energy.

overall experimental effects the following regression equations were found:

$Y_{dCP}=92.1-0.36X$ ($R^2=0.80$),

and $Y_{Nu}=71.8-0.49X$ ($R^2=0.77$)

where X is the replacement level (either 0, 25 or 50% of CP replacement)

By expressing dOM (Y_{OM}) as a function of the dietary NDF content (X in % of DM) the following overall regression equation was found: $Y_{OM}=97-1.1X$ ($R^2=0.81$) (table 5). Also, similar regression equations were obtained ($p<0.001$) for the dOM of individual diets in relation to their NDF content. However, a positive relationship was found for the dOM of the Ind diets ($p<0.001$). Only a small statistically non-significant overall effect of the dietary NDF (X g per kg DM) content on dCP (Y_{CP}) was found: $Y_{CP}=81+0.2X$ ($R^2=0.04$)

DISCUSSION

Chemical composition

The present study shows that the content of OM is low in the aquatic species (WS and DW), confirming earlier studies on DW (Dudley and Culley, 1978; Journey et al., 1991). This is due to the structural elements in aquatic species having a mineral basis, whereas in terrestrial species primarily fibrous elements are the structural bases (van Soest, 1994). The Tric leaf surface was observed to be covered by a high density of small hairs, and we suspect that the high silica content of these hairs could explain the high ash values (Brown and Pitman, 1991). The leaf products of the terrestrial plant species were characterized by a higher CP content compared with the foliage products (averaging 28.2 and 21.8% of DM, respectively), and the corresponding NDF contents of the leaves were lower (28.4 versus 33.6% of DM, respectively). A further separation of

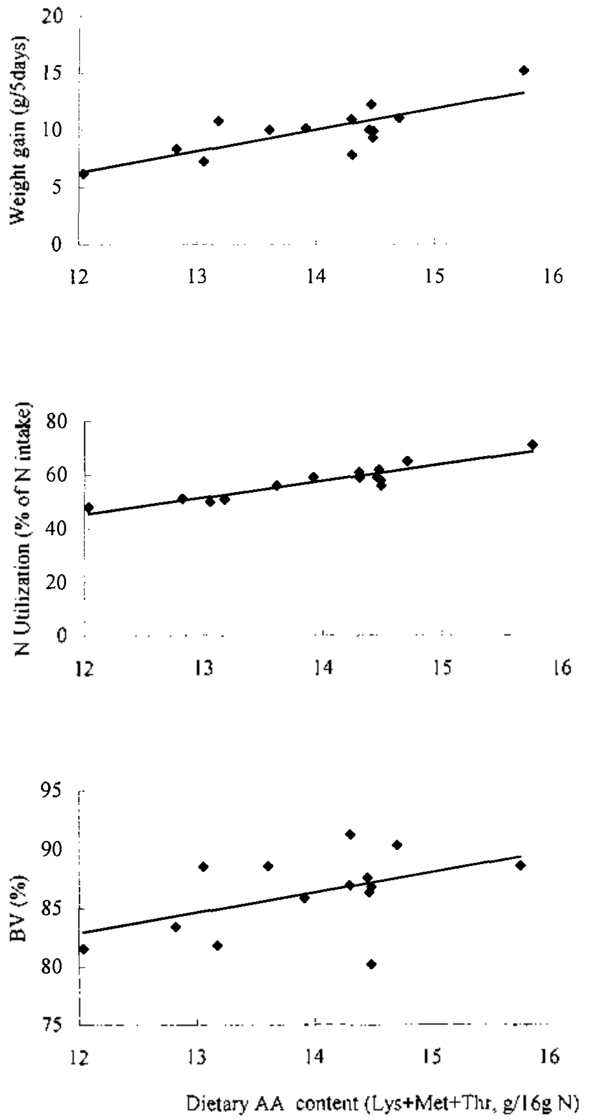

Figure 1. A/ Relationship between weight gain (g/5 days) and dietary amino acid content (Lys+ Met+ Thr; g/ 16 gN); Y=1.85X-15.97, R^2=0.62.

B/ Relationship between N utilization (% of N intake) and dietary amino acid content (Lys+ Met+Thr; g/16 gN); Y=6.21X-29.23, R^2= 0.87.

C/ Relationship between BV (%) and dietary amino acid content (Lys+Met+Thr; g/16 gN); Y=1.72X+62.25, R^2=0.23.

the leaves from the twigs of the foliage products would probably result in an upgrading of their nutritive value.

The biomass products used in the present study were found to be high in CP, and had a comparable AA profile to, e.g., alfalfa and soybean meal (table 1). The AA compositions of the biomass products are in agreement with earlier reports for WS (Bruemmer and Roe, 1979; Jain et al., 1987), LL (D'Mello and Acamovic, 1989; Rosales et al., 1993; Garcia et al., 1996; Phuc and Lindberg, 2000), DW (Dudley and Culley, 1978; Journey et al., 1991; Leng et al.,1995), GF (Göhl, 1998; Larbi et al., 1999; Phuc and Lindberg, 2000), Mb (Göhl, 1998) and CL (Eggum, 1970; Ravindran, 1990, 1993; Phuc and Lindberg, 2000). However, concentrations of EAA's were higher than those reported for Tric (Rosales et al., 1993) and for Ind (Göhl, 1998). An inter-species comparison revealed an inferior content of Lys in GF and Tric compared with the other species analyzed. The contents of Thr in DW, Tric, Ind, Mb, and CL were quite acceptable compared with the AA requirement for pigs, while the concentration of the S-containing AA, Met and Cys, would be limiting (NRC, 1998). However, in evaluating the potential of these biomass products as AA sources their availability to the animal has to be assessed.

Feed intake, digestibility and N utilization

At the 25% replacement level of CP by the different biomass products the rats readily consumed their daily feed allowances. However, at the higher replacement level consumption problems occurred, particularly for diets $Tric_{50}$, Ind_{50} and LL_{50}. In these treatment groups the lowered feed intake also resulted in reduced weight gain of the rats. It should be emphasized that the replacement of the casein on an isonitrogenous basis in treatments 25 and 50% resulted in varying inclusion levels of the biomass products due to differences in their CP content. Thus, replacing 50% of casein CP meant that the inclusion of the biomass products varied between 13.0% (DW) and 20.8% (Mb) of dietary DM. This variation in inclusion level of the different biomass products has to be addressed as an important factor for the variation in the acceptability of the diets to the rats. The high level (20.5%) of biomass inclusion in the $Tric_{50}$ may have reduced feed intake as well as affecting dOM and dCP. As a result of the different inclusion levels, the dietary NDF content varied between 2.7 and 7.7% of DM at the 50% replacement level. The present results demonstrate an overall regression coefficient for the dOM on the NDF content (in percent of DM) of 1.10 (table 5), which means a calculated difference in dOM of 6 percent at 50 g NDF per kg DM. Lindberg and Andersson (1998) in a study with pigs reported a corresponding calculated difference in dOM of 8 percent, although the NDF content varied more widely than in the present experiment, which may have affected the accuracy of the regression coefficients. Also the choice of feedstuffs, as well as the rat being a coprophagic species, could have contributed to the differences between the studies. Thus, differences observed in dOM in the present investigation may be explained mainly by the differences in dietary content of NDF. Moreover, the process of nutrient digestion is greatly influenced by differences in the chemical and physical structures of fibrous components (Chen et al., 1982; Agarwall and Chauhan, 1989). Also, antinutritional factors in the biomass products may have interfered with the process of digestion (Makkar, 1993). In CL tannins are known to occur and may have adverse effects on the dCP (Ravindran, 1993; Oke, 1994). It has also been reported that Tric and LL contain tannins (Rosales et al., 1993).

The biomass based diets generally resulted in low weight gain of the rats compared to the control diet, despite the feeds being isoenergetic. The explanation for these observations may be differences in the AA profile and their supply between the casein and the biomass products (tables 1 and 2), and particularly the differences in the availability of the CP (i.e. AA) between the treatment groups, which has been demonstrated earlier (Mongeau et al., 1989; Nyman, 1990; Eggum, 1992; Verstegen et al., 1997). The dCP of the casein diet was 93%, whereas the dCP of the biomass diets averaged 77%. The nutritive effects of the differences in AA profile and dCP of the biomass diets observed on weight gain of the rats (Figure 1A) was also reflected in N retention, but had very little effect on BV (Figure 1B and C). Stepwise regression analyses indicated that Met (R^2=0.61) as well as Lys (R^2=0.59) were the major limiting AA (data not shown). The weak relationship with BV can be explained by a high AA supply in relation to the requirements, so that further increases in AA supply only leads to marginal increases in BV due to higher urinary nitrogen excretion. At the 50% level of replacement the biomass products depressed N retention. This can partly be explained by the lowered dOM and dCP, but also by changing the route of N excretion from the urinary to the fecal route due to increased hindgut microbial activity (Knudsen et al., 1984; Tetens et al., 1996; Lenis et al., 1996). There was thus a considerable variation in dOM, dCP and DE content of the biomass products used in this study (table 6). Ind had the highest digestibility coefficients, although the low palatability and the possible occurrence of anti-nutritional factors (D'Mello, 1995) could have reduced the animal performance. CL and WS had high dOM, dCP and DE, while digestibility values for Tric were lowest.

CONCLUSION

The present investigation has demonstrated marked differences in the nutritive properties of tropical biomass products potentially useful as monogastric feed resources. In particular the content of NDF appears to be an important interfering factor that can explain inter-species differences in dietary digestibility of organic matter. In addition, the CP utilization was affected by differences in the digestibility of CP and the AA profile of the biomass protein, as indicated by differences in weight gain and N retention. Further, the present study indicates that the occurrence of anti-nutritive component(s) may influence the processes of digestion and metabolism. Of the biomass products studied, water spinach, duckweed, mungbean and groundnut foliage, and cassava leaves, were the nutritionally most promising products for inclusion in the diets of monogastric animals.

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