Probing Equivocal Effects of Heat Processing of Legume Seeds on Performance of Ruminants - A Review -

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ABSTRACT : Published studies show that effects of heat processing of legume seeds on animal performance are equivocal. In this article, we used a nutrition model - the DVE/OEB system to re-analyze nutrient supply (such as truly absorbed intestinal protein DVE value and protein degradation balance OEB value) to ruminants from published studies to probe reasons for such equivocal effects and provided some explanation why equivocal effects occurred. The analysis results showed that an unsuitable supply of nutrients in terms of DVE and OEB intakes (negative total OEB intake, oversupply of total DVE values) resulted in an inability to detect the effectiveness of heat processing in altering bypassing protein (BCP) and/or starch (BST) and their effects. The overall nutrient supply to animal in an experiment should be the context in which any animal performance study is developed. The information described in this article may give better understanding of animal performance in relation to nutritive changes occurring upon processing of legume seeds. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 6 : 869-876)***

Key Words : Animal Performance, Legume Seeds, Seed Processing, The DVE/OEB System

INTRODUCTION

The principal purpose of manipulating digestive behavior of legume seeds by heat treatments is to enhance the supply of essential amino acids (Beever and Thomson, 1977; Goelema, 1999) and/or glucose (Nocek and Tamminga, 1991) to the productive ruminants. The milk production, average daily gain (ADG), feed:gain or feed conversion and N utilization are the usual measures used to determine animal responses to the heat treated feeds.

Published studies show that effects of heat treatments of legume seeds on performance of ruminants are equivocal (Broderick et al., 1990; Kung et al., 1991; Robinson and McNiven, 1993; Murphy and McNiven, 1994; Yu, 1995; Baiden, 1997; Yu et al., 2001a,b,c), although the rate and extent of rumen degradation of treated legume seeds are reduced to some extent. However, some of them could be explained by using the advanced the DVE/OEB system (Tamminga et al., 1994).

The DVE/OEB system (Tamminga et al., 1994) has been built and developed based on the principles already formulated in existing modern protein evaluation systems (such as ARC, 1984; NKJ-NJF, 1985; PDI-INRA, 1987; AP-NRC, 1985 etc). This advanced system considers the strong elements of other recently developed protein evaluation systems and it also introduces new elements, such as the role of energy balance in protein supply (Tamminga et al., 1994).

The objective of this study was to use the advanced DVE/OEB system (Tamminga et al., 1994) to reanalyze some published studies to investigate reasons and provide some explanation for the equivocal effects of heat treatments of legume seeds on performance of ruminants. Hopefully, the information described in this article may give better insight in the mechanisms involved in animal performance in relation to nutritive changes occurring upon processing of legume seeds in a diet.

THE ADVANCED DVE/OEB SYSTEM: A BRIEF EXPLANATION AND POINTS

In the DVE/OEB system (Tamminga et al., 1994), each feed has a DVE value, which stands for true absorbable protein in the small intestine, composed of the digestible true protein contributed by digestible feed true protein escaping rumen degradation (ABCP), digestible true microbial protein (AMP) synthesized in the rumen and a correction for endogenous protein losses (ENDP) in the digestive tract. Each feed also has an OEB value, which stands for rumen degraded protein balance. The OEB value shows the (im)balance between microbial protein synthesis potentially possible from available rumen degradable protein (N_MP), and that potentially possible from the energy extracted during anaerobic fermentation in the rumen (E_MP).

In a diet, when OEB is positive, it indicates the potential loss of N of a feed from the rumen. When negative,

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Table 1. The list of abbreviations used in the article

ABCP	Truly absorbed rumen undegradable protein in the small intestine (g/kg DM)
AMP	Truly absorbed microbial protein in the small intestine (g/kg DM)
BCP	Rumen undegradable or bypass protein (g/kg DM)
% BCP	Percent rumen undegradable or bypass protein (% of CP)
BSt	Rumen undegradable starch (g/kg DM)
% BSt	Percent rumen undegradable starch (% of starch)
dASH	Digestibility of ash (%)
dBCP	Digestibility of rumen undegradable protein in the small intestine (%)
dTCP	Total tract digestibility of crude protein (%)
DOM	Digested organic matter (g/kg DM)
DVE	Truly digested protein in the small intestine (g/kg DM)
ED	Effective degradability of CP (% of CP) or starch (% of starch)
ENDP	Endogenous protein secretion in the small intestine (g/kg DM)
FOM	Organic matter fermented in the rumen (g/kg DM)
E_MP	Microbial protein synthesized in the rumen based on available energy (g/kg DM)
N_MP	Microbial protein synthesized in the rumen based on available nitrogen (g/kg DM)
OEB	Degraded protein balance (g/kg DM)
TPSI	True protein supplied to the small intestine (g/kg DM)
UASH	Undigested ash (g/kg DM)
UDM	Undigested dry matter (g/kg DM)
UOM	Undigested organic matter (g/kg DM)

microbial protein synthesis in the rumen may be impaired because of a shortage of N in the rumen (Tamminga et al., 1994). The most important is that this DVE/OEB system can give the quantitative aspects of protein potential degradation and digestion of both raw and heat-processed legume seeds in details. It can predict the changes of potential nutrient supply to ruminants from legume seeds after heat processing (Yu et al., 1999; Yu et al., 2000). It can also provide information for the decision for the optimal treatment conditions of legume seeds in terms of protein DVE and OEB values (under certain circumstances) Yu et al., 2002. It can also be used to formulate a diet for the ruminant.

The detailed concepts and formulas of the DVE/OEB system were provided by Tamminga et al. (1994). Here a brief explanation and points were given as follows in order to understand how to use it to calculate potential protein nutrient supply from legume seeds affected by heat processing (in a diet). The abbreviations used in the text show in Table 1. (a) The BCP values were calculated as: BCP (g/kg DM)=1.11×CP (g/kg DM)×% BCP/100, where, BCP was calculated using a passage rate value of 6%/h and the factor 1.11 in the formula was the regression coefficient of *in vivo* on *in sacco* degradation data; (b) The BSt were calculated as: BSt (g/kg DM)=Starch (g/kg DM)×% BSt /100, where, BSt was calculated using a passage rate value of 6%/h. For the factor 0.1 in the formula and assuming that for starch 10% of S escaping rumen fermentation (Tamminga et al., 1994); (c) The FOM in the rumen was calculated as: FOM (g/kg DM)=DOM (g/kg DM)-CFat (g/kg DM)-BCP (g/kg DM)-BSt (g/kg DM)-FP (g/kg DM), where, FP: fermentation products for conserved forages, not for legume seeds; (d) Subsequently, E_MP was estimated as: E_MP (g/kg DM)=0.15×FOM (g/kg DM), where, the factor 0.15 means that per kg FOM, 150 g of microbial protein is assumed to be synthesized; (e) The TPSI value was calculated as: TPSI (g/kg DM)=BCP (g/kg DM)+0.75×MP (g/kg DM), where, factor 0.75 means that 75% of microbial N is present in AA, the remaining part of N in nucleic acids; (f) The previous BCP and TPSI did not give exact enough information on the amount of amino acid absorbable from the small intestine. A correction is needed for protein losses due to incomplete digestion and resulting from endogenous excretion; (g) True digestibility of microbial protein is assumed to be 85% (Egan et al., 1985) and therefore the amount of AMP can be estimated as: AMP (g/kg DM)=0.85×0.75×0.15×FOM (g/kg DM); (h) The ABCP value is calculated as: ABCP (g/kg DM)=dBCP (%) /100×BCP (g/kg DM); (i) In DVE/OEB model, ENDP in the intestine is related to the amount of DM excreted in the feces. According to the DVE/OEB model, 75 g of absorbed protein per kg DM in fecal excretion is required to compensate for endogenous losses. Therefore, ENDP is estimated as: ENDP (g/kg DM)=75×UDM (g/kg DM), where, UDM (g/kg DM)=UOM (g/kg DM)+UASH (g/kg DM); UOM (g/kg DM)=OM (g/kg DM)-DOM (g/kg DM); UASH (g/kg DM)=ASH (g/kg DM)-ASH (g/kg DM)× dASH (%). dASH is 50% (CVB, 1996); (j) The DVE value was estimated as: DVE (g/kg DM)=ABCP (g/kg DM)+ AMP (g/kg DM)-ENDP (g/kg DM); (k) The OEB value is balance between potentially microbial protein synthesis from rumen degradable CP and that potentially from the energy extracted during anaerobic fermentation in the rumen. Therefore the OEB value was estimated as: OEB (g/kg DM)=N_MP (g/kg DM)-E_MP (g/kg DM), where, N_MP (g/kg DM)=CP (g/kg DM)-BCP (g/kg DM)=CP

Table 2. The prediction of potential nutrient supply from raw and pressure toasted lupin seeds, faba beans, peas and soybeans, using the DVE/OEB system

Temp. (°C)	Raw	100			118				136		
Time (min.)		7	15	30	3	7	15	30	3	7	15
The prediction of potential nutrient supply from raw and pressure toasted lupin seeds											
BCP (g/kg DM)	76.1	111.9	135.7	140.8	138.2	146.6	166.4	172.3	175.7	170.1	185.0
FOM (g/kg DM)	778.3	742.5	718.7	713.7	716.2	707.8	688.0	682.1	678.8	684.3	669.4
E_MP (g/kg DM)	116.8	111.4	107.8	107.0	107.4	106.2	103.2	102.3	101.8	102.6	100.4
TPSI (g/kg DM)	163.7	195.5	216.6	221.1	218.8	226.3	243.8	249.1	252.0	247.1	260.3
AMP (g/kg DM)	74.4	71.0	68.7	68.2	68.5	67.7	65.8	65.2	64.9	65.4	64.0
dBCP (%, mobile)	93.8	95.3	95.6	95.6	95.8	95.5	95.7	94.9	96.2	96.1	95.0
dTCP (%, nylon+mobile)	98.6	98.4	98.2	98.1	98.2	98.0	97.8	97.3	97.9	97.7	97.1
ABCP (g/kg DM)	71.4	106.7	129.7	134.6	132.4	140.0	159.3	163.6	169.0	163.5	175.8
N_MP (g/kg DM)	248.3	212.5	188.7	183.6	186.2	177.8	158.0	152.1	148.7	154.3	139.4
DVE (g/kg DM)	132.6	168.9	189.8	193.3	194.0	198.4	216.2	218.1	226.3	220.7	232.8
OEB (g/kg DM)	141.7	105.7	84.1	79.8	81.8	71.6	57.7	53.7	49.8	57.5	44.4
The prediction of potential nutrient supply from raw and pressure toasted horse beans											
BCP (g/kg DM)	47.2	48.7	56.3	65.4	73.8	71.2	94.3	99.0	112.5	128.8	147.8
BSt (g/kg DM)	93.5	106.8	105.8	113.6	119.1	126.3	144.0	147.7	148.4	163.7	173.5
FOM (g/kg DM)	651.0	631.5	613.4	592.1	597.2	592.3	464.7	530.5	516.7	493.1	464.7
E_MP (g/kg DM)	97.7	94.7	92.0	88.8	89.6	88.8	81.1	79.6	77.5	74.0	69.7
TPSI (g/kg DM)	120.5	119.7	125.3	132.0	141.0	137.8	155.1	158.6	170.4	184.2	200.1
AMP (g/kg DM)	62.3	60.4	58.2	26.6	57.1	56.6	51.7	50.7	49.4	47.2	44.4
ENDP (g/kg DM)	13.0	13.4	14.2	14.6	13.1	13.1	13.9	14.1	14.1	13.5	13.4
dBCP (%, mobile)	85.0	87.8	87.5	89.6	89.0	90.4	91.3	91.4	92.4	93.4	94.0
dTCP (%, nylon+mobile)	96.4	96.7	96.4	96.7	96.2	96.5	96.3	96.2	96.4	96.5	96.4
ABCP (g/kg DM)	40.1	42.7	49.2	58.6	65.7	64.4	86.1	90.5	103.7	120.3	138.9
N_MP (g/kg DM)	198.6	201.8	196.8	187.9	178.8	181.4	155.6	151.1	136.7	119.8	101.6
DVE (g/kg DM)	89.4	89.7	93.7	100.6	109.7	107.9	123.8	127.1	139.1	154.0	169.9
OEB (g/kg DM)	100.9	107.1	104.8	99.1	89.2	92.5	74.5	71.5	59.2	45.8	31.9
The prediction of potential nutrient supply from raw and pressure toasted field peas											
BCP (g/kg DM)	58.2	67.3	-	79.9	88.3	100.2	109.6	119.1	123.1	137.3	148.6
BSt (g/kg DM)	158.4	166.8	-	179.4	198.6	207.7	215.2	231.2	232.4	238.6	248.3
FOM (g/kg DM)	689.8	672.3	-	647.1	619.5	598.5	581.6	556.1	550.9	530.5	509.5
E_MP (g/kg DM)	103.5	100.8	-	97.1	92.9	89.8	87.2	83.4	82.6	79.6	76.4
TPSI (g/kg DM)	135.8	143.0	-	152.7	158.0	167.5	175.0	181.6	185.1	197.0	205.9
AMP (g/kg DM)	66.0	64.3	-	61.9	59.2	57.2	55.6	53.2	52.7	50.7	48.7
dBCP (%, mobile)	92.5	94.8	-	95.6	95.2	95.9	96.3	96.9	96.5	97.1	97.6
dTCP (%, nylon+mobile)	98.3	98.6	-	98.6	98.3	98.3	98.4	98.5	98.3	98.4	98.6
ABCP (g/kg DM)	53.8	63.8	-	76.4	84.1	96.1	105.6	115.4	118.8	133.3	145.1
N_MP (g/kg DM)	191.6	182.5	-	169.9	161.5	149.6	140.2	130.7	126.7	112.5	101.2
DVE (g/kg DM)	115.3	123.6	-	133.7	138.8	148.8	156.7	164.1	167.0	179.6	189.3
OEB (g/kg DM)	88.2	81.6	-	72.9	68.6	59.8	53.0	47.3	44.1	32.9	24.8
The prediction of potential nutrient supply from raw and pressure toasted soybean seeds											
BCP (g/kg DM)	121.1	149.3	163.9	180.8	177.9	188.5	185.3	182.6	178.5	187.3	188.8
FOM (g/kg DM)	578.5	550.2	535.7	518.8	521.6	511.1	514.2	516.9	521.0	512.2	510.7
E_MP (g/kg DM)	86.8	82.5	80.4	77.8	78.2	76.7	77.1	77.5	78.2	76.8	76.6
TPSI (g/kg DM)	186.2	211.2	224.1	239.2	236.6	246.0	243.2	240.8	237.1	244.9	246.3
AMP (g/kg DM)	55.3	52.6	51.2	49.6	49.9	48.9	49.2	49.4	49.8	49.0	48.8
dBCP (%, mobile)	84.4	79.4	85.3	88.5	89.6	89.8	92.6	91.8	91.9	93.7	94.1
dTCP (%, nylon+mobile)	95.2	92.2	93.9	94.7	95.3	95.1	96.5	96.2	96.4	97.0	97.2
ABCP (g/kg DM)	102.2	118.6	139.8	160.0	159.4	169.2	171.6	167.6	164.1	175.5	177.7
N_MP (g/kg DM)	272.5	244.3	229.7	212.8	215.7	205.1	208.3	211.0	215.1	206.3	204.8
DVE (g/kg DM)	152.5	166.2	186.0	204.6	204.3	213.1	215.8	212.1	208.9	219.5	221.5
OEB (g/kg DM)	185.8	161.7	149.4	135.0	137.4	128.5	131.1	133.4	136.9	129.5	128.2

Sources: Yu, 1995; Goelema, 1999; Yu et al., 1999; Yu et al., 2000 and Yu et al., 2000a,b,c.

(g/kg DM)-1.11×% BCP/100; E_MP (g/kg DM)=0.15× FOM (g/kg DM).

EVALUATION OF CHANGES OF POTENTIAL NUTRIENT SUPPLY UPON PROCESSING OF LEGUME SEEDS BY THE DVE/OEB SYSTEM

Numerous publications (such as Annexstad et al., 1987; Cros et al., 1991.1992; Benchaar et al., 1994) indicated that heat treatment does reduce effective degradability and increase BCP, but none of them provide detailed how heat processing affected microbial protein synthesis and potential nutrient supply and none of them were optimal heating conditions identified or studied. Heating above the optimal temperature may overprotect the protein so that the protein is neither fermented in the rumen nor digested in the

Table 3. The prediction of potential nutrient supply from raw and dry roasted whole lupin seeds and whole faba beans, using the DVE/OEB system

Temp. (°C)	Raw	110			130			150		
Time (Min)		15	30	45	15	30	45	15	30	45
The prediction of potential nutrient supply to dairy cows from raw and dry roasted of whole lupin seeds										
BCP (g/kg DM)	111.2	114.9	116.1	106.6	116.1	141.3	134.1	164.6	223.6	246.2
FOM (g/kg DM)	790.3	788.2	789.9	801.6	791.9	769.7	777.9	749.7	691.1	659.1
E_MP (g/kg DM)	118.6	118.2	118.5	120.2	118.8	115.5	116.7	112.5	103.7	98.9
TPSI (g/kg DM)	200.1	203.6	204.9	196.8	205.2	227.9	221.6	248.9	301.4	335.3
AMP (g/kg DM)	75.6	75.4	75.5	76.7	75.7	73.6	74.4	71.7	66.1	63.0
ENDP (g/kg DM)	2.3	2.2	2.1	2.1	2.1	2.0	2.2	2.1	2.1	1.9
ABCP (g/kg DM)	106.0	110.7	112.6	102.5	111.4	136.7	130.2	158.2	214.5	250.8
N_MP (g/kg DM)	275.3	273.0	264.6	270.7	263.7	243.6	246.0	227.8	158.4	124.9
DVE (g/kg DM)	179.3	183.9	186.0	177.1	185.1	208.2	202.4	227.8	278.4	312.0
OEB (g/kg DM)	156.8	154.8	146.1	150.5	144.9	128.2	129.3	115.3	54.8	26.0
The prediction of potential nutrient supply to dairy cows from raw and dry roasted whole faba beans										
BCP (g/kg DM)	39.9	31.2	32.5	35.1	45.0	45.9	56.2	60.5	83.6	148.5
BSt (g/kg DM)	98.4	94.9	91.4	92.8	100.7	105.8	118.7	126.9	145.4	199.9
FOM (g/kg DM)	801.0	813.6	819.5	818.3	795.9	795.0	771.2	758.2	718.1	600.6
E_MP (g/kg DM)	120.1	122.0	122.9	122.8	119.4	119.3	115.7	113.7	107.7	90.1
TPSI (g/kg DM)	130.0	122.8	124.7	127.1	134.5	135.3	144.0	145.8	164.3	216.0
AMP (g/kg DM)	76.6	77.8	78.4	78.3	76.1	76.0	73.7	72.5	68.7	57.4
ENDP (g/kg DM)	1.7	1.8	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5
ABCP (g/kg DM)	34.9	26.9	28.3	31.2	39.7	40.8	49.9	53.9	76.7	141.3
N_MP (g/kg DM)	277.4	286.2	287.4	283.7	278.1	278.3	262.0	261.5	236.8	161.9
DVE (g/kg DM)	109.7	103.0	105.1	107.9	114.3	115.3	122.1	124.9	143.7	197.2
OEB (g/kg DM)	157.3	164.2	164.5	161.0	158.7	159.1	146.3	147.8	129.1	71.8

Source: Yu et al., 1999.

small intestine (Stern et al., 1985). Yu et al. (1999, 2000) and Goelema (1999) have attempted to use the advanced DVE/OEB model to predict potential microbial protein synthesis and potential nutrient supply to ruminants from four major legume seeds affected by pressure toasting (Table 2) and dry roasting (Table 3) and to determine optimal processing conditions of pressure toasting and dry roasting of faba beans, lupin seeds, peas and soybeans in terms of the protein DVE and OEB values. These studies were systematically evaluate the effects of heat treatments on rumen degradation and intestinal digestion characteristics of raw and heated legumes seeds at various conditions to give the quantitative aspects of how the heat treatments affecting the protein degradation and digestion in detail and provided information for ration formula and the decision for the optimal treatment conditions in animal industry. The items assessed in those experiments were not only rumen degradation characteristics (Yu et al., 1999; Geolema, 1999; Yu et al., 2000) but also BCP, BSt, FOM, ABCP, E_MP, N_MP, TPSI, AMP, ENDP, DVE and OEB values. The most important values are potential protein DVE and OEB values, which were changed by heat processing for each legume seed.

Table 2 and 3 show the prediction of potential nutrient supply to ruminants from raw and heated lupin seeds, faba beans, peas and soybeans by using the DVE/OEB system. Input data from *in sacco* and mobile bag techniques were from dairy cows. Consequently the data generated by the model, though of significance in the dairy cows, are best regarded as characteristics of the test materials. These studies indicated that pressure toasting (Table 2) significantly increased the predicted BCP, BSt, true protein value of TPSI supplied to the small intestine, truly intestinal absorbed rumen undegradable protein value of ABCP and increased truly digested intestinal protein value of DVE. Pressure toasting decreased rumen fermented OM value of FOM, microbial protein value of E_MP synthesized in the rumen based on available energy, truly intestinal absorbed rumen synthesized microbial protein value of AMP, microbial protein value of N_MP synthesized in the rumen based on available N and degraded protein balance value of OEB with increasing temperature and time (Table 2). Though pressure toasting reduced microbial protein synthesis due to a reduction in FOM and a reduction in rumen protein degradation, the total truly digested intestinal protein value of DVE did not decrease but increased markedly. This was due to the fact that absorbable BCP value was highly increased more than enough to compensate for the computed decrease in microbial protein production. Therefore the net absorbable DVE value in the animal was substantially increased (DVE=ABCP+AMP-ENDP). The studies (Table 2) showed that raw lupin seeds, horse beans, peas and soybeans all had high OEB values (142, 101, 88 and 186 g/kg DM, respectively), which

Table 4. Observation (ADG) and prediction (ΔW) of daily live-weight gain from known DMI and MEI and supplied (DVE) and required metabolisable protein (MRP) of growing female lambs (Yu et al., 2001c)

	Nil	Supplements			
		RWLS	HWLS	RWFB	HWFB
Initial live weight (kg)	34.8	35.2	34.8	35.4	35.5
Feed intake					
Total DMI (g/d)	1,167.4	1,156.2	1,163.7	1,168.9	1,166.0
Total CPI (g/d)	186.1	185.4	184.7	186.7	187.3
Total MEI (MJ/d)	9.5	10.1	10.1	10.5	10.5
Daily live weight gain					
Observed ADG (g/d)	110.4	148.8	159.2	170.5	179.8
Predicted ΔW (g/d)	218.8	241.9	242.0	254.3	254.4
Difference (g/d) (=ADG-ΔW)	-108.4	-93.1	-82.8	-83.8	-74.4
Total truly absorbed intestinal protein (for predicted ΔW)					
Required MPR (g/d)	92.9	98.2	98.1	101.0	101.1
Supplied DVE (g/d)	45.9	62.6	91.5	54.5	83.0
Difference (g/d) (=DVE-MPR)	-47.0	-35.6	-6.6	-46.5	-18.1
Protein degradable balance					
OEB (g/d)	42.2	31.4	3.2	41.6	19.8

Nil: not legume seeds. RWLS; raw whole lupin seeds. HWLS; heated whole lupin seeds. RWFB; raw whole faba bean. HWFB: heated whole faba beans. Prediction models: the DVE/OEB system (Tamminga et al., 1994) and AFRC (1993).

indicated a potential imbalance between feed N degradation and utilization and indicated a potentially large N loss from rumen. Pressure toasting reduced the OEB values with increasing time and temperature, but did not cause them to become negative. High positive OEB values in the most treatments except 136°C for 15 min for horse beans and peas indicated that there were still large potential losses of N in the rumen. In other words, the treatments of 100°C /7, 15 or 30 min, 118°C/3, 7, 15 or 30 min and 136°C/3 or 7 min were not sufficient to reduce N loss in the rumen if they are used as rumen undegradable protein sources for high production ruminants. The above results indicated that with pressure toasting, temperature and/or duration could go still higher than 136°C and/or longer than 15 min with soybeans and lupins (due to their high OEB values, 128.2 and 44.4 g/kg DM, respectively) to further prevent potential N loss in the rumen if total tract digestion is not depressed. But pressure toasting up to 136°C for 15 min might cover the optimal treatment range for peas and faba beans (under certain circumstances) in terms of treating to achieve target values for potential high net absorbable protein in the small intestine while holding any N loss in the rumen to a low level.

Yu et al. (1999) used the same approach by using the DVE/OEB model to predict changes of potential nutrient supply to ruminants from whole lupin seeds and faba beans after dry roasting at various conditions, which are commonly used for ruminants on farm basis in Australia (Table 3) and to determine the optimal dry roasting conditions under certain circumstances for whole lupin seeds and faba beans (in terms of treating to achieve target values for potential high net absorbable protein in the small intestine while holding any N loss in the rumen to a low level), and found that dry roasting of whole lupin seeds and whole faba beans increased BCP, BSt, TPSI, ABCP and DVE values and decreased FOM, E_MP, AMP, N_MP and OEB with increasing temperature and time. Though dry roasting was effective in shifting protein degradation from rumen to intestine, and increased net absorbable protein DVE value, dry roasting up to 150°C for 45 min could not fully prevent potential N loss in the rumen for whole faba beans. But dry roasting up to 150°C for 45 min of whole lupin seeds might cover the optimal treatment range (Table 3) due to its high net absorbable DVE value (increasing from 110 to 197 g/kg DM) and lowest OEB value (reducing from 157 to 26 g/kg DM).

PROBE THE REASONS FOR EQUIVOCAL EFFECTS OF HEAT TREATMENT ON PERFORMANCE OF RUMINANTS

The results reported above are outputs from the DVE/OEB system with inputs based on *in sacco* and mobile bag techniques measurements. The challenge is to apply the predictions and evaluate them in an animal performance experiment. In the results of published studies that have been examined, the effect of heat treatments of legume seeds on animal performance are equivocal. However, some of them can be explained by using the DVE/OEB system.

In the lamb performance study (Yu et al., 2001c), a strong effort was made to select the dry roasting conditions on the basis of measured effects on nutritionally important

Table 5. The reanalysis of total DVE and OEB intakes in the lambs fed the diets with raw and roasted lupin in the study by Baiden (1997)

	DVE (g/kg DM)	OEB (g/kg DM)
Each feedstuff nutritional values		
Lupin (raw)	170	156
Lupin (130°C/45 min)	195	129
Oaten chaff	10	-20
Lucerne	46	49
Barley	97	-13
Lamb intake	Raw lupin diet	Roasted lupin diet
Lupin (raw) (g/d)	400	0
Lupin (130°C/45 min) (g/d)	0	410
Barley (g/d)	360	330
Roughage (g/d)	320	260
Oaten chaff (g/d)	299	243
Lucerne chaff (g/d)	21	17
Total DMI (g/d)	1,080	1,000
Total DVE intake (g/d)	107	114
Total OEB intake (g/d)	51	-9

The DVE and OEB values in raw lupin and roasted lupin (130°C /45 min) from Yu et al., 1999; The DVE and OEB values in the other feedstuffs from Tamminga and Janson (1993).

characteristics, particularly on DVE and OEB values as shown in Table 3. Comparing lupin with faba bean treatments, the increases of ADG and gain:feed ratio were greater for lambs fed faba bean diets than those fed lupin diets (Table 4). This was mainly because: (a) DMI of legume seeds was higher in lambs fed faba bean diets than those fed lupin diets (356.4 vs. 296.9 g/d); (b) Total ADFI were higher in the lambs fed lupin diets (ADFI: 289.7 g/kg vs. 258.8 g/kg DM) as a result of higher acid detergent fiber content in lupin and higher roughage intake in lupin diets; (c) Faba bean diets provided not only BCP as a potential AA source but also BSt as a potential glucose source; (d) The energy intake (MEI) was slightly higher in lambs fed faba bean diets due to a higher legume seeds DMI. Dry roasted (150°C/45 min) lupin seed and faba bean as protein supplements in the diets provided much more DVE value (Table 4). The results (Yu et al., 2001c) showed variability but lambs tended to increase ADG and improve gain:feed ratio. This effect was consistent with that predicted to be mainly mediated through a decrease in ruminal CP degradability of the roasted seeds, increased truly intestinally absorbed protein (DVE value), reduced OEB value and increased retained N (Yu et al., 1999, 2000; 2001c). These results indicate that dry roasting legume seeds can be a means to improve nutritive values of legume seeds for ruminants. These results are consistent with the results of Petit et al. (1997) who reported that ADG and gain:feed ratio of lambs fed extruded seeds was higher than that of lambs fed non-extruded seeds. In similar vein, Singh et al. (1995) observed that with roasted lupin seeds as protein supplements, lactating cows produced more milk, higher yields fat, protein and lactose than those fed raw lupins. The predicted liveweight gain (ΔW) (Table 4) was all higher than the observed ADG for all treatments. This was mainly because the supplies of total truly absorbable intestinal protein from the diets (DVE intake) were lower than the estimated requirements of the animal (Table 4). However the purpose in this study was not to obtain a maximum growth rate but to detect the effect of dry roasting of faba bean and lupin on lamb performance and compared observed results with predictions based on the analytical procedures already described.

In this study (Yu et al., 2001c), several considerations in the diet formulation were important in detecting the effectiveness of dry roasting of legume seeds on lamb performance. (a) The net absorbable intestinal protein intake (DVE) was not in excess relative to estimated animal requirements. They were all lower than animal requirements; (b) Although protein intake was kept the same among the treatments, the supplies of DVE values were different between roasted diets and non-roasted diets; (c) The OEB values in all the diets were positive. This indicated that the microbial protein synthesis was not impaired by lack of N in the rumen. The moderate quality roughage in the diets played an important role in keeping OEB value above zero, particular in the diets with dry roasted (150°C/45 min) legume seeds (because OEB values in dry roasted legume seeds were low (Table 3).

In the studies of Robinson and McNiven (1993) and Murphy and McNiven (1994), roasting lupin at 105-110°C failed to improve the performance of cows and beef steers. Our study shows that dry roasting of lupins at 105-110°C did not have any effect on the DVE value as shown in Table 3 (e.g. DVE: 179 (raw) vs. 177 g/kg DM (110°C/45 min, respectively). Thus, the total DVE intake of cows and beef steers fed control and roasted diets in the above studies was more than likely very similar.

Baiden (1997) found that lambs fed dry roasted lupins (130°C/35 min) had similar ADG to lambs fed raw lupins as part of the diet. When using the DVE/OEB system to reanalyze the nutritive value of the diet in Baiden's study (1997), it was found that two potential reasons for a lack of improvement in ADG (Table 5). (a) The total OEB value in the roasted lupin diet was negative (-9 g/d) and (b) The difference (107 vs. 114 g/d) in the DVE intakes between treatments was small. The calculated negative OEB value indicated that microbial protein synthesis in the lamb fed roasted lupin diet was impaired, because of a shortage of N in the rumen, thus, the negative OEB caused the lambs receiving a slightly higher DVE diet to perform poorly. The negative OEB value in the roasted lupin diet was due to use of the large amounts of feedstuffs with negative OEB values, such as barley (OEB=-13 g/kg DM) and oaten chaff (OEB=-20 g/kg DM).

Kung et al. (1991) observed a decrease in the *in sacco* protein degradation of roasted lupin, but this did not translate into a significant improvement in growth of lambs fed a hay and cracked corn basal diet, supplemented with the roasted lupin (exit temperature of 130°C). The data in Table 3 clearly show that roasting at 130°C did not have a profound effect on DVE value for roasted lupins. This may explain why lambs fed roasted lupin failed to improve in performance in the study by Kung et al. (1991).

Broderick et al. (1990) observed increased milk production and milk protein yield when dairy cows consumed 20 kg/day DM of an alfalfa silage-based diet containing a supplement of expelled soybean meal, when compared with cows fed a supplement of unexpelled soybean meal. However, when DMI was 24.4 kg/day, soybean meal supplementation did not alter production, and the advantage of expelling was not observed. One explanation for this is that when DMI increased to 24.4 kg/day, the DVE intakes in all diets may have been in excess of animal requirements. If protein supplies are adequate, additional quantities may have no effect (Chapula, 1974). Due to a lack of detailed information on the diets in the study of Broderick et al. (1990), the total DVE and OEB intakes in the treatments could not be calculated by the DVE/OEB system.

SUMMARY OF THE REASONS FOR EQUIVOCAL EFFECTS

The published results suggest that the overall nutrient supply to animal in an experiment should be the context in which any *in vivo* animal performance study is developed. An unsuitable supply of nutrients in terms of DVE and OEB intakes (e.g. negative total OEB intake (eg. Baiden, 1997; oversupply of total DVE values (eg. Broderick et al. 1990))) will result in an inability to detect the effectiveness of heat treatment in altering BCP and/or BSt and their effects.

In published studies, where heat treatments improve ruminant performance, the reasons are probably that: 1) Protein digested in the small intestine - one or more essential AAs - is a principal factor limiting performance; 2) Heat treatments decrease effective degradability of protein and thus increase BCP to the small intestine where it can be digested and absorbed (eg. Yu, 1995; Goelema, 1999); 3) Heat treatments increase total digestibility of BCP and increase calculated net absorbable true protein (the DVE values) in the small intestine and reduce protein degradable balance (the OEB values) (eg. Yu et al., 1999; Goelema, 1999); 4) Heat treatments reduce degradation rate of the potentially degradable fraction of protein in the rumen and can also benefit rumen microbial fermentation by providing a more sustained release of peptides and AA to meet nutrient requirements of some key microbial species. Reducing extent and the rate of rumen degradation of CP could also increase the fiber digestion. This was attributed to slow release of N from feed (eg. Veen, 1986); 5) Heat treatment can increase the amount of essential AA effectively protected and improve efficiency of rumen bacterial protein synthesis (eg. Cros et al., 1992; Keery et al., 1993; Benchaar et al., 1994) and 6) Heat treatments resulted in increases in N retention which indicates that heat treatments of legumes improved dietary N utilization (eg. Baiden, 1997; Yu et al., 2001c).

If heat treatments of a protein supplement fails to improve or results in decreased animal performance, the reasons might be that: 1) Protein digested in the small intestine was not the principal factor limiting performance; 2) Heating conditions may not be optimal, the feed being either underheated (the DVE value not changed by heat treatment or overheated (eg. Kung et al., 1991; Robinson and McNiven, 1993; Murphy and McNiven, 1994; Baiden, 1997); 3) The evaluation models, nylon bag techniques and *in vitro* technique used in some studies may be flawed to some extent, resulting in an inability to detect the extent of an effect of heat treatment on animal performance. Although the models and techniques are appropriate, their application misrepresents some effects of heat treatment (eg. Kung et al., 1991; Baiden, 1997); 4) The total nutrient supply to the animal might be unsuitable for the animal used in the performance study. For example there may be either over supply of the DVE value (eg. Broderick et al., 1990) or negative OEB intake in a diet (eg. Robinson and McNiven, 1993; Baiden, 1997) and 5) Other factors may have contributed to adversely affect animal performance, which include toxins and antinutritional factors. Inhibitory factors present in some seeds could affect microbial digestion or increase the rate of passage and could affect intestinal enzyme digestion (eg. Holmes et al., 1991).

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