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Ruminal Degradation Kinetics of Wheat Straw Irradiated by High Doses of Electron Beam

Research Article

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ABSTRACT

This study was conducted to evaluate the effect of electron beam irradiation at doses of 250 and 500 kGy on the chemical composition and ruminal dry matter (DM) and neutral detergent fiber (NDF) degradability of wheat straw. Nylon bags of untreated or irradiated wheat straw were suspended in the rumen of three rams for up to 72 h, and resulting data were fitted to non-linear degradation model to calculate the degradation parameters of DM and NDF. Electron beam irradiation had no effect on crude protein, ether extract and ash, but decreased ($P<0.05$) contents of NDF and acid detergent fiber. The water soluble and potentially degradable fractions, degradation rate and effective degradability of DM and NDF increased linearly ($P<0.001$) with increases in irradiation dose. Based upon these results, electron beam irradiation can be used to improve DM and NDF degradation kinetics of wheat straw in the rumen.

KEY WORDS degradation, ionizing irradiation, ruminant feed, sheep, wheat straw.

INTRODUCTION

Lignocellulosic residue forms a major source of ruminant feeds in many parts of the world. Most of the carbohydrate fractions in these materials, especially wheat straw (WS), are not available for utilization; because the complex resistant lignin molecule is present and also its cell wall contain three dimensional structures that is less available for microbial degradation in the rumen (Van Soest, 1994). Consequently, major nutrients of WS escape from ruminal degradation and are wasted as feces. The nutritive value of straws can be increased by modification of cell wall structure. Some physical treatments, such as milling, chopping and steaming have been used to improve the ruminal degradability of WS (Morrison, 1983). The small effect of these treatments in improving degradability is mainly due to the increase in surface area. Chemical methods such as alkali, acids, hydrogen peroxide and ammonization have also been used to improve the digestibility of WS (Yosef and Ben-Ghedalia, 2000; Chaudhry, 2000; Sahoo *et al.* 2002). These chemicals can break down the bonds between lignin and hemicellulose and cellulose. However, these methods require a high amount of water for removal of chemicals after treatment and add to the already existing problems of chemical pollutants. In addition, it increases the risk of exposing ruminants to the danger of latent chemicals in the feed. The use of ionizing irradiation for the conversion of straws into industrial or animal feed has been an active area of research (Al-Masri and Zarkawi, 1994a, b; Bak *et al.* 2009; Driscoll *et al.* 2009). Gamma and electron beam irradiation have been examined as a mean of enhancing the enzymatic hydrolysis in cellulose industry (Takacs *et al.* 1999), and of improving crop residue digestibility (Al-Masri and Zarkawi, 1994 a, b). The effects of gamma irradiation were previously evaluated, but there was limited information about the effect of electron beam irradiation on nutritive value and ruminal fiber degradability of WS. Therefore, the objective of the present study was to characterize the response of WS to electron beam irradiation in terms of changes in the cell wall composition and degradation kinetics.

MATERIALS AND METHODS

Irradiation treatments

Wheat straw samples of three batches were packed in nylon bags 30 cm × 40 cm × 4 cm (with 0.5 mm thickness) and exposed to 250 and 500 kGy electron beam using Rhodotron accelerator (model TT200, IBA Co., Belgium) at the Yazd radiation processing center (AEOI) Yazd center, Iran) at room temperature. Each sample was placed in a metal tray and multiple passages were used to obtain the required doses. The dose rate was determined using cellulose triacetate films (ISO / ASTM 51650, 2005). Uncertainty and Dmax / Dmin were around 5% and 1.2, respectively. Similarly packed samples without irradiation served as control.

Nylon bag technique

Nylon bags (7 cm×14 cm) with a pore size of 45 µm were filled with 3 g of the samples. Duplicate bags filled with untreated or irradiated samples were incubated in the rumen of three rams (65 kg) for periods of 0, 8, 12, 24, 48 and 72 h according to the method of Ørskov and McDonald (1979). Bags were placed in the rumen, just before the animals were offered their first meal in the morning (i.e., 07:30 h). The same procedure was applied to two series of two bags to obtain the 0 h value. All of the bags were washed, dried and stored until dry matter (DM) and fiber analysis.

Chemical analyses

Chemical compositions in duplicate were completed for untreated or irradiated samples obtained from three batches of WS as replicates. Moisture content was estimated from the mass of samples before and after they were stored overnight in an oven at 105 °C (Methods 925.09; AOAC, 1995). Nitrogen (method 984.13), ether extract (method 920.39), ash (method 942.05) and acid detergent fiber (ADF) were determined according to AOAC (1995). Neutral detergent fiber (NDF) was analyzed according to the method of Van Soest *et al.* (1991).

Statistical analysis

Disappearances (i.e., P) of DM and NDF (including 0 h values) were fitted for each sheep to the exponential model of Ørskov and McDonald (1979) as: $P= a + b\,(1-e^{-ct})$.

In this model, the constant parameters "a" and "b" represent, respectively, the washout fraction and the potentially degradable component, which disappears at a constant degradation rate "c" per time. Data were analyzed using the general linear models procedure of SAS (1996) with the following statistical model:

$$Y_{ijk}= \mu + T_i + B_j + e_{ijk}$$

Where:
Y_{ijk}: dependent variable.
μ: overall mean.
T_i: irradiation effect.
B_j: animal effect.
e_{ijk}: residual error, assumed normally and independently distributed.

Differences between the treatment means were separated using Duncan test. Polynomial orthogonal contrasts was used to determine linear, quadratic, and cubic relationships (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Effects on chemical composition

The chemical compositions of WS are shown in Table 1. Electron beam irradiation had no effect on crude protein, ether extract and ash. Irradiation at doses of 250 and 500 kGy decreased (P<0.05) NDF content by 10 and 17%, and ADF contents by 5 and 11% compared to untreated WS, respectively.

Effects on DM and NDF degradability

Ruminal degradation characteristics of DM and NDF of untreated and irradiated WS are shown in Table 2. Increasing irradiation dose increased linearly the soluble fraction, degradable fraction, degradation rate and effective degradability of DM and NDF (P<0.001). At doses of 250 and 500 kGy, effective degradability of NDF at ruminal passage rate of 0.05 / h increased by 25 and 32% compared to untreated WS, respectively.

Chemical composition

No significant differences in ether extract, protein and ash between the irradiated and non-irradiated WS are in agreement with the results of Al-Masri and Zarkawi (1994a, b). The decrease in NDF and ADF contents in this study due to irradiation is similar to the report of Flachowsky *et al.* (1990), in which NDF and ADF contents of irradiated wood byproducts decreased with increasing irradiation dose over the range 100-2000 kGy with increasing doses of ionizing rays.

Table 1 Chemical composition of untreated and electron beam irradiated wheat straw (g/kg DM).

Treatment	Dry matter	Crude protein	Ether extract	Ash	NDF[1]	ADF[1]
Control	930	36	27	87	564[a] [3]	473[a]
EB-250 kGy[2]	933	35	28	85	507[b]	459[b]
EB-500 kGy	939	33	27	84	467[c]	418[c]
SEM[4]	6.4	3.8	1.6	4.1	31.6	13.3

[1] NDF: neutral detergent fiber and ADF: acid detergent fiber.
[2] EB: electron beam irradiation.
[3] a-c The means within the same column with at least one common letter, do not have significant difference (P>0.05).
[4] SEM: standard error of the means.

Table 2 Ruminal degradation parameters and the effective degradability of dry matter and neutral detergent fiber related to untreated and electron beam irradiated wheat straw

Characteristics	Control	Electron beam irradiated		SEM[1]	Contrasts	
		250 kGy	500 kGy		L[2]	Q[2]
Ruminal degradation parameters of dry matter						
Water soluble or *a* fraction (g/kg)	161	218	266	14.6	**[3]	NS[3]
Degradable or *b* fraction (g/kg)	257	328	347	17.9	*	NS
Degradation rate or *c* constant (h^{-1})	0.036	0.039	0.041	0.0039	*	NS
Effective degradability of dry matter (g/kg) at ruminal passage rate of:						
0.02 h^{-1}	327	435	499	22.3	**	NS
0.05 h^{-1}	268	361	422	21.6	**	NS
0.08 h^{-1}	241	325	383	19.1	**	NS
Ruminal degradation parameters of neutral detergent fiber						
Water soluble or *a* fraction (g/kg)	42	57	69	5.5	**	NS
Degradable or *b* fraction (g/kg)	329	419	443	18.2	*	NS
Degradation rate or *c* constant (h^{-1})	0.055	0.060	0.063	0.0049	*	NS
Effective degradability of neutral detergent fiber (g/kg) at ruminal passage rate of:						
0.02 h^{-1}	283	371	405	19.2	**	NS
0.05 h^{-1}	214	285	316	17.9	**	NS
0.08 h^{-1}	176	237	264	16.4	**	NS

[1] SEM: standard error of the means.
[2] L: linear effect and Q: quadratic effect.
[3] NS: non significant; * P<0.05 and ** P<0.01.

Our result also is in agreement to Gralak *et al.* (1994) who reported that decreasing of NDF and ADF in irradiated straws and roughages due to depolymerisation and delignification were directly proportional to the increasing dose of radiation. Similarly, Al-Masri and Zarkawi (1994a, b) reported that gamma irradiation significantly decreased the values of NDF and ADFof agriculture residues. The decrease of NDF and ADF of agricultural residues by irradiation treatment could be a result of degradation of cellulose and hemicellulose into soluble materials (Banchorndhevakul, 2002). Study of Takacs *et al.* (1999) showed that under beam irradiation, cell wall constituents undergo degradation due to the breaking off the glucosidal bond and modification in their structures. Modification may be caused by several factors that finally lead to the opening of the anhydroglucose ring and releasing of glucose.

The DM and NDF degradability

The results of the present study for the rate and extent of WS degradability are comparable to those of Ørskov *et al.* (1990). However, differences between the results of this study and them be due to difference in straw varieties and their physico-chemical properties.

Differences in *in sacco* degradability parameters between straw varieties and studies have been reported by Ørskov *et al.* (1990). It may be attributed to differences in the proportion of leaf and stem, animal and diet effects, particle size, incubation characteristics, rumen conditions and microbial contamination (Huntingdon and Givens, 1995; Ramanzin *et al.* 1997).

The improvement of DM disappearance, degradation parameters and effective degradability due to ionizing irradiation is similar to the results of Gralak *et al.* (1994). In their study, irradiation raised the potential rumen degradability and effective degradability of tDM of wheat and triticale straws. The DM disappearance increased with increasing irradiation dose that is in agreement with Flachowsky *et al.* (1990) who worked on wood byproducts.

Similar to our finding, these authors also reported that irradiation decreased particle size and increased dustiness of material. Therefore, increased DM disappearance during *in sacco* incubation, in addition to solubilisation, in part may be due to loss of fine particles from the artificial nylon bags. The improvement in the ruminal disappearance and effective degradability of NDF with irradiation observed in the present study was likely due to a combination of the decreased particle size, increasing the surface area exposed for microbial attachment, the alteration in the chemical composition especially the reduction in NDF content and corresponding increase in sugar content, a possible increase in solubility, reducing in crystallinity, random depolymerisation and decomposition of cellulose and hemicellulose and seriously weakens the cellulosic fiber (Charlesby 1995; Iller *et al*. 2002; Bouchard *et al*. 2006; Yang *et al*. 2008; Driscoll *et al*. 2009). Grous *et al*. (1986) has shown a good correlation between the available surface area and ease of chemical and enzymatic hydrolysis. Driscoll *et al*. (2009) showed that the available surface area of microcrystalline cellulose increased with increasing dose of irradiation.

They also observed a significant decrease in crystallinity and molecular weight of cellulose with increasing dose of irradiation. A decrease in molecular weight of cellulose with increasing radiation dose was also reported by Charlesby (1995). Reduction in crystallinity of cellulose (Iller, 2002; Alberti *et al*. 2005) can be another reason for increasing fiber hydrolysis of irradiated straw in the rumen. The crystallinity index of microcrystalline cellulose, flax, cotton and viscose was reduced up to 12% with a dose of 200 kGy.

Random depolymerisation and decomposition of cellulose and hemicellulose during electron beam irradiation is important reason for rises in fiber degradability. Ions which are produced by electron beams can initiate chemical reactions and cleavage chemical bonds in a material (Charlesby, 1995). Such ionizing radiation predominantly degrades or depolymerizes cellulose. (Bouchard *et al*. 2006; Yang *et al*. 2008). In addition, the link of lignin with other compounds in cell walls is broken by irradiation (Wasikiewicz *et al*. 2005). Lignin, a major component of secondary cell walls in WS, 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. Hence, irradiation treatment has the potential to increase the nutritive value of WS for ruminant nutrition.

CONCLUSION

Based on the results of this study, electron beam irradiation can be used to improve the degradability of the DM and fiber of WS and therefore enhance its nutritive value for ruminants.

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