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Modeling Nutrient Supply to Ruminants: Frost-damaged Wheat vs. Normal Wheat

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ABSTRACT : The objectives of this study were to use the NRC-2001 model and DVE/OEB system to model potential nutrient supply to ruminants and to compare frost damaged (also called "frozen") wheat with normal wheat. Quantitative predictions were made in terms of: i) Truly absorbed rumen synthesized microbial protein in the small intestine; ii) Truly absorbed rumen undegraded feed protein in the small intestine; iii) Endogenous protein in the digestive tract, iv). Total truly absorbed protein in the small intestine; and v). Protein degraded balance. The overall yield losses of the frozen wheat were 24%. Results showed that using the DVE/OEB system to predict the potential nutrient supply, the frozen wheat had similar truly absorbed rumen synthesized microbial protein (65 vs. 66 g/kg DM; $p>0.05$), tended to have lower truly absorbed rumen undegraded feed protein (39 vs. 53 g/kg DM; $p<0.10$) and had higher endogenous protein (14 vs. 9 g/kg DM; $p<0.05$). Total truly absorbed protein in the small intestine was significantly lower (89 vs. 110 g/kg DM, $p<0.05$) in the frozen wheat. The protein degraded balance was similar and both were negative (-2 vs. -1 g/kg DM). Using the NRC-2001 model to predict the potential nutrient supply, the frozen wheat also had similar truly absorbed rumen synthesized microbial protein (average 56 g/kg DM; $p>0.05$), tended to have lower truly absorbed rumen undegraded feed protein (35 vs. 48, g/kg DM; $p<0.10$) and had similar endogenous protein (average 4 g/kg DM; $p>0.05$). Total truly absorbed protein in the small intestine was significantly lower (95 vs. 108 g/kg DM, $p<0.05$) in the frozen wheat. The protein degraded balance was not significantly different and both were negative (-16 vs. -19 g/kg DM). In conclusion, both models predict lower protein value and negative protein degraded balance in the frozen wheat. The frost damage to the wheat reduced nutrient content and availability and thus reduced nutrient supply to ruminants by around 12 to 19%. (**Key Words :** Frost Damaged Wheat, Modeling, Nutrient Supply, Ruminants)

INTRODUCTION

Wheat has an attractive energy and protein content. It is high in starch (ca. 60%). In western Canada, wheat is the primary cereal grain grown for export and as a main ingredient of foods for human consumption. Wheat usually has a high rumen degradation rate (19%/h) (NRC, 2001) and a high effective degradability (>700 g/kg DM). This may result in digestive disorders, bloat and acidosis (Ørskov et al., 1979; Givens et al., 1993) when feeding wheat-based concentrate diets. In Canada, frost damage to wheat is common. In year 2004 alone, more than 50% of wheat was frost damaged (called "frozen") in Canada, rendering millions of tonnes of wheat to be unsuitable for human consumption (Vern Racz, Director of Prairie Feed Resource Center, personal contact). There is an urgent need for the feed, crop, and livestock industries to fully assess the nutritive value of the frozen wheat, not only chemical characterization but also nutritive characterization in animals. The detailed chemical profile differences between the frost-damaged and normal wheat will be published soon in Yu et al. (2008). So far, little research has been conducted to systematically determine the magnitude of the differences in potential nutrient supply between the frozen wheat and normal wheat.

To quantitatively predict nutrient supply, both in the rumen and intestines, several sophisticated models exist. Modern protein evaluation systems, the DVE/OEB system (Tamminga et al., 1994) and the NRC-2001 model (NRC, 2001), have been developed based on principles in the existing models or protein evaluation systems (INRA, 1978; ARC, 1984; Madsen, 1985; NKJ-NJF, 1985; NRC, 1985; Verité and Geay, 1987; Varhegyi et al., 1998). These two

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List of abbreviations

ADF	Acid detergent fiber
ADICP	Acid detergent insoluble crude protein
ADL	Acid detergent lignin
AECP	Truly absorbed rumen endogenous protein in the small intestine (g/kg DM) (NRC, 2001)
AMCP	Truly absorbed microbial protein in the small intestine
ARUP	Truly absorbed rumen undegraded protein in the small intestine
CFat	Crude fat
CP	Crude protein
DM	Dry matter
DOM	Digestive OM
DVE	Truly digested protein in the small intestine (DVE/OEB system)
ECP	Rumen endogenous protein (NRC, 2001)
E_MCP	Microbial protein synthesized in the rumen based on available energy
ENDP	Endogenous protein in the small intestine
FOM	Fermented organic matter
Kd	The rate of degradation
MCP_{RDP}	Microbial protein synthesized in the rumen based on RDP
MCP_{TDN}	Microbial protein synthesized in the rumen based on discounted TDN (NRC, 2001)
MP	Metabolizable protein (NRC, 2001)
NDF	Neutral detergent fiber
NDICP	Neutral detergent insoluble crude protein
N_MCP	Microbial protein synthesized in the rumen based on available nitrogen (g/kg DM)
OEB	Protein degraded balance (DVE/OEB system)
PDB	Protein degraded balance (NRC, 2001)
RDDM	Rumen degraded dry matter
RDP	Rumen degraded feed protein
RDST	Rumen degraded feed starch
RUDM	Rumen undegraded dry matter
RUP^{DVE}	Rumen undegraded feed protein calculated the DVE/OEB system
RUP^{NRC}	Rumen undegraded feed protein calculated the NRC-2001 model
RUST	Rumen undegraded feed starch
ST	Starch
TPSI	True protein supplied to the small intestine
UDM	Undigestive DM

models consider the strong elements of other developed protein evaluation systems and introduce new elements, such as the role of energy balance in intestinal protein supply (Tamminga et al., 1994). Although the principles of these two models are similar, some of the factors used in quantifying calculations and some concepts differ (Tamminga et al., 1994; Yu et al., 2003). The NRC-2001 model is a TDN-based model but the DVE/OEB system is a non-TDN based model. The detailed comparison between these two models has been published (Yu et al., 2003a; Yu, 2005).

The objectives of this study was to use both the DVE/OEB system (Tamminga et al., 1994) and NRC-2001 model (NRC, 2001) to systematically determine the magnitude of the differences in potentially nutrient supply to ruminants between the frozen wheat and the normal wheat.

MATERIALS AND METHODS

Frost damaged and normal wheat (AC Barrie)

The normal wheat (cv. *AC Barrie*; 3 samples) and frost damaged wheat samples (2 samples, with 24% of overall weight losses) were provided by Crop Development Center (CDC) and Prairie Feed Resource Center (PFRC), University of Saskatchewan, Canada.

Animals and diets

Three dry Holstein-Friesian cows fitted with large rumen cannulas with an internal diameter of 10 cm were housed in tie stalls and bedded with straw at the dairy experimental station of the University of Saskatchewan. Each cow received daily 15-kg TMR, consisting of 27.5% pelleted concentrate, 55% barley silage, 12.5% alfalfa hay, and 5% dehydrated alfalfa. The diets were formulated to meet dairy cow maintenance requirement (NRC, 2001). All cows were individually fed twice daily at 0800 and 1600 h. Water was always available. Cows had free access to exercise grounds. The animals used in the experiment were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

In situ rumen incubation

Ruminal degradation characteristics were determined using the *in situ* method (Yu et al., 2003). The samples were ground through a 3-mm screen. Incubation of all treatments in the rumen was with 7 g DM in each number-coded nylon bag (10×20 cm) with the pore size of ca. 40 μm. These bags were tied about 2 cm below the top, allowing a ratio of sample size to bag surface area of 28 mg/cm^2. The rumen incubations were performed according to the 'gradual addition/all out' schedule (the bags were inserted sequentially and retrieved at the same time). Samples were incubated in the rumens for 24, 12, 8, 4, 2 and 0 h. After incubation, the bags were removed from rumen and rinsed under a cold stream of tap water to remove excess ruminal contents and to stop microbial activity. The bags were washed with cool water without detergent by hand and subsequently dried at 55°C for 48 h. The 0 h incubation samples were only washed under the same conditions. The residues were pooled according to treatments and incubation times and then ground through a 1-mm screen

(Retsch ZM-1, Brinkmann Instruments (Canada) LTD, Ontario) for chemical analysis.

Chemical analysis

The dry matter (DM) (AOAC official method 930.15), ash (AOAC official method 942.05), crude fat (Cfat) (AOAC official method 954.02) and crude protein (CP) (AOAC official method 984.13) contents were analyzed according to the procedure of AOAC (1990). The starch was analyzed using the Megazyme Total Starch Assay Kit (Megazyme International Ireland Ltd., Ireland). The acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) values were analyzed according to the procedures of Van Soest et al. (1991). Neutral detergent fiber was determined without sodium sulfite (Van Soest et al., 1991). The acid detergent insoluble N (ADIN) and neutral detergent insoluble N (NDIN) values were determined according to the procedures of Licitra et al. (1996).

Using the DVE/OEB system to predict potential nutrient supply

The detailed concepts and formulas of the DVE/OEB system are provided by Tamminga and Jansman (1993) and Tamminga et al. (1994). The following are brief explanations of the prediction of protein supply to the small intestine of dairy cows (Yu et al., 1999) as a result of feeding the above concentrates frost-damaged wheat.

Calculation of FOM and RUP^{DEV} : Ruminally undegraded feed protein (RUP^{DEV}) was calculated as: RUP^{DEV} (g/kg DM) = 1.11×CP×%RUP. Where, %RUP = U+D×Kp/(Kp+Kd), the passage rate (Kp) of 6%/h was adopted (Tamminga et al., 1994). The content of organic matter fermented in the rumen (FOM) was estimated from digestible organic matter subtracted ether extract (EE), RUP^{DEV}, ruminally undegraded feed starch (RUST) and fermentation products (assumed to be zero for concentrate feedstuffs) (FOM = DOM-CFat-RUP-RUST-FP) (Tamminga et al., 1994).

Microbial protein synthesis in the rumen based on available energy : Microbial protein synthesized in the rumen (E_MCP) was estimated as 15% of the rumen fermented organic matter (FOM). Of the microbial protein, 75% was added to the undegraded feed protein (RUP^{DEV}) to estimate the true protein supplied to the small intestine (TPSI). The remaining 25% represented N in nucleic acids.

Intestinal digestion of feed and microbial protein : The previously discussed RUP^{DEV} and TPSI must be corrected for incomplete digestion and endogenous secretions (Tamminga et al., 1994). A correction is needed for protein losses due to incomplete digestion and from endogenous secretions. True digestibility of microbial protein is assumed to be 85% (Egan et al., 1985) and therefore the amount of truly absorbed rumen synthesized microbial protein in the small intestine (AMCP) was estimated as: AMCP = 0.85×0.75×E_MCP. For feed ingredients, the content of truly absorbed rumen undegraded feed protein in the small intestine (ARUP) was calculated as: ARUP = dRUP×RUP^{DVE}.

Endogenous protein losses in the small intestine : Endogenous protein losses in the digestive tract (ENDP) are related to the amount of undigested DM (UDM) excreted in the faeces, calculated as: ENDP = 0.075×UDM, where, UDM was calculated as undigested organic matter (UOM) plus undigested ash (UASH).

Truly digested and absorbed protein in the small intestine : Truly digested and absorbed protein in the small intestine (DVE value) are contributed by i) feed protein escaping rumen degradation (RUP^{DVE}), ii) microbial protein synthesized in the rumen (E_MCP), and iii) a correction for endogenous protein losses in the digestive tract (ENDP). Therefore the DVE value was estimated as: DVE = ARUP+AMCP-ENDP.

Degraded protein balance : The degraded protein balance (OEB value) is the balance between microbial protein synthesis from rumen degradable protein and that from the energy extracted during anaerobic fermentation in the rumen. Therefore the OEB value was estimated as: N_MCP - E_MCP, where, N_MCP = CP-1.11×RUP.

Using the NRC-2001 model to predict potential nutrient supply

The detailed concepts and formulas are provided by NRC (2001). A brief explanation is as follows:

Calculation of RDP^{NRC} and RUP^{NR} : Ruminally undegraded feed protein was calculated as: RUP^{NRC} = CP×RUP. Ruminally degraded feed protein was calculated as: RDP = CP×RDP, where, RDP was calculated as: RDP = S+D×Kd/(Kp+Kd), where, Kp of 6%/h was adopted.

Rumen microbial protein synthesis : Ruminally synthesized microbial protein was calculated as: MCP = 0.13×TDN, when RDP exceeded 1.18×TDN-predicted MCP (MCP_{TDN}). When RDP was less than 1.18×TDN-predicted MCP (MCP_{TDN}), then MCP was calculated as 0.85 of RDP (MCP_{RDP}).

Intestinal digestion pf feed and microbial protein : Digestibility and true protein of ruminally synthesized microbial protein are assumed to be 80%, therefore the amount of truly absorbed MCP was estimated as: AMCP = 0.80×0.80×MCP.

For feed ingredients, truly absorbed rumen undegraded feed protein in the small intestine (ARUP) was calculated as: ARUP = dRUP×RUP^{NRC}.

Rumen endogenous protein in the small intestine : Rumen endogenous CP was calculated as: ECP = 6.25×1.9

×DM/1,000 (where, DM in g/kg). Assuming that 50% of rumen endogenous CP passes to the duodenum and 80% of rumen endogenous CP is true protein, therefore the truly absorbed endogenous protein in the small intestine (AECP) was estimated as: AECP = 0.50×0.80×ECP.

Total metabolizable protein : Metabolizable protein is contributed by i) digestible RUP^{NRC}, ii) digestible MCP^{NRC}, and iii) ECP, calculated as: MP = ARUP+AMCP+AECP.

Degraded protein balance : The degraded protein balance (DPB) reflects the difference between the potential microbial protein synthesis based on ruminally degraded feed crude protein (RDP^{NRC}) and that based on 1.18 times of energy (TDN) available for microbial fermentation in the rumen, calculated as: DPB = RDP-1.18MCP_{TDN}.

Statistical analysis

Statistical analyses were performed using the Mixed Model procedure of SAS (1999) by generalized least squares analysis (GLSA) with a CRD model. Significance was declared at $p<0.05$.

RESULTS AND DISCUSSION

Chemical and nutritive characterization of the normal and frozen wheat

Table 1 shows the chemical composition of the normal wheat and frozen wheat. The detailed chemical profile, energy values, CNCPS protein and carbohydrate subfractions, and *in situ* degradation kinetics of the frost-damaged and normal wheat will be published in Yu et al. (2008). Briefly, frozen wheat had similar chemical composition in DM and ash to the normal wheat. However, the frozen wheat was lower ($p<0.05$) in starch (47 vs. 62% DM), but higher in ADF (6 vs. 2% DM), NDF (22 vs.11% DM), lignin (ADL: 2 vs. 1% DM), ADICP (3 vs. 1% CP) and NDICP (19 vs. 14% CP) than the normal wheat. Bushel weight for the frozen wheat was 17.5 kg per bushel, compared with 23.1 kg per bushel of the normal wheat. Cromey et al. (1998) reported that frost caused overall yield losses between 13 and 33% in affected crops. Grains were sectioned and examined with a scanning electron microscope. Whereas in healthy grains, the layers making up the pericarp and testa were compressed, in the frost damaged these layers comprised loosely compressed and unstructured network of cells (Cromey et al., 1998). The aleurone layer was less ordered in frost damaged than in normal grains, and was not always readily distinguished from the starchy endosperm. Generally, most of the chemical compositions of the normal wheat in this study are close to tabular values in NRC (2001). The frost caused wheat to be lower in starch content and higher in crude fat (or ether extract), ADF, NDF, ADL, ADICP and NDICP.

The effects of the frost on rumen degradation kinetics of DM and CP (Ørskov and McDonald, 1979) and starch (Tamminga et al., 1994) are shown in Table 1. The *in situ* results showed that the frozen wheat was not different ($p>0.05$) in Kd, RUDM (average: 263 g/kg) and RDDM (average: 736 g/kg), in comparison to the normal wheat.

Table 1. Comparison of normal wheat with frost damaged wheat in chemical composition, overall weight losses and degradation kinetics

Items	Wheat		SEM	p value
	Normal	Frost damaged (called "Frozen")		
Basic chemical composition				
DM (%)	89.92	87.89	1.08	0.2752
Ash (% DM)	2.05	1.98	0.07	0.4854
CFat (% DM)	1.88[b]	2.68[a]	0.11	0.9581
CP (% DM)	16.30	15.89	0.90	0.7671
ST (% DM)	61.59[a]	47.29[b]	1.93	0.0135
ADF (% DM)	2.44[b]	5.52[a]	0.24	0.0028
NDF (% DM)	10.90[b]	22.49[a]	0.80	0.0020
ADL (% DM)	0.77[b]	1.62[a]	0.05	0.0010
ADICP (% DM)	0.13[b]	0.44[a]	0.02	0.0012
NDICP (% DM)	2.30	3.09	0.27	0.1291
Overall weight losses (%)				
Kg/bushel	23.1	17.5	-	-
Weight loss (%)	-	24	-	-
Rumen degradation kinetics of dry matter (DM), crude protein (CP) and starch (ST)				
KdDM (%/h)	23.03	35.9	4.89	0.1594
RUDM (%)	27.6	25.7	1.31	0.3828
KdCP (%/h)	10.34	19.04	4.59	0.2731
RUP (%)	33.1	28.0	2.94	0.3090
KdST (%/h)	32.39	45.11	3.03	0.0594
RUST (%)	14.9	11.6	0.74	0.0506

For the abbreviations see the List of Abbreviations; Data source used for prediction of nutrient supply from Yu and Racz (2009)

Similar differences were found for CP degradation kinetic. The frozen wheat was not different ($p>0.05$) in Kd, RUP (average: 487 g/kg DM) and RDP (average: 103 g/kg DM), in comparison to the normal wheat. However, for starch degradation characteristics (Table 1), the frozen wheat tended to be higher ($p<0.10$) in Kd (45 vs. 32%/h) and lower in RUST (52 vs. 91 g/kg DM and RDST (401 vs. 518 g/kg DM) in comparison to the normal wheat. The above results indicated that i) normal wheat has very higher rumen degradable starch and protein and contain less sources of rumen undegradable CP and starch; ii) the frost changed rumen degradation characteristics of wheat, but each component of wheat affected by the frost was different. The frost caused the changes of degradation kinetics mainly in starch.

Prediction of potential nutrient supply from the normal and frozen wheat: Most mammals can only metabolize dietary protein as amino acids or peptides absorbed from the small intestine. In ruminants, the relationship is somewhat more complicated. As such sophisticated models have been developed for dairy cows, such as PDI, ARC, NJK-NJF, AAT-PVB, AP, ADPLS and MF. Based on principles in existing protein evaluation systems, modern protein evaluation systems: the DVE/OEB system (Tamminga et al., 1994) and NRC-2001 dairy model (NRC, 2001) have been developed. These two models consider the strong elements of other recently developed protein evaluation systems and they also introduce new elements, such as the role of energy balance in intestinal protein supply. In the DVE/OEB system, the protein value for feeds and the requirements for dairy cows are both expressed as the amount of protein (microbial and feed source) truly digested in and absorbed from the small intestine of the animal. This system can give information on the quantitative aspects of both ruminal and post-ruminal protein digestion in ruminants. In the DVE/OEB system, each feed has a DVE value, which stands for true absorbable protein in the small intestine, composed of: i) digestible feed true protein escaping rumen degradation; ii) digestible true microbial protein synthesized in the rumen, and iii) a correction for endogenous protein losses in the digestive tract. Each feed also has a rumen degraded protein balance value, called OEB in Dutch, which shows the (im)balance between microbial protein synthesis potentially possible from available rumen degradable protein and that potentially possible from the energy extracted during anaerobic fermentation in the rumen. When OEB is positive, it indicates the potential loss of N from the rumen. When negative, microbial protein synthesis may be impaired because of a shortage of N in the rumen. The optimum OEB value in a ration is therefore zero or slightly above (Tamminga et al., 1994). The NRC dairy model (2001) introduced the concepts of metabolizable protein (MP), defined as true protein that is digested and absorbed by the intestine, and contributed by i) ruminally undegraded feed CP, ii) ruminally synthesized microbial CP, and iii) endogenous CP from rumen. Based on the data from NRC dairy model (NRC, 2001), the rumen protein degradation balance can be calculated and it reflects the difference between the potential microbial protein syntheses based on ruminally degraded feed CP and that based on TDN as energy available for microbial fermentation in the rumen. Although the principles of these two models are similar, some of the factors used in quantifying calculations and some concepts differ. The differences in prediction of nutrient supply between the two models have been reported (Yu et al., 2003; Yu, 2005).

Prediction of the potential nutrient supply to dairy cattle from the wheat as affected by frost using the DVE/OEB system is shown in Table 2. No difference was found between the frozen and normal wheat in FOM, E_MCP, TPSI, and AMCP with average of 681, 102, 125 and 65 g/kg DM. However, the frozen wheat tended to be lower in ARUP (39 vs. 53 g/kg DM, $p<0.10$) and was significantly higher ($p<0.05$) in UDM from the normal wheat. Therefore, ENDP in the frozen wheat was higher ($p<0.05$) than that in the normal wheat. Total DVE value in the frozen wheat was lower ($p<0.05$) than the normal wheat. All wheat had negative OEB values (-6.1 vs. -2.4). Our results showed that although the frozen wheat had similar absorbed rumen undegraded feed protein in the small intestine (ARUP) and similar absorbed microbial CP (AMCP) (due to similar fermented OM), it had higher endogenous protein loss (14 vs. 9 g/kg DM) in digestive tract due to higher undigestible DM in the frozen wheat. Therefore, total nutrient supply of the DVE value (DVE = AMCP+ARUP-ENDP) was different between the frozen and normal wheat (89 vs. 110 g/kg DM). The frost reduced about 19% protein DVE value.

The OEB value (OEB = N_MCP-E_MCP) shows the (im)balance between microbial protein synthesis from available rumen degradable CP and potential energy extracted from anaerobic fermentation in the rumen. The optimum OEB value in a ration is therefore zero or slightly above (Tamminga et al., 1994). The margin for safety is to allow for asynchrony- a factor important in feeding supplements to grazing animal or feeding an ingredient separately of the main basal feed. The present study showed that both the frozen and normal wheat had negative OEB values, which indicates an imbalance between feed N degradation and utilization and indicates a potential shortage of N in the rumen.

Table 3 shows the results of using the NRC dairy model -TDN based model (2001) to predict the potential nutrient supply of total metabolizable protein (MP) to dairy cattle from wheat as affected by frost. The frozen wheat was not

Table 2. Comparison of normal wheat with frozen wheat in prediction of the potential nutrient supply (e.g. AMCP, ARUP, ENDP, DVE and OEB) to dairy cattle from wheat, using the DVE/OEB system

Items	Wheat		SEM	p value
	Normal	Frost damaged (called "Frozen")		
Using the DVE/OEB system to predict of the potential nutrient supply				
Truly absorbed rumen synthesized microbial protein in the small intestine (g/kg DM)				
FOM	694.1	675.4	14.20	0.4207
E_MCP (based on FOM)	104.1	101.3	2.13	0.4215
TPSI	135.0	120.6	4.22	0.0946
RDP	98.0	98.9	5.81	0.9193
N_MCP (Based on RDP)	98.0	98.9	5.81	0.9193
AMCP	66.4	64.6	1.36	0.4214
Truly absorbed rumen undegraded feed protein in the small intestine (g/kg DM)				
RUP^{DVE}	56.9	44.6	4.90	0.1740
dRUP (%)	93.0	86.8	1.55	0.0692
ARUP	52.7	38.7	4.11	0.0943
Endogenous protein losses in the digestive tract (g/kg DM)				
DOM	861.2^{a}	799.1^{b}	13.77	0.0498
UDM	116.5^{b}	188.1^{a}	13.78	0.0350
ENDP	8.7^{b}	14.1^{a}	1.03	0.0350
Total truly absorbed protein in the small intestine (g/kg DM)				
DVE (= AMCP+ARUP-ENDP)	110.3^{a}	89.1^{b}	4.21	0.0377
Protein degraded balance (OEB, g/kg DM)				
OEB	-6.1	-2.4	3.91	0.5506

For the abbreviations see the List of Abbreviation; Means with the same letter in the same raw are not significantly different ($p>0.05$).
SEM = Standard error of mean.

Table 3. Comparison of normal wheat with frozen wheat in prediction of the potential nutrient supply (e.g. AMCP, ARUP, AECP, MP, PDB) to dairy cattle from wheat, using the NRC-2001 dairy model

Items	Wheat		SEM	p value
	Normal	Frost damaged (called "Frozen")		
Using the NRC-2001 dairy model to predict of the potential nutrient supply				
Truly absorbed rumen synthesized microbial protein in the small intestine (g/kg DM)				
MCP_{RDP} (based on RDP)	88.1	87.8	4.61	0.9699
MCP_{TDN} (based on TDN)	103.6	100.9	-	-
MCP	88.1	87.8	4.61	0.9699
AMCP	56.4	56.2	2.95	0.9696
Truly absorbed rumen undegraded feed protein in the small intestine (g/kg DM)				
RUP^{NRC}	51.3	40.2	4.42	0.1739
ARUP	47.5	34.8	3.71	0.0944
Endogenous protein in the digestive tract (g/kg DM)				
ECP	10.7	10.8	-	-
AECP	4.3	4.3	-	-
Total truly absorbed protein in the small intestine (g/kg DM)				
MP (= AMP+ARUP+AECP)	108.1^{a}	95.3^{b}	2.73	0.0454
Protein degraded balance (PDB, g/kg DM)				
PDB	-18.6	-15.8	5.47	0.7375

For the abbreviations see the List of Abbreviation; Means with the same letter in the same raw are not significantly different ($p>0.05$).
SEM = Standard error of mean.

significantly different from the normal wheat in AMCP and AECP, but tended to be significant in ARUP ($p<0.10$). However, total MP value in the frozen wheat was significantly lower ($p<0.05$) from the normal wheat (95 vs. 108 g/kg DM, $p<0.05$). The frost reduced about 12% protein MP value. The results showed that using the NRC model (2001), one could detect the difference of potential nutrient supply to dairy cows between the frozen and normal wheat. Again the protein degraded balance (PDB = $EDCP-1.18MCP_{TDN}$) in both wheat was negative, compared with prediction from the DVE/OEB model, indicating a potentially higher shortage of N in the rumen. Model-

predicted results showed that potential nutrient supply of wheat to ruminants was highly associated with the weather. In general, the frost significantly reduced the potential nutrient supply to dairy cattle.

CONCLUSIONS

It was concluded that the frozen wheat differed in chemical characterization. Total truly digestive protein in the small intestine (DVE or MP value) was lower in frozen wheat. Both the frozen and normal wheat had negative protein degradation balance, indicating the potential imbalance between microbial protein synthesis from available rumen degradable CP and potential energy from anaerobic fermentation in the rumen. The frost caused significantly the decrease of the nutrient contents and availability in wheat grain and thus reduced nutrient supply to ruminants around 12 to 19%.

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