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Effects of Electron Beam Irradiation on Ruminal NDF and ADF Degradation Characteristics of Barley Straw

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Abstract: Samples of barley straw were irradiated with various doses of electron beam (100, 200 and 300 kGy) to evaluate the effects of electron beam irradiation on Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) degradation. Nylon bags of untreated or irradiated barley straw were suspended in the rumen of three Taleshi bulls for up to 962 h and resulting data were fitted to non-linear degradation model to calculate degradation parameters of NDF and ADF. Results showed that the washout fractions (a) and the potentially degradable fraction (b) of NDF and ADF of barley straw increased linearly ($p<0.001$) as irradiation dose increased. The degradation rate of the b fraction of NDF of barley straw decreased as irradiation dose increased (linear effect, $p<0.001$), but this fraction in ADF of samples was the highest at dose of 100 kGy. Effective degradability of NDF and ADF of samples increased linearly ($p<0.001$) with increasing irradiation dose. Electron beam irradiation at doses of 100, 200 and 300 kGy increased the effective degradability of NDF and ADF at rumen outflow rate of 0.05 h^{-1} by about 3, 4 and 5% for NDF and 3, 6 and 8% for ADF, respectively. In the condition of this study, electron beam irradiation at dose of 200 kGy appeared to be a suitable dose for improving NDF and ADF degradability of barley straw in the rumen.

Key words: Barley straw, electron beam irradiation, NDF, ADF

INTRODUCTION

The cereals such as barley extensively cultivated for grain production which generate large amounts of straw with a high cell wall content of poor digestibility. In order to avail these by-products for ruminant nutrition, different techniques have been proposed to increase its nutritive value. Chemical agents such as ammonia, sodium hydroxide or urea was used to breakdown the lignocellulose materials of roughages or to solubilize the hemicellulose (Van Soest *et al*., 1984; Mason *et al*., 1988), but their effects on animal health and environmental pollution limited them. Gamma and electron beam irradiation, without adverse effects, have been used to decrease cell wall constituents (Al-Masri and Zarkawi, 1994) or depolymerize and delignify the fiber (Sandev and Karaivanov, 1977) of agricultural by-products.

Therefore, the purpose of this study was to find out possible drastic change of cell wall components on electron beam treated samples for better ruminant digestion of barley straw.

MATERIALS AND METHODS

Sample preparation and irradiation treatment: Substrate used was barley straw. Barley straw was collected from fields at the Kerman-shah Branch, Islamic Azad University. The TT_{200} Rhodotron accelerator of was used for irradiation treatments of samples. The irradiation was accomplished in Yazd irradiation processing center (Atomic Energy Organization of Iran). All samples were irradiated at a fixed beam energy of 10 MeV (Edward and Kukiela, 2002; Kuczumow *et al*., 1999) and the required irradiation doses were obtained by adjusting the electron

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beam parameters (electron beam current, conveyor speed and etc). Three polyethylene packages of samples were electron beam irradiated at doses of 100, 200 and 300 kGy in the presence of air.

Animals and diets: Three Taleshi bulls with an average live weight of 400 kg fitted with rumen fistulas were placed in individual pens (3.4 × 4.9 m) with concrete floors that were cleaned regularly. Bulls were fed 8 kg dry matter; a total mixed ration containing 700 g kg^{-1} of dry matter of high quality alfalfa hay and 300 g kg^{-1} of dry matter concentrate. The concentrate consisted of ground barley, soybean meal, cottonseed meal, wheat bran, salt, dicalcium phosphate and vitamin + mineral premix (500, 160, 100, 210, 10, 10 and 10 g kg^{-1} dry matter, respectively). Diet was fed twice daily at 08:00 and 15:00 h.

***In sacco* ruminal degradability**: Nylon bags (9×21 cm) with a pore size of 46 μm were filled with approximately 4.5 g of untreated or irradiated wheat straw samples ground to pass 3 mm screen. All bags were simultaneously placed in the rumen, just before the animals were offered their first meal in the morning (i.e., 08:00 h). Bags were incubated in the rumen for periods of 0, 6, 12, 24, 48, 72 and 96 h. After retrieved from the rumen, bags were washed with tap water and stored at -20°C. After thawing, bags were washed 3 times for 5 min in a turbine washing machine. The same procedure was applied to 2 series of two bags to obtain the 0 h value. Samples were analyzed for NDF and ADF by the Van Soest (1982) procedure.

Statistical analysis: Disappearances of dry matter were fitted for each bull to the exponential model of Ørskov and McDonald (1979) as: $p = a+b (1-e^{-ct})$. In this model, the constant a and b represent, respectively, the washout fraction and the non-soluble but degradable component, which disappears at a constant fractional rate c per unit time. The Effective Degradability (ED) was calculated using ERD = a + bc/(c + k), estimated outflow rates (k) of 0.02, 0.05 and 0.08 h (AFRC, 1993). Data were analyzed using the general linear models procedure of SAS (1996) with the following statistical model of Yijk = μ + Ti + Bj + eijk, where Y in the dependent variable, μ the overall mean, Ti the electron beam effect, Bj the animal effect and eijk, is the residual error, assumed normally and independently distributed. Differences among treatments were separated using polynomial orthogonal contrasts to determine linear, quadratic and cubic responses. The means comparative of treatments was accomplished with using of Duncan's multiple range tests (Steel and Torrie, 1980).

RESULTS

The results of ruminal NDF and ADF disappearance of barley straw at different incubation times indicated that the percent of NDF and ADF disappearance at different incubation time increased as irradiation dose increased (Table 1, 2). The highest ($p<0.05$) disappearance rate was for barley straw samples exposed to 200 and 300 kGy electron beam irradiation doses.

Ruminal degradability parameters of NDF and ADF of untreated and electron irradiated the experimental feeds showed that the increasing electron beam irradiation dose, increased the washout fraction (a) and the potentially degradable fraction (b) of NDF and ADF (linear effect, $p<0.001$). The degradation rate of the b fraction of NDF of (linear effect, $p<0.001$) barley straw decreased as irradiation dose increased (linear effect, $p<0.001$) (Table 3). The degradation rate of the b fraction of ADF of

Table 1: Results of means comparatives of %NDF disappearance of barley straw with Duncans multiple range test

	Ruminal incubation periods (hour)						
Irradiation dose	0	6	12	24	48	72	96
Untrated	1.42^{c}	3.63^{c}	5.8^{d}	10.65^{c}	16.49^{d}	17.18^{d}	18.78^{d}
100 kGy	2.75^{b}	5.18^{b}	7.69^{c}	13.77^{b}	19.87^{c}	20.84^{c}	21.72^{c}
200 kGy	3.8^{a}	6.69^{a}	9.45^{b}	15.34^{a}	21.8^{b}	23.87^{b}	24.7^{b}
300kGy	3.87^{a}	6.86^{a}	10.43^{a}	15.55^{a}	23.89^{a}	25.53^{a}	27.38^{a}
SEM	0.099	0.143	0.179	0.248	0.129	0.107	0.119

Means with the different superscripts within column are differ ($p<0.05$)

Table 2: Results of means comparatives of % ADF disappearance of barley straw with Duncans multiple range test

	Ruminal incubation periods (hour)						
Irradiation dose	0	6	12	24	48	72	96
Untrated	3.42^{d}	7.31^{c}	14.35^{d}	24.7^{d}	30.71^{d}	33.74^{a}	35.27^{d}
100 kGy	4.48^{c}	10.32^{b}	18.5^{c}	27.2^{c}	34.7^{c}	36.71^{b}	37.94^{c}
200 kGy	7.38^{b}	12.48^{a}	20.62^{b}	31.38^{b}	40.4^{b}	43.39^{c}	45.31^{b}
300kGy	8.26^{a}	12.51^{a}	21.4^{a}	34.52^{a}	44.42^{a}	45.48^{d}	47.24^{a}
SEM	0.227	0.243	0.37	0.182	0.607	0.228	0.45

Means with the different superscripts within column are differ ($p<0.05$)

Table 3: Rumen degradation parameters of NDF of untreated and electron irradiated barley straw

		Electron irradiated barley straw				Contrasts		
Parameters	Untreated barley straw	100 kGy	200 kGy	300 kGy	SEM	L	Q	C
A	0.83	1.91	3.17	3.28	0.109	***	NS	NS
B	19.15	21.15	23.23	26.12	0.124	***	NS	NS
a + b	43.87	72.14	77.53	76.48	2.17	***	NS	NS
c (/h)	0.03	0.033	0.030	0.027	0.0004	**	***	NS
Effective rumen degradation								
0.02 /h	12.28	15.06	17.19	18.51	0.129	***	NS	NS
0.05 /h	7.97	10.3	11.96	12.65	0.145	***	NS	NS
0.08 /h	6.02	8.07	9.57	10.05	0.141	***	NS	NS

SEM: standard error of the means; L, linear contrast; Q, quadratic contrast; C, cubic contrast; Significance: NS, not significant; * $p<0.05$; ** $p<0.01$; ***$p<0.001$ a, the washout fraction, b, the potentially degradable fraction and c the rate of degradation

Table 4: Rumen degradation parameters of ADF of untreated and electron irradiated barley straw

		Electron irradiated barley straw				Contrasts		
Parameters	Untreated barley straw	100 kGy	200 kGy	300 kGy	SEM	L	Q	C
A	2.13	3.67	6.14	6.09	0.262	***	**	NS
B	33.87	34.77	40.29	42.55	0.348	***	NS	NS
a + b	43.87	72.14	77.53	76.48	2.17	***	NS	NS
c (/h)	0.039	0.045	0.038	0.041	0.0014	***	***	NS
Effective rumen degradation								
0.02 /h	24.64	27.74	32.57	34.71	0.148	***	***	NS
0.05 /h	17.11	20.14	23.57	25.27	0.149	***	***	NS
0.08 /h	13.35	16.19	19.15	20.52	0.165	***	***	NS

SEM: standard error of the means; L, linear contrast; Q, quadratic contrast; C, cubic contrast; Significance: NS, not significant; * $p<0.05$; ** $p<0.01$; ***$p<0.001$ a, the washout fraction, b, the potentially degradable fraction and c the rate of degradation.

(linear effect, $p< 0.001$) barley straw was the highest at 100 kGy irradiation dose (Table 4). Effective degradability of NDF and ADF of barley straw linearly increased ($p<0.001$) as irradiation dose increased.

DISCUSSION

Although, processing of agricultural residues with gamma irradiation (Alberti *et al*., 2005; Al-Masri and Zarkawi, 1994) and other physical processes such as grinding (Tassinari *et al*., 1982), steam treatment and chemical pretreatments with sodium hydroxide (Raininko *et al*., 1981) and ammonia have been occurred plentifully, However, irradiation with electron beam has not been still accomplished to improve the nutritive value of the feedstuffs. Irradiation treatment (gamma rays) has been used as a physical method to improve the nutritive value and digestibility of feedstuff due to its effects on the peptide bonds (Shawrang *et al*., 2007) and lignocellulosic bonds (McManus*et al*., 1972; Al-Masri and Zarkawi, 1994).

The organic matter digestibility as a result of gamma irradiation increased for wheat straw with a clear decrease in the crude fiber and NDF content (Yu *et al*., 1975; Bear *et al*., 1980). In a feeding experiment on wether lambs fed with barley straw by a gamma ray dose of 370 kGy dose, disappearance of NDF decreased and dry matter increased (Al-Masri, 1997), significantly. In addition, Pritchard *et al*. (1962) reported that the solubility and digestibility of wheat straw increased by gamma irradiation. Han *et al*. (1981) reported that the dry matter solubility of sugarcane bagasse irradiated with 500 kGy increased significantly. In other experiments, the digestibility of organic matter and dry matter degradability increased in wheat straw, cotton wood, olive cake and apple pruning products after treatment with γ-irradiation (Al-Masri and Guenther, 1993). Shawrang *et al*. (2007) reported that gamma irradiation at dose higher than 50 kGy could increase ruminal dry matter degradability. In their study the effective DM degradability of γ-irradiated Alfalfa at doses of 25, 50 and 75 kGy at rumen outflow rate of 0.05 h^{-1} were 64.35, 64.03 and 69.77%, respectively. McManus and Manta (1972) have indicated that an effect of irradiation on poor-quality roughages (Lucerne straw and rice straw) given to sheep has started from dose of 250 kGy.

Irradiation of cellulose by electron beam leads to modification in its structure. This improvement may be due to several factors such as consequences of reaction of the primary radicals. The breaking of β-bonding of the radicals can leads to the opening of the anhydroglucose ring or breaking down the glucoside bond. In this case, carbonyl groups are produced as a result of the breaking. In cellulose, different types of radicals produced by H atom elimination from a C-H bonding expected (Takacs *et al*., 1999). It has been suggested that lignin is linked to

both hemicellulose and cellulose forming a physical seal around of two compounds that is impenetrable barrier preventing penetration of solutions and enzymes (Arora *et al*., 2002). Therefore, delignification results in changes in cell wall structure beyond the simple removal of lignin and cell content is readily available for rumen microorganisms, so that could cause to increase wheat straw digestibility. The degradation of cellulose and hemicellulose into soluble materials by irradiation treatment leads to the increasing of NDF and ADF degradability of agricultural residues (Banchorndhevakul, 2001). This study suggests that Electron beam irradiation at dose of 200 kGy is suitable dose for breaking down the hydrogenic and covalent crosslinkages between hemicellulose and cellulose, as well as between these 2 polymers with lignin that causes the increasing of NDF and ADF degradation of barley straw in the rumen.

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