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The effects of different processing methods on the estimated nutritional value of rice bran according to the NRC-2001 Model[5] or DVE/OEB System[6*]

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ABSTRACT

Four dairy cows fitted with ruminal and T-shaped duodenal cannulas were used to investigate the effects of processing methods on the nutritional value of rice bran and to compare the potential nutrient supply according to the NRC-2001 model or the DVE/OEB system. Three different types of processed rice bran (puffed rice bran, PRB; expeller rice bran, ERB; solvent-extracted rice bran, SRB) and unprocessed rice bran were chosen as materials. The results showed that the ERB and SRB protein concentrations were higher ($P<0.05$) than in unprocessed rice bran. According to the DVE/OEB system and the NRC-2001 model, the small intestine-absorbable protein contents (DVE or MP) in SRB and ERB were higher than in unprocessed rice bran (RB) ($P<0.05$). The nutritional values of rice bran were highly associated with the processing methods. The degraded protein balance (OEB) and the predicted absorbable small intestine protein (ASIP) using the NRC-2001 model were consistent with those using the DVE/OEB system.

KEY WORDS: rice bran, processing methods, nutritional value, DVE/OEB system, NRC-2001 model

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Abbreviations: [5]NRC-2001, Nutrient Requirements of Cattle-2001; [6]DVE/OEB, the Dutch Protein Evaluation System

INTRODUCTION

Rice bran, a by-product of rice processing, is the cuticle between paddy husks. Removed rice bran is rich in protein, oil, vitamin E, vitamin C, beta-carotene, polyphenols, and oryzanol, and is high in calories; it is largely used as an ingredient in animal feeds. Despite the large production of rice by-products, limited research is available on their nutritive value, such as degradation characteristics, and on the application of rice bran in the ruminant industry (Foster et al., 1994). The high content of fat in rice bran hinders its storage, especially under tropical or subtropical conditions. In addition, feeding excessive fat to ruminants decreases fibre digestibility (Palmquist and Jenkins, 1980). Despite the use of defatting processing, which can improve the storage properties of rice bran, the energy content of rice bran inevitably decreases. Heating rice bran can prevent its rancidity because it inhibits the activity of lipase, but it may also cause the Maillard reaction (Zhao et al., 1996). With the rapid development of technology, producers and researchers have been striving to develop better methods to improve the nutritive value of rice bran. Various methods have been applied to optimize its use. Drying and steaming processing methods are widely used for stabilizing rice bran, and expeller and solvent-extracting methods are commonly used to separate oil from rice bran (Proctor and Bowen, 1996). Despite this, only a few studies have been conducted to determine the differences between different processed rice brans in terms of the nutritive value and potential nutrient supply to ruminants.

In this study, the nutritional values of differently processed rice bran were investigated. The specific objectives of this study were as follows: 1. to compare the chemical composition and rumen degradability of differently processed rice bran; 2. to predict the nutrient supply to the small intestine of differently processed rice bran using the NRC model (2001) and the DVE/OEB system (Tamminga and Van Straalen, 1994), and 3. to determine the protein absorbable in the small intestine (ASIP) concentration and compare it with the predicted values using the NRC-2001 model and the DVE/OEB system.

MATERIAL AND METHODS

Material

In this study, the rice bran (RB) was processed *via* puffing, extracting, or expeller pressing to produce puffed rice bran (PRB), solvent-extracted rice bran (SRB), and expeller rice bran (ERB), respectively. Each kind of rice bran sample was collected from three different areas. To produce the puffed rice bran, fresh rice

bran was put into an extruder and heated to 130°C, and then ejected through small holes to make the puffed rice bran into certain lengths of loose small particles. The solvent-extracted rice bran was extracted at 85-95°C for 15 min in hexane to remove the oil from it, followed by centrifugation, and then the precipitate was dried into solvent-extracted rice bran meal. The expellering treatment involved feeding cracked rice bran into expeller presses with a central revolving shift. The pressure created by extruding extracted the oil mechanically from the rice bran; the temperature reached a maximum of 123°C; the expelled rice bran was then cooled and dried. Samples and degraded samples analyzed for nutrient contents were ground to pass a 1-mm screen in a Wiley mill, and samples prior to rumen incubation were ground to pass a 2 mm screen in a Wiley mill.

Animals and feeding

Four dairy cows (560±25 kg) equipped with rumen cannulas (Bar Diamond, Parma, ID) and T-shaped duodenal cannulas were used for the in *situ* measurements of ruminal degradability and intestinal digestibility *in sacco* study. The procedures of ruminal and intestinal cannulation surgery and the experimental protocol were all approved by the Northeast Agricultural University Animal Science and Technology College Animal Care and Use Committee. The diet was formulated according to the NRC (2001). The ration was composited of roughage and concentrate at a ratio of 60:40. The ration was formulated with soyabean meal (7% DM), cottonseed meal (4% DM), cracked maize (21% DM), wheat bran (6% DM), maize silage (60% DM), and premix (2% DM) (including vitamin premix A, D and E, limestone, calcium hydrogen phosphate, and salt). Ruminal incubation *in situ* was carried out after the adaptation period. The cows were fed twice daily (8:00 am and 17:00 pm) and clean water was always available.

Rumen incubation method

The rice bran samples were incubated for 0, 2, 4, 8, 12, 24, and 48 h, respectively. Two nylon bags of one time-point loaded with rice bran samples were placed in each cow at each period *via* a rumen cannula. Fifty-six nylon bags were used for each kind of processed RB. Ruminal degradation traits were determined using the method of Ørskov and McDonald (1979). The bags were inserted in reverse order of the incubation period so that they could all be removed at the same time (NRC, 2001). Each nylon-coded bag (5 cm × 7 cm) with a pore size of approximately 50 μm was loaded with 4 g of different processed RB. Before incubation, the bags were soaked in water (39°C) for 20 min, attached to a stainless-steel weight, and placed in the ventral sac of the

rumen. Once the bags were removed from the rumen, they were immersed in 20-l buckets containing cold water, then washed in an automatic washing machine (5 × 1-min wash, 2-min spin) until the rinse water was clear, and dried at 65°C for 48 h.

Chemical analysis

Dry matter (DM), ether extract (EE), and crude protein (CP) contents were analysed according to AOAC (1990) procedures. The analyses of neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were performed according to the methods of Van Soest et al. (1991) using the Ankom system (Ankom 220 fibre analyzer; Ankom) with heat-stable α-amylase and without sodium sulphite. Nitrogen fractions, defined according to the Cornell Net Carbohydrate and Protein System (CNCPS), were determined using the methods of Licitra et al. (1996). Starch was analysed using the anthrone shade selection method (Mc Donald and Henderson, 1964).

Partitioning protein and carbohydrate fractions

The CP and carbohydrate (CHO) fractions were partitioned according to the CNCPS (Sniffen et al., 1992). PA is the fraction of CP that was instantaneously solubilized at time zero. PB_1 is the fraction of CP that was soluble in borate-phosphate buffer and precipitated with trichloroacetic acid. PB_2 is calculated as total CP minus the sum of fractions PA, PB_1, PB_3, and PC. PB_3 is calculated as the difference between the portions of total CP recovered with NDF and ADF. PC is the fraction of CP recovered with ADF and is considered undegradable. PC contains proteins associated with lignins, tannins, and heat-damaged proteins, such as Mailard reaction products. CA is the fraction of total carbohydrate with a rapid Kd (degradation rate in h^{-1}) (3 h^{-1}) and includes different kinds of sugars (fermentable soluble). CB_1 is the fraction of total carbohydrate with an intermediate Kd (0.2-0.5 h^{-1}) and includes starch and pectin. CB_2 is the fraction of total carbohydrate with a slow Kd (0.02-0.1 h^{-1}) and includes available cell walls. CC is the fraction of total carbohydrate that includes unavailable cell wall and cannot be fermented.

Rumen degradation characteristics

Rumen degradation characteristics of CP and starch were determined by the *in sacco* method. Then the results were calculated using the nonlinear regression model (NLIN) procedure of the statistical package of SAS (1999) using iterative least squares regression (Gauss–Newton method) by following the first-order kinetics equations:

$$R(t) = U + D \times \exp(-Kd \times (t - T_0)) \text{ for CP}$$

and $R(t) = D \times \exp(-Kd \times t)$ for starch (Ørskov and McDonald, 1979; Tamminga and Van Straalen, 1994),

where: R (t) stands for residue of the incubated material after t h of rumen incubation (g/kg); U and D stand for undegradable and potentially degradable fractions, respectively in g/kg; lag time (T_0) in h; and the rate of degradation of fraction D (Kd) in h^{-1}.

The effective degradability (ED) values were calculated as:

$$EDCP\ (EDST)\ (g/kg) = S + D \times Kd / (Kp + Kd)$$
$$EDCP\ (g/kg\ DM) = CP\ (g/kg\ DM) \times EDCP\ (g/kg)$$
$$EDST\ (g/kg\ DM) = ST\ (g/kg\ DM) \times EDST\ (g/kg)$$

where: the soluble fraction (S) is expressed in g/kg; ST stands for starch in g/kg DM; EDCP and EDST stand for effective degradation rate of feed CP or starch in g/kg or g/kg DM; the passage rate (Kp) of 0.06 h^{-1} is adopted from Tamminga and Van Straalen, 1994.

The rumen undegradable protein (RUP) values were calculated as:

$$RUP\ (g/kg) = U + D \times Kp / (Kp + Kd)$$
$$RUP\ (g/kg\ DM) = 1.11 \times CP\ (g/kg\ DM) \times RUP\ (g/kg)$$

where: the Kp of 0.06 h^{-1} is adopted (see above). The factor 1.11 in the formula is taken from the French PDI and Dutch DVE/OEB systems, and 1.11 was the regression coefficient of *in vivo* degradation data.

The rumen undegradable starch (RUST) values were calculated as:

$$RUST\ (g/kg) = D \times Kp / (Kp + Kd) + 0.1 \times S$$
$$RUST\ (g/kg\ DM) = ST\ (g/kg\ DM) \times RUST\ (g/kg)$$

where: the Kp of 0.06 h^{-1} is adopted (see above). The factor 0.1 in the formula is adopted from an assumption that 100 g/kg of soluble fraction (S) escapes from rumen fermentation for starch (Tamminga and Van Straalen, 1994).

Prediction of potential nutrient supply using the DVE/OEB system

Tamminga and Van Straalen (1994) provided the detailed concepts of the DVE/OEB system. Yu and Meier (2003) provided a brief explanation of the potential nutrient supply.

Fermentable organic matter (FOM) in the rumen was calculated as:

$$FOM = DOM - EE - RUP - RUST - FP$$

where: digested organic matter (DOM), EE, RUP and RUST are expressed in g/kg DM; Fermentation products (FP) are expressed just for conserved forages (g/kg DM) (and assumed to be 'zero' for barley grain). Subsequently, microbial protein synthesized in the rumen based on available energy (E_MCP) was estimated as:

$$E\_MCP = 0.15 \times FOM$$

where: E_MCP in g/kg DM, the factor 0.15 means that for every kg of rumen FOM, 150 g of microbial protein is assumed to be synthesized. True protein supplied to small intestine (TPSI) was calculated as:

$$TPSI = RUP + 0.75 \times E\_MCP$$

where: the factor 0.75 means that 750 g/kg of microbial N is present in amino acids, and the remaining part of N is in nucleic acids.

True digestibility of microbial protein (MCP) is assumed to be 850 g/kg, and the amount of truly absorbable microbial protein in the small intestine (AMCP) was estimated as:

$$AMCP = 0.85 \times 0.75 \times 0.15 \times FOM$$

where: AMCP is expressed in g/kg DM.

Truly absorbable rumen undegradable protein in the small intestine (ARUP) was calculated as:

$$ARUP = RUP \times d\ RUP,$$

where: digestibility of rumen undegradable protein in the small intestine (d RUP) is assumed to be 850 g/kg (NRC, 2001).

According to the DVE/OEB system, 75 g of absorbable protein (kg DM) in fecal excretion is required to compensate for endogenous losses. Endogenous protein in the small intestine (ENDP) was estimated as:

$$ENDP = 75 \times UDM$$

where: undigested DM (UDM) and ENDP are expressed in g/kg DM; UDM = undigested organic matter (UOM) + undigested inorganic ash (UASH), where: UOM = OM – DOM, OM stands for organic matter; UASH = ASH − ASH ×digestibility of inorganic matter (d ASH), where d ASH is assumed to be 650 g/kg.

The total truly digested protein in the small intestine (DVE, absorbable small intestine protein) value was estimated as:

$$DVE = ARUP + AMCP – ENDP$$

where: DVE is expressed in g/kg DM.

The degraded protein balance (OEB) value is the balance between microbial protein synthesis from rumen degradable CP and from the energy extracted during anaerobic fermentation in the rumen. The OEB value was estimated as:

OEB = nitrogen − microbial protein (N_MCP) − energy - microbial protein (E_MCP)

where: N_MCP = CP − RUP = CP − 1.11 × CP × RUP; E_MCP = 0.15 × FOM; all parameters in g/kg DM.

Prediction of potential nutrient supply using the NRC-2001 model

The detailed concepts and formulas were provided by NRC (2001). The following is a brief explanation.

Potential ruminally synthesized microbial CP (MCP) was calculated as:

MCP (g/kg DM) = 0.13 × total digest nutrient (TDN) (discounted), when effective digestibility protein (EDCP) exceeded 1.18 × TDN-predicted MCP (MCP_TDN). When EDCP was less than 1.18 × TDN-predicted MCP (MCP_TDN), then MCP was calculated as 0.85 of EDCP (MCP_EDCP), where EDCP is expressed in g/kg DM. The factor 0.13 means that 130 g of microbial protein is assumed to be synthesized for every kilogram of discounted TDN.

In the NRC model (2001), true protein and digestibility of ruminally synthesized microbial CP are assumed to be 800 g/kg. Therefore, the amount of truly absorbable MCP (AMCP) was estimated as:

$$AMCP = 0.80 \times 0.80 \times MCP$$

where: AMCP is expressed in g/kg DM.

Rumen endogenous CP (ECP), according to the NRC (2001), is calculated as:

$$ECP\ (g/kg\ DM) = 6.25 \times 1.9 \times DM\ (g/kg).$$

Assuming that 500 g/kg of rumen endogenous CP passes into the duodenum and 800 g/kg of rumen endogenous CP is true protein (NRC, 2001); the truly absorbable rumen endogenous protein in the small intestine (AECP) value was estimated as:

$$AECP = 0.50 \times 0.80 \times ECP$$

where: AECP and ECP is expressed in g/kg DM.

Total metabolizable protein (MP, absorbable small intestine protein) in the NRC (2001) model is contributed by: 1. ruminally undegradable feed CP (RUP); 2. ruminally synthesized microbial CP (MCP); and 3. rumen endogenous CP (ECP). Therefore, MP = ARUP + AMCP + AECP, where: MP is expressed in g/kg DM.

Based on data from NRC (2001), OEB (g/kg DM) reflects the difference between the potential microbial protein synthesis based on ruminally degradable feed CP (EDCP) and that based on energy (discounted TDN) available for microbial fermentation in the rumen, which was calculated as:

OEB = EDCP − 1.18 MCP_TDN where: OEB is expressed in g/kg DM.

Determining the absorbable small intestine protein concentration (ASIP) using the mobile nylon method

The same four cows were used to ruminally incubate additional RBs and estimate the intestinal digestibility of CP. The small intestine digestibility (SID) of RUP was determined using the method of Hvelplund (1985).

$$ASIP = MCP \times 0.7 + RUP \times d\ RUP\ (MCP = RUP \times 0.9)$$

where: d RUP - the small intestine digestibility of RUP (Feng and Lu, 2001).

Statistical analysis

Data were analysed using the randomized complete block design with the MIXED procedure of SAS (SAS, 1999). Using the feed and the cow as fixed and random effects, respectively, the following model was adopted:

$$Yij = u + F\ i + C\ j + E\ ij$$

where: Y ij - the value of the variable studied on the Ith feed for the jth cow, u - the overall mean, F i - the fixed effect of the ith feed (i = 1-4), C j - the random effect of the jth cow (j = 1-4), and E ij - random error.

RESULTS

Chemical composition of rice bran

The chemical compositions of differently processed rice bran are presented in Table 1. The concentrations of EE in PRB, ERB, and SRB were lower($P<0.05$), the CP concentrations of ERB and SRB were higher ($P<0.05$), and the starch concentration of SRB was 54 g/kg higher than unprocessed rice bran ($P<0.05$). The ADF concentrations in processed RBs were lower ($P<0.05$) and PRB had the lowest ADF content among the treatments ($P<0.05$). The concentrations of NDF in ERB and SRB were significantly higher than those in RB ($P<0.05$). The ERB and SRB had much lower ADL and soluble crude protein (SCP) contents and much higher neutral detergent insoluble crude protein (NDICP) and acid detergent insoluble crude protein (ADICP) contents than the other two rice brans ($P<0.05$).

Table 1. Effect of different processing on chemical composition, protein and carbohydrate fractions of rice bran

Composition	RB	PRB	ERB	SRB	SEM
Chemical composition					
EE, g/kg DM	152[a]	138[b]	92[c]	22[d]	15.32
CP, g/kg DM	134[c]	131[c]	170[b]	181[a]	6.69
Starch, g/kg DM	270[b]	283[b]	290[b]	324[a]	6.28
ADF, g/kg DM	133[a]	76[d]	115[b]	98[c]	6.59
NDF, g/kg DM	309[c]	302[c]	382[a]	325[b]	9.53
ADL, g/kg NDF	52[a]	51a	23[b]	25[b]	4.16
SCP, g/kg CP	292[a]	298[a]	160[b]	146[c]	21.49
NDICP, g/kg CP	217[c]	178[d]	399[a]	327[b]	26.65
ADICP, g/kg CP	16[c]	26[b]	30[a]	27[b]	1.62
Protein and carbohydrate fractions, CNCPS					
PA , g/kg CP	246[a]	247[a]	157[b]	142[c]	14.73
PB_1, g/kg CP	46[b]	51[a]	3[c]	4[c]	6.83
PB_2, g/kg CP	490[b]	524[a]	455[c]	527[a]	9.13
PB_3, g/kg CP	201[c]	152[d]	355[a]	300[b]	24.17
PC, g/kg CP	16[c]	26[b]	30[a]	27[b]	1.62
CA, g/kg CHO	277[a]	284[a]	209[b]	291[a]	10.30
CB_1, g/kg CHO	270[b]	283[b]	290[b]	324[a]	6.28
CB_2, g/kg CHO	391[b]	376[b]	468[a]	357[c]	12.82
CC, g/kg CHO	62[a]	57[b]	34[c]	28[d]	4.45

means with the same letter in the same raw are not significantly different ($P>0.05$); SEM - standard error of mean; RB - rice bran; PRB - puffed rice bran; SRB - solvent-extracted rice bran; ERB - expeller rice bran; EE - ether extract; CP - crude protein; ADF - acid detergent insoluble fibre; NDF - neutral detergent fibre; ADL - acid detergent lignin; SCP - soluble crude protein; NDICP - neutral detergent insoluble protein; ADICP - acid neutral detergent insoluble protein; PA - instantaneously solubilized protein; PB_1 - rapidly degraded protein; PB_2 - intermediate degraded protein; PB_3 - slow degraded protein; PC - unavailable protein; CA - rapid speed available carbohydrate; CB_1 - intermediate speed available carbohydrate; CB_2 - slow speed available carbohydrate; CC - unavailable carbohydrate

Protein and carbohydrate fractions

The processes of expelling and solvent-extracting could reduce the contents of PA and PB_1 by 36.2-94.1%, and these two methods also could increase the content of PB_3 significantly, when compared with that in unprocessed RB ($P<0.05$). The ERB had a much lower content of PB_2 (455 g/kg CP) than the other processed rice brans. Processing could also enhance the PC concentration of rice bran by more than 38%. The concentration of CA in ERB was 209 g/kg CHO, which was much lower than the other rice brans. The process of solvent-extracting made the content of CB_1 much higher than in RB, PRB, and ERB. The ERB had the highest content of CB_2, and SRB had the lowest CB_2 content, while the other two kinds of rice bran were intermediate. Unprocessed rice bran had a much higher content of CC (62 g/kg), suggesting different processing methods could significantly decrease the CC concentration of rice bran ($P<0.05$).

In sacco rumen degradation traits

Rumen degradation characteristics of CP and starch in different kinds of rice brans are presented in Table 2. The unprocessed rice bran had the highest contents of soluble fraction (S) and unavailable protein (U), while it had the lowest content of the degradable fraction (D) and degradation rate (Kd) among all the treatments. Increased RUP concentrations were found in ERB (77 g/kg DM), SRB (77 g/kg DM), and PRB (66 g/kg DM). Puffed and expellered rice bran had lower contents of D, however, these two processing methods enhanced the degradation rate of starch in rice bran. The three different processing methods lowered the contents of RUST (g/kg DM) and improved the contents of EDST (g/kg DM) in rice bran ($P<0.05$).

Table 2. Effect of different processing methods on rumen degradation characteristics of crude protein (using the Øskov model) and starch, using the DVE/OEB system

Degradation	RB	PRB	ERB	SRB	SEM
In sacco rumen degradation characteristics of crude protein (using the Øskov model)					
S, g/kg	500[a]	335[c]	399[b]	358[c]	19.74
D, g/kg	261[c]	487[b]	468[b]	553[a]	33.33
U, g/kg	232[a]	172[b]	132[c]	91[d]	15.97
Kd, h^{-1}	0.022[b]	0.036[a]	0.034[a]	0.043[a]	0.0026
RUCP, g/kg DM	61[c]	66[b]	77[a]	77[a]	2.19
EDCP, g/kg DM)	73[b]	65[b]	93[a]	104[a]	4.82
In sacco rumen degradation characteristics of starch (using the DVE/OEB system)					
S, g/kg	544[b]	606[a]	655[a]	564[b]	16.28
D, g/kg	455[a]	393[b]	334[b]	436[a]	16.28
Kd, h^{-1}	0.031[b]	0.067[a]	0.069[a]	0.054[b]	0.006
RUST, g/kg DM	76[a]	47[b]	41[b]	69[b]	4.55
EDST, g/kg DM	194[b]	236[a]	249[a]	255[a]	8.63

means with the same letter in the same raw are not significantly different ($P>0.05$); SEM - standard error of mean; RB - rice bran; PRB - puffed rice bran; SRB - solvent-extracted rice bran; ERB - expeller rice bran; S - soluble fraction; D - potentially degradable fractions; U - undegradable fractions; kd - degraded rate in in h^{-1}; RUCP - rumen undegradable protein; EDCP -effective degradable protein; RUST - rumen undegradable starch; EDST - effective degradable starch

Predicted potential nutrient supply using the DVE/OEB system and the NRC-2001 model

The predicted potential nutrients supplied to the dairy cattle small intestine using the DVE/OEB system are presented in Table 3. The FOM contents in ERB and SRB were greater than those of the other two kinds of rice bran ($P<0.05$). There were no significant differences in the DOM content and the ENDP content among all the treatments. The TPSI contents in the processed RBs were much greater ($P<0.05$) than in unprocessed RB. Processed RB had a higher content of DVE

Table 3. Prediction of the potential nutrient supply of different processing rice bran to dairy cattle using the DVE/OEB system and NRC-2001 dairy model

Degradation	RB	PRB	ERB	SRB	SEM
DVE/OEB system to predict the potential nutrient supply to dairy cattle, g/kg DM					
FOM	574^{c}	582^{c}	604^{b}	674^{a}	11.93
DOM	851	861	862	877	3.45
RUP	61^{c}	66^{b}	77^{a}	77^{a}	2.19
ENDP	6	6	5	4	0.34
TPSI	126^{d}	131^{c}	145^{b}	153^{a}	3.33
DVE (ASIP)	100^{d}	105^{c}	118^{b}	126^{a}	3.13
E_MCP (based on FOM)	86^{c}	87^{c}	91^{b}	101^{a}	1.79
N_MCP	73^{b}	65^{b}	93^{a}	104^{a}	4.82
OEB	-13	-22	3	2	-
NRC-2001 model to predict the potential nutrient, g/kg DM					
TDN	881^{c}	888^{c}	914^{b}	945^{a}	7.66
RUP	61^{c}	66^{b}	77^{a}	77^{a}	2.19
ECP	11	11	11	11	-
AECP	4	4	4	4	-
MP(ASIP)	88^{c}	87^{c}	112^{b}	128^{a}	4.25
E_MCP (MCP_TDN)	115^{c}	115^{c}	119^{b}	123^{a}	0.10
N_MCP (MCP_EDCP)	62^{b}	56^{b}	79^{a}	80^{a}	4.10
OEB	-53	-60	-40	-35	-
Mobile nylon methods for nutrient determination					
SID, g/kg RUP	693^{d}	852^{b}	778^{c}	921^{a}	25.70
ASIP, g/kg DM	90^{d}	95^{c}	118^{b}	136^{a}	5.62

means with the same letter in the same raw are not significantly different (P>0.05); SEM - standard error of mean; RB - rice bran; PRB - puffed rice bran; SRB - solvent-extracted rice bran; ERB - expeller rice bran; FOM - fermentable organic matter; DOM - digested organic matter; RUP - rumen undegradable protein; ENDP - endogenous protein in the small intestine; TPSI - true protein supplied to small intestine; DVE - the total truly digested protein in the small intestine; E_MCP - Energy_ Microbial protein; N_MCP - Nitrogen _ Microbial protein; TDN - total digest nutrients; ECP - endogenous protein in the small intestine; AECP - absorbable endogenous protein in the small intestine; MP - total metabolizable protein; E_MCP (MCP_TDN) - the potential microbial protein synthesis based on energy (discounted TDN) available; N_MCP (MCP_EDCP) - the potential microbial protein synthesis based on ruminally degradable feed CP (EDCP); OEB - the potential microbial protein synthesis based on ruminally degradable feed CP (EDCP) and that based on energy (discounted TDN) available for microbial fermentation in the rumen; SID - small intestine digestibility; ASIP - absorbable small intestine protein

(which represents absorbable small intestine protein, ASIP) than unprocessed RB (P<0.05), whereas SRB had the highest concentration of DVE (P<0.05). As for the contents of E_MCP and N_MCP, solvent-extracting and expellering increased them to above the level in unprocessed RB (P<0.05), whereas the content of PRB was similar to that in unprocessed RB. The OEB values (degradable protein balance) of SRB and ERB were 2 g/kg DM and 3 g/kg DM, respectively, showing that solvent-extracting and expeller processing could decrease N loss. Compared with unprocessed rice bran (-13 g/kg DM), the OEB value of PRB was -22 g/kg

DM, showing that PRB had more energy loss when MCP was synthesized.

The predicted results of the potential nutrients supplied to the small intestines of dairy cattle using the NRC dairy model (2001) are presented in Table 3. The concentrations of total digestible nutrients (TDN) in SRB and ERB were greater ($P<0.05$), when compared with that in unprocessed RB. The RUP content had a similar tendency with TDN within treatments. No matter which kind of rice bran, the ECP and AECP contents were 11 g/kg DM and 4 g/kg DM, respectively. The processes of expellering and solvent-extracting could enhance MP (represent absorbable small intestine protein, ASIP) content to 27.3-34.1% more than in unprocessed RB ($P<0.05$). The ERB and SRB had higher concentrations of E_MCP (MCP_TDN) and N_MCP (MCP_EDCP) than unprocessed rice bran ($P<0.05$), and PRB had a similar content as unprocessed RB in terms of E_MCP and N_MCP contents. The OEB values of SRB and ERB were almost -35 g/kg DM and -40 g/kg DM, respectively, indicating that SRB and ERB could largely synthesize MCP and avoid energy loss. Compared with unprocessed rice bran, however, (-53 g/kg DM), the OEB value of PRB was -60 g/kg DM, indicating that PRB had a greater energy loss than unprocessed rice bran.

The determined contents of SID and ASIP in processed RB were higher than those in unprocessed RB, with SRB having the highest level and RB, the lowest ($P<0.05$).

As shown in Table 4, the unprocessed RB had a significantly higher predicted ASIP concentration using the DVE/OEB system than the result obtained using the mobile nylon bag method ($P<0.05$), and no significant difference was found in the obtained ASIP concentration in unprocessed RB between the NRC-2001 model and the mobile nylon bag method. The ASIP concentration obtained by the DVE/OEB system was at the highest level in PRB, that obtained by the NRC-2001 model was the lowest, while the determined ASIP concentration using the mobile nylon bag method was intermediate. No significant difference in ERB was observed between using the DVE/OEB system and the mobile nylon bag method, and the predicted value was lowered by 6.49 g/kg when using the NRC-2001 model ($P<0.05$). The SRB had a lower predicted ASIP concentration when

Table 4. Comparative analysis of determined absorbable small intestine protein (ASIP) concentration and predicted ASIP concentration

ASIP	Calculated value	Predict value, the DVE system	Predict value, the NRC model	SEM
RB, g/kg DM	90^{b}	101^{a}	88^{b}	2.14
PRB, g/kg DM	95^{b}	105^{a}	87^{c}	2.64
ERB, g/kg DM	119^{a}	118^{a}	112^{b}	1.34
SRB, g/kg DM	136^{a}	126^{b}	118^{c}	2.65

means with the same letter in the same raw are not significantly different ($P>0.05$); SEM - standard error of mean; RB - rice bran; PRB - puffed rice bran; SRB - solvent-extracted rice bran; ERB -expeller rice bran

using the DVE/OEB system and the NRC-2001 model than when using mobile nylon bag method ($P<0.05$). No matter which kind of processing was employed, the concentrations of ASIP of the rice brans were much higher when obtained by the DVE/OEB system than by the NRC-2001 model ($P<0.05$).

Based on the data of ASIP concentrations obtained by the three different methods, the correlation coefficients (R^2) among them were 0.9578 (DVE/OEB system vs mobile nylon method), 0.9442 (NRC-2001 model vs mobile nylon method) and 0.9127 (DVE/OEB system vs NRC-2001 model), respectively, as shown in Figures 1, 2, and 3.

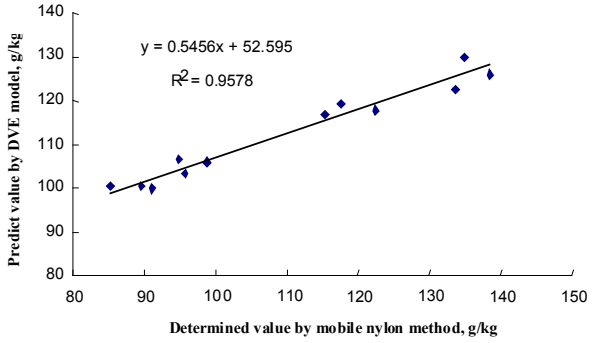

Figure 1. Correlation coefficient of predicted value using DVE system and determined value using mobile nylon bag method

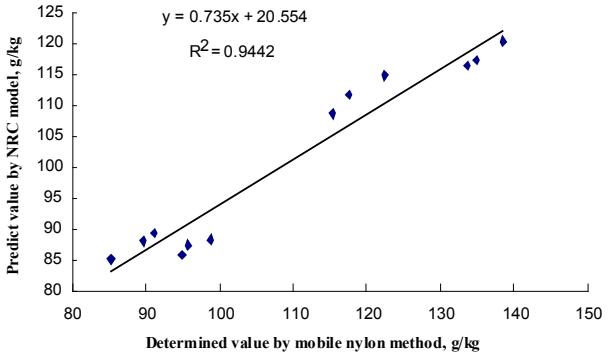

Figure 2. Correlation coefficient of predicted value using NRC system and determined value using mobile nylon bag method

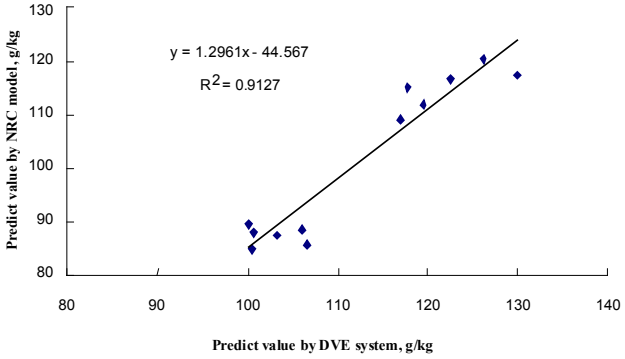

Figure 3. Correlation coefficient of predicted value using NRC system and DVE/OEB system

DISCUSSION

Comparative analysis of nutritional value in four kinds of rice bran

Foster et al. (1994) found that defatted rice bran had higher concentrations of CP and NDF than the full fat rice bran, which was in agreement with the results in our study. A similar impact of heat treatment on protein and fibre fractions was found in SBM (Demjanec et al., 1995). The concentrates of NDICP and ADICP in ERB and SRB were greater than those in unprocessed RB, which might be due to produced heat and chemical reactions during the processing (Demjanec et al., 1995). The increase in NDICP reflected an increase in the protein fraction that was slowly degraded in the rumen (Mustafa et al., 2000), whereas the increase in ADICP was an indication of increased heat-damaged protein, which would reduce protein digestibility (Can and Yilmaz, 2002). The soluble protein concentrations of ERB and PRB were lower than in unprocessed rice bran, which was due to heat denaturation during processing, resulting in reduced solubility of feed protein (Liu, 1999). In the current study, the concentrations of ADL of ERB and SRB were lower than those of unprocessed RB, which might be due to the high temperature, high pressure, and high shearing force generated in rice bran processing, resulting in a chemical bond split that could change heteropolarity and make unavailable fibre become available. The rapidly degraded protein (PA) in ERB and SRB decreased, indicating that the processing methods referred to might form combination structures of protein and fibre, preventing the protein from being rapidly degraded, which is consistent with the results of Anderson and Guraya (2001). The sum of PB_1, PB_2, and PB_3 concentrations is the true

absorbable protein concentration (PB). The PB concentration increased when the rice bran was expeller processed and solvent-extracted. The CC concentration of processed RB decreased, showing that the available carbohydrate increased and the processed rice bran may have increased MCP (microbial protein) content.

The fraction S of CP was decreased and the fraction D of CP was increased in PRB, ERB, and SRB, owing to the heating process, which is consistent with the results of Wang et al. (1997) in which heating decreased the soluble protein content and increased slow-degradable- and undegradable protein contents. The protein of rice bran underwent denaturation, racemization, and cross-linking reactions when the rice bran was heat-treated and defatted, rendering protein less susceptible to be microbial enzymes, leading to it being slowly degraded in the rumen (Wallace, 1994). Expeller and solvent-extracted processing decreased protein rumen degradability and increase bypass rumen protein content, which is similar to the results in an earlier report (Borucki et al., 2007). The EDST (g/kg DM) content was at a higher level for processed rice brans because of the breakdown of the adhesive properties of protein and starch during high temperature- and high pressure processing (McAllister et al., 1993). The synchronized increase in ammonia and energy in the rumen may increase MCP production, which prevents energy loss. Moreover, the efficiency of the synthesis of MCP increases with increasing speed of starch degradation (Hoover and Stroke, 1991). Sauvant and Milgen (1994) had also drawn the same conclusion, in which the replacement by rapidly degradable starch of slowly degradable starch could increase MCP production into the duodenum by 10%.

Processing can increase the protein availability of rice bran, as shown in the present study. The tendency of the determined ASIP concentrations of different RBs using the mobile nylon method was similar with those seen using the two systems, as shown by comparative analysis of correlation coefficients. The ASIP concentration can be increased by the following three ways: 1. increasing feed protein concentration, 2. increasing RUP concentration, and 3. increasing RUP digestibility in the small intestine (NRC, 2001). The degrees of defatting od SRB and ERB were higher, and thus, the protein concentrations were greater and the heat and chemical reactions produced during the processing increased RUP concentrations and SID, thereby resulting in a higher concentration of ASIP being found in SRB and ERB.

Comparative analysis of the potential nutrient supply using the DVE/OEB system and the NRC-2001 model

In the DVE/OEB system, each feed has a DVE value that represents the true ASIP concentration. And each feed has a rumen degraded protein balance

(called OEB in Dutch) value, which shows the balance of microbial synthesized protein based on the potentially rumen degradable protein and on the energy during ruminal fermentation. The NRC-2001 model introduces the concepts of MP, which represents the ASIP, and each feed also has the rumen degraded protein balance, which represents the difference between the potential synthesized microbial protein based on ruminally degraded feed CP and that based on TDN as energy available for microbial fermentation in the rumen.

In the DVE/OEB system, the DVE (ASIP) contents in SRB and ERB were greater than in unprocessed RB, whereas SRB had the highest DVE content. In the NRC model, SRB and ERB had greater contents of MP ($P<0.05$) (ASIP) than that in unprocessed RB, whereas SRB had the highest MP content, which was consistent with that in the DVE/OEB system. The OEB values of ERB and SRB were almost zero in the NRC-2001 model and DVE/OEB system, indicating that ERB and SRB had a potentially lower energy deficit in the rumen. The OEB values of PRB in the two systems were, however, far from zero compared with those of the unprocessed RB, indicating that PRB had a greater energy deficit in the rumen, and PRB had a greater DVE content than unprocessed RB in DVE/OEB system, but no significant difference of MP was found between PRB and RB in the NRC model, which is owed to the different concepts used for the calculations on data from the two models. These results show that the potential nutrient supply was highly associated with the processing methods.

Comparative analysis of the determined ASIP (DVE, MP) using the mobile nylon method and the predicted ASIP using the DVE/OEB system and NRC-2001 model

The correlation coefficients (R^2) of predicted values using the two systems and determined value were higher than 0.9000, respectively, indicating that the NRC-2001 model and the DVE/OEB system could predict the ASIP concentration. Comparative analysis using the correlation coefficients (R^2) showed that the effect of the predicted ASIP concentration using the DVE/OEB system was better than with the NRC-2001 model. In addition, the correlation coefficient (R^2) of the predicted ASIP concentrations using the DVE/OEB system and the NRC-2001 model was 0.9127, indicating that the predicted results using the NRC model were consistent with the DVE/OEB system. Yu et al. (2003) also found that the predicted values from the DVE/OEB system and the NRC-2001 model had significant correlations with high R^2 (>0.9600) values, when these two systems were compared in predicting protein supply to dairy cows from selected forages. The consistencies were due to the similar principles of the predicted metabolizable protein values from the two models (Yu et al., 2003).

CONCLUSIONS

The nutritional value, rumen degradability of rice bran, and intestinal digestibility were found to be highly influenced by different processing methods, and the processing could increase the absorbable small intestine protein concentration of rice bran. The degraded protein balance and the predicted absorbable small intestine protein (ASIP) values using the NRC-2001 model were consistent with those using the DVE/OEB system, which had better predicted function in ASIP concentration of rice bran.

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