Journal of Arid Agriculture

J. Arid Agric. Vol. 11, 137 - 141 (2001)

0189-7551

ESTIMATION OF NUTRITIVE VALUE OF RUMINANT FEEDS BASED ON FERMENTATION MODELS

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Received June 29, 2000; accepted November 16, 2000

ABSTRACT

The rumen and post-ruminal catabolism of the digestive organic matter (DOM) components of diets and feeds leads to the production of volatile fatty acids (VFA), CO2, CH4, H2, ATP, amino acids, glycerol, etc. The proportions in which these digestive products and metabolites exist depend on the nutrient composition and quality of the diet or feed. Quantitative estimates of stoichiometric products have previously been made by many workers based on these characteristics and digestive trends. A predictive rumen fermentation model has been demonstrated here whereby notable fermentation indices were used to compare their relationship and suggest the possibility of their being used to predict the nutritive value of ruminant feeds. It is suggested that the comparison of fermentation indices like gross energy (GE) lost as % of CH_4, ATP yield as % GE, estimated non-protein nitrogen (NPN) as % microbial nitrogen, etc., set against the chemical composition of feeds could lead to a regression trend which might be used for predicting DOM fermentation trends.

Keywords: Stoichiometry, ruminant feeds, fermentation model

INTRODUCTION

In ruminants, digesta are subjected to the microbial fermentation in the rumen before digestion by animal hydrolytic enzymes, whereas in all animals, including ruminants, microbial population in the lower digestive tract (hindgut or large intestine e.g. caecum and colon) ferment feed components resistant to endogenous hydrolytic digestion, mixed with considerable amounts of endogenous proteinaceous substrates (Demeyer, 1991).
Both rumen and hindgut fermentation enables animals to utilize plant cell walls mainly consisting B-glucosidic linked carbohydrate polymers, not available to animal hydrolytic enzymes. In both fermentation systems, volatile fatty acids (VFA) and microbial biomass (mainly protein) are the main end products.

The microbial complex of bacteria, protozoa and fungi in the rumen initially produces soluble carbohydrates, glycerol, peptides and amino acids, which are used by the organisms themselves, or crossfed to other organisms, not initially degrading fibre. The whole microbial complex derives energy for growth and maintenance from substrate oxidation involving electron transfer to acceptors other than oxygen. All monoses produced are eventually oxidized to NAD or ferrodoxin-related cofactors. It is believed that to obtain maximal energy yield, regeneration of these cofactors should not involve pyruvate or acetyl CoA as terminal hydrogen acceptors, and hydrogenases producing gaseous H_2 provide an electronic sink. The production of H_2 is thermodynamically favourable at low partial pressures only. In the rumen, H_2 partial pressure is kept low by continuous removal of H_2 in the production of methane (Prins and Clark, 1979; Demeyer, 1991). Such removal enabling maximal production of acetate and thus maximal energy yield has been demonstrated by co-culture of several anaerobic micro-organisms with metanogens. This interspecies transfer of H_2 provides for complex interactions between rumen microbes. Because of interspecies transfer of carbohydrate, H_2, succinate, etc., the end products of rumen metabolism are almost exclusively CO_2, CH_4 and the VFA.

The stoichiometric interrelationships in the organic matter components of ruminant feedstuffs informed the rumen fermentation model (Figure 1) used as the basis for the feedstuff nutritive value predictions subsequently suggested here.

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MATERIALS AND METHODS

The stoichiometric and fermentation processes involved in the organic matter catabolism of ruminant feedstuffs as proposed by Demeyer (1991) and used as a rumen fermentation model by Bogoro (1997) formed the basis of this work.

The experimental diets used in previous animal feeding experiments by Fomukong (1995), Obed (1996) and Bogoro (1997) were compared for the purpose of determining the feasibility of using some of their fermentation indices for predicting the nutritive value of feedstuffs especially in situation where inadequate information is available on their potential nutritive value.

The fermentation indices used in the study included gross energy (GE) lost as methane (CH4), ATP yield, non-nitrogen organic matter, total rumen degradability percentage, estimated total digestible undegraded protein (DUP) as % crude protein (CP) for all feeds; estimated total rumen degradable protein (RDP) as % crude protein for all feeds; estimated non-protein nitrogen (NPN) as % microbial nitrogen (MN) and estimated amino acids as microbial nitrogen.

RESULTS AND DISCUSSION

Effect of dietary composition on the predictive rumen fermentation model

The Bogoro (1997) rumen fermentation model (Fig. 1) is based on some specific, postulated and also variable indices. Postulated values based on Van Soest (1994) and Prins and Wolin (1997) include those of estimated proportions of amino acids (70%) and non-protein nitrogen, GE (10%) lost as methane (CH_4) as well as the total dietary crude protein (CP) is also postulated in the Bogoro (1997) model. The values of CP and non-nitrogen organic matter (OM) are, however determined and analytically implied.

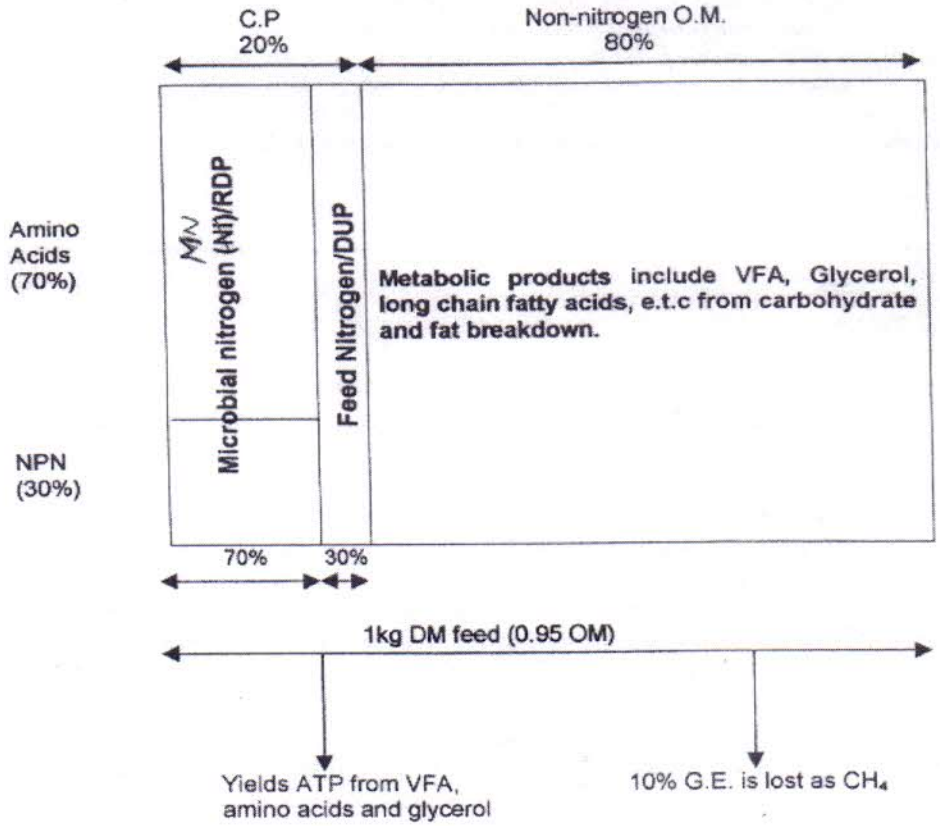

Fig. 1. Rumen fermentation model based on digestible organic matter (DOM) components of experimental diets (Bogoro, 1997)

RDP = rumen degradable protein; DUP = digestible rumen undergraded protein; NPN = non-protein nitrogen; CP = crude protein; OM = organic matter; GE = gross energy; ATP = adenosine triphosphate; VFA = volatile fatty acids; CH_4 = methane; MN = microbial nitrogen

Furthermore, as shown in Table 1, each experimental diet has its peculiar and distinct fermentation characteristics as suggested by their varying stoichiometric indices. Diets I, II and III (Bogoro, 1997; Fomukong, 1995 and Obed, 1996 respectively) differed in their CP values. Their respective crude protein (CP), rumen degradable protein (RDP) and digestible undegraded protein (DUP) values of 15%, 62%, 38% (Diet I); 15%, 31%,

38% (Diet II) and 12%, 60%, 40% (Diet III) illustrates the differences in their character and composition. Where each of the dietary set of fermentation and stoichiometric indices replace those in Fig. 1, a lot of rumen physiological parameters and activities are affected in reflection of the inherent changes in the predictive model. Specifically, it is expected that where these fermentation indices for many more variable experimental diets are compared, a definite pattern and regression trend may sufficiently develop as to strengthen the basis for the predictive model. In particular, it would appear that a definite relationship could be easily established with the analytical values for crude fibre (CF), acid detergent fibre (ADF) and neutral detergent fibre (NDF).

Table 1. Ingredient and nutrient composition of experimental diets

Diet I (70%, 48-hour rumen degraded)				Diet II (72%, 48-hour rumen degraded)				Diet III (75%, 48-hour rumen degraded)			
Ingred-ient	%	Nutrient	%	Ingred-ient	%	Nutrient	%	Ingredient	%	Nutrient	%
		CP	15	Sorghum stover/ rice				Sorghum stover	70	DM	93
urea-treated		RDP	62	Straw (50:50)	60	DM	95	Groundnut haulm	15	OM	95
Sorghum stover	65	DUP	38	Cotton seed cake	20	CP	15	Maize bran	5	Ash	8
		OM	95	Groun dnut haulm	10	CF	21	Maize offal	10	NDF	48
Maize bran	10	DM	93	Maize bran	10	OM	94	Salt lick	*Ad*	ADF	37
		Ash	5	Salt lick	*Ad*	ADF	46		*lib*	CP	12
Cottonseed cake	25	CF	26		*lib*	NDF	38			RDP	60
Salt lick	*Ad*					RDP	31			DUP	40
	lib					DUP	38			CF	32

Key: Diet I (bogoro, 1997), Diet II (Fomukong, 1995), Diet III (Obed, 1996)
DUP = Digestible rumen undergraded protein; RDP = Rumen degradable protein; CP = Crude protein;
ADF = Acid detergent fibre; NDF = Neutral detergent fibre; OM = Organic matter; DM = Dry matter;
CF = Crude fibre

Rumen fermentation profile of diets

Stoichiometric acid catabolic basis for the digestible organic matter (DOM) fraction of diets has been documented by many previous workers (Orskov, 1982; Church, 1998 and Van Soest, 1994). It has been further demonstrated in the work of Demeyer (1991) with some lucid detail. Since matter is neither created nor destroyed in nature, a profile of some carefully chosen fermentation products (estimated, calculated or determined) as shown in Table 2 further gives expression to the scientific basis for any predictions. The detail dietary stoichiometric and fermentation indices include among others, GE lost as CH_4, potential adenosine triphosphate (ATP) yield as % GE and also non-nitrogen organic matter (OM) as % total OM. The profile and relationship might perhaps be better appreciated and more graphically illustrated as shown in Fig. 2. The comparison of more variable diets might go a long way in establishing relationship between the various fermentation and stoichiometric indices of diets sufficient to form predictive basis for the nutritional quality of diets and feedstuffs.

Rumen hydrogen utilization and implications for rumen fermentation and physiology

Many predominant rumen bacterial species are capable of producing hydrogen. The utilization of hydrogen reduces hydrogen concentration. The normal rumen level of hydrogen is about 10^{-4} atmospheres and will favour a net production of hydrogen. Thus, the result of a two-species culture *Ruminoccocus* and *Methanobacterium*,

respectively hydrogen-producing and -utilizing organisms, is to stimulate a four-fold or larger increase in hydrogen production (Van Soest, 1994). Wolin (1975) has pointed out that methanogens keep the partial pressure of H_2 extremely low and thus allow otherwise thermodynamically unfavourable reactions to occur. Coupling methanogens and hydrogen-producing anaerobes allows growth of the methanogenic bacteria in the absence of detectable H_2. According to Thauer (1977), complete degradation of organic matter to CO_2 and H_2 in fermentation is not possible for thermodynamic reasons.Thus, the extent of ionic changes and electron transfer or scavenging by microbes is an added important factor in determining the direction at which the fermentation and stoichiometric changes proceed. This underscores the intricate relationship between ATP changes, GE loss as CH_4, rumen degradability changes, etc., as they form the basis for predicting the nutritive value and characteristics of diets and feedstuffs.

Table 2. Rumen fermentation parameter profile of diets

Rumen fermentation parameters	Diet I	Diet II	Diet III
1. [1]Gross energy (GE) lost as CH_4 (%)	10	10	10
2. [2]Potential ATP yield loss as % GE	90	90	90
3. Non-nitrogen organic matter lost as % total OM	80	85	81
4. Total dry matter (DM) rumen degradability	85	76	79
5. Estimated DUP lost as % CP of diet	30	45	38
6. Estimated RDP lost as % CP of diet	70	55	62
7. [3]Estimated NPN lost as % microbial nitrogen (N)	30	30	30
8. [4]Estimated amino acids lost as % microbial N	70	70	70

Items with superscripts 1, 2, 3 and 4 are estimates based on values as reported by Van Soest (1994). Exact values can be determined or more accurately predicted for specific experimental diets

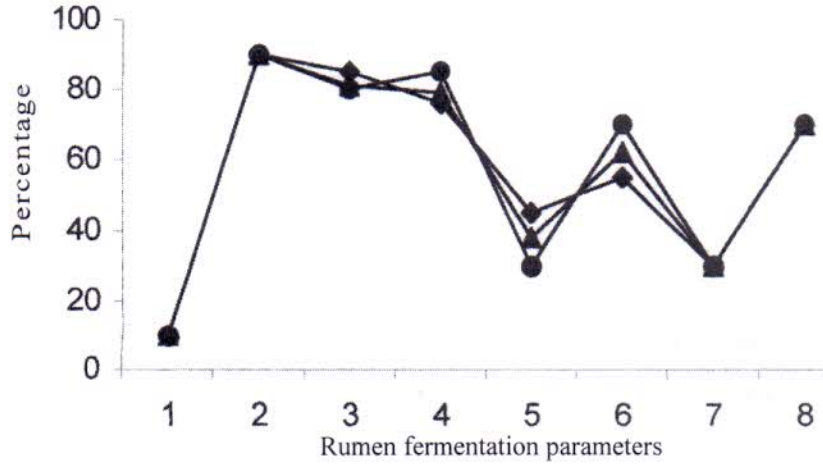

Fig. 2. Curve of rumen fermentation parameter as shown in Table 2, where 1 = gross energy lost as methane (CH_4); 2 = potential ATP yield lost as % gross energy (GE); 3 = non-nitrogen organic matter (OM) lost as % total OM; 4 = total dry matter (DM) rumen degradability; 5 = estimated digestible rumen undergraded protein (DUP) lost as % CP of diet; 6 = estimated rumen degradable protein (RDP) lost as % of CP; 7 = estimated non-protein nitrogen (NPN) lost as microbial N; 8 = estimated amino acids lost as % microbial N

CONCLUSION AND RECOMMENDATION

While the ionic and metabolic characteristics of the catabolic fate of diets have been documented, there appear to be no comparative analysis of obvious fermentation and stoichiometric indices as a tool in predicting the nutritive value of diets. Granted the natural relationship between these fermentation indices, there appears to be a strong case for the comparative analysis of these otherwise closely-related fermentation indices like GE loss as CH4, potential ATP as % GE, rumen kinetic indices of specific digestible organic matter components, etc. Towards a better understanding of the above-stated relationship, it is recommended that future work include the comparison of fermentation parameters set against the chemical profile of diets and feeds.