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Effects of Electron Beam Irradiation on Dry Matter Degradation of Wheat Straw in the Rumen

[1]H.R. Shahbazi, [1]A.A. Sadeghi, [2]H. Fazaeli, [3]G. Raisali, [1]M. Chamani and [4]P. Shawrang
[1]Department of Animal Science, Faculty of Agriculture,
Science and Research Branch,
Islamic Azad University, P.O. Box 14515-4933, Tehran, Iran
[2]Animal Science Research Institute, Karaj, Iran
[3]Radiation Applications Research School,
Nuclear Science and Technology Research Institute,
Atomic Energy Organization of Iran, Tehran, Iran
[4]Agricultural, Medical and Industrial Research School,
Nuclear Science and Technology Research Institute,
Atomic Energy Organization of Iran, 31485-498, Karaj, Iran

Abstract: The effect of electron beam irradiation at doses of 100, 200 and 300 kGy on ruminal dry matter degradation kinetics of wheat straw was investigated. Samples were irradiated by electron beam irradiator under identical conditions of temperature and humidity. Nylon bags of untreated or irradiated wheat straw were suspended in the rumen of three Taleshi steers for up to 96 h and resulting data were fitted to non-linear degradation model to calculate degradation parameters of dry matter. Results show that the washout fractions of dry matter increased linearly ($p<0.001$), but potentially degradable fraction and degradation rate decreased linearly ($p<0.001$) by electron beam irradiation. As a consequence, the effective degradability of dry matter 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 dry matter at rumen outflow rate of 0.05/h by about 7, 15 and 18%, respectively. In the condition of this study, electron beam irradiation at dose of 200 kGy appeared to be a suitable dose for improving dry matter degradability of wheat straw in the rumen.

Key words: Wheat straw, electron beam irradiation, dry matter degradability

INTRODUCTION

The huge production of the high fiber materials represents an excellent potential resource for increasing ruminant production in under-developing countries. The limitation for introducing this cheap source of feedstuffs into animal diets is the presence of lignocellolosic materials which have low digestibility (Al-Masri and Zarkawi, 1994). Physical and chemical processing methods have been used to improve ruminal digestibility of these materials. Processing such as grinding, steam treatment, irradiation, sodium hydroxide, ammonia and biological applications have been used to breakdown the lignocellulosic materials of agricultural residues and to improve their nutritive value (Yu *et al*., 1975; Brownell and Saddler, 1987; Al-Masri and Zarkawi, 1994; Banchorndhevakul, 2002; Arora *et al*., 2002; Jafari *et al*., 2007; Sadeghi and Shawrang, 2007a, b). The application of irradiation on dry matter and cell-wall constituents of some agricultural residues has been reported in the literature (Al-Masri and Zarkawi, 1994). In cellulose industry, the effects of gamma and electron beam irradiation on degradation of cellulose were widely investigated in the past mainly with the aim of enhancing the enzymatic hydrolysis (Takacs and Wojnarouits, 1999; Kuczumow *et al*., 1999). Recently, Sadeghi and Shawrang (2007a, b) reported that electron beam irradiation is effective on ruminal degradation of cell wall constituents of straws and sugarcane bagasse.

Corresponding Author: H.R. Shahbazi, Department of Animal Science, Faculty of Agriculture,
Science and Research Branch, Islamic Azad University, P.O. Box 14515-4933, Tehran, Iran
Tel: +98 912 660-2719 Fax: +98 21 4480-4180

As far as we know, there is limited information concerning effects of electron beam irradiation on ruminal degradation kinetics of cereal straws used in ruminant nutrition. Therefore, our purpose of this study was to investigate the effect of electron beam irradiation on ruminal dry matter disappearance characteristics and degradability parameters of wheat straw.

MATERIALS AND METHODS

Sample preparation and irradiation treatments: This study was conducted from December 2006 to June 2007. The wheat straw samples were collected from five farms in Kerman-shah province of Iran. Samples were mixed and air dried for 48 h and stored in seal plastic bags. The dry matter of wheat straw was determined in an oven at 105°C for 24 h before of the irradiation treatments. The TT_{200} Rhodotron accelerator was used for irradiation treatments of samples. The irradiation was accomplished in the Yazd irradiation processing center (Atomic Energy Organization of Iran). All samples were irradiated at a fixed beam energy of 10 MeV (Kuczumow *et al*., 1999; Iller and Kukielka, 2002) and the required irradiation doses were obtained by adjusting the electron 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 steers 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. Steers 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 three times for 5 min in a turbine washing machine. The same procedure was applied to two series of two bags to obtain the 0 h value. All residues were oven dried (65°C for 48 h) and dry matter determined (Hvelplund and Weisbjerg, 2000).

Statistical analysis: Disappearances of dry matter were fitted for each steer 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 ED = a+ bc/(c+k), estimated outflow rates (k) of 0.02, 0.05 and 0.08 h (Agricultural and Food Research Council, 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 using Duncan's multiple range tests (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The percent of dry matter disappearance at different incubation time increased as irradiation dose increased. The highest ($p<0.05$) disappearance rate was for wheat straw samples exposed to 200 and 300 kGy electron beam irradiation doses (Table 1).

Increasing electron beam irradiation dose, increased the washout fraction (α) and decreased the potentially degradable fraction (b) of dry matter (linear effect, $p<0.001$). The degradation rate of the b fraction increased as irradiation dose increased (linear effect, $p<0.001$). Effective degradability of dry matter linearly increased ($p<0.001$) as irradiation dose increased (Table 2).

Table 1: Dry matter disappearance (%) of wheat straw in different incubation periods

	Ruminal incubation period (h)						
Items	0	6	12	24	48	72	96
Untreated	23.49^{d}	30.47^{b}	36.64^{c}	40.04^{c}	42.45^{c}	43.85^{c}	44.64^{b}
100 kGy	25.32^{c}	31.47^{b}	38.15^{c}	51.92^{b}	57.57^{b}	69.23^{b}	69.50^{b}
200 kGy	36.68^{b}	39.21^{a}	46.81^{b}	60.34^{a}	63.47^{a}	72.37^{a}	74.05^{a}
300 kGy	38.36^{a}	39.96^{a}	50.41^{a}	62.00^{a}	64.90^{a}	73.16^{a}	75.29^{a}
SEM	0.790	1.282	2.628	2.535	1.526	0.512	0.694

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

Table 2: Rumen degradation parameters of dry matter of untreated and electron beam irradiated wheat straw

Items	Untreated wheat straw	Electron beam irradiated wheat straw			SEM	Contrasts		
		100 kGy	200 kGy	300 kGy		L	Q	C
Parameters (%)								
a	23.48	24.82	35.71	36.73	0.671	***	NS	**
b	20.39	47.32	41.82	39.75	1.500	***	***	***
a + b	43.87	72.14	77.53	76.48	2.173	***	**	NS
c (/h)	0.076	0.029	0.031	0.032	0.0081	**	*	*
Effective rumen degradation (%)								
0.02 /h	39.61	53.31	59.87	61.38	0.554	***	**	NS
0.05 /h	35.77	42.47	50.63	52.45	0.772	***	**	**
0.08 /h	33.41	37.60	46.43	48.28	0.716	***	*	***

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

Although, processing with gamma irradiation and other physical processes have been occurred plentifully (Alberti *et al*., 2005; Sadeghi and Shawrang, 2007a, b), however, with electron beam irradiation has not been completely 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 and Manta, 1972).

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). 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 of dry matter increased (Al-Masri, 1997), significantly. In addition, Pritchard and Pigden (1962) reported that the solubility and digestibility of wheat straw increased by gamma irradiation. 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. 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, 1997). Recently, Sadeghi and Shawrang (2007b) reported that electron beam irradiation at doses higher than 100 kGy could increase cell wall degradability of straws and sugarcane bagasse in the rumen. In their study the effective cell wall degradability of 50, 100, 200 and 300 kGy electron beam irradiated sugarcane bagasse at rumen outflow rate of 0.05/h increased by 2, 13, 25 and 29%, respectively.

Under beam or gamma irradiation, cell wall constituents may undergo degradation or cross-linking and at higher doses; degradation predominates, which is more likely due to the splitting of the glucosidal bond (Takacs and Wojnarouits, 1999). Therefore, electron beam irradiation of cellulose or cellulose containing materials will lead to modification in its structure. This modification may be due to several factors such as consequences of unimolecularor bimolecular reaction of the radicals. The beta cleavage of the radical can lead to the opening of the anhydroglucose ring or breaking off the glucoside bond (Takacs and Wojnarouits, 1999). It has been suggested that lignin is linked to both hemicellulose and cellulose forming a physical seal around the latter two compounds that is impenetrable barrier preventing penetration of solutions and enzymes (Arora *et al*., 2002). The decrease of NDF and ADF of agricultural residues by irradiation treatment could be the cause of degradation of cellulose and hemicellulose into soluble materials (Banchorndhevakul, 2002). Finally based upon the results of this study, electron beam irradiation appeared to be suitable for increasing dry matter degradation of wheat straw in the rumen.

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