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THE EFFECT OF MICROWAVE RADIATION ON PHYSICO-CHEMICAL PROPERTIES AND *IN VITRO* DIGESTIBILITY OF BARLEY STRAW

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SUMMARY

The effects of microwave radiation on chemical properties and *in vitro* digestibility of barley straw were investigated. Barley straw (90% dry matter, DM) was separated manually into stem, leaf and leaf sheath. Only the stem component was the subject of the study. The stem samples were cut into 5 cm long segments before exposing to one of 5 different times of microwave radiation (MWR), 1.5 kw, 2450 MHz: T0 = control (without MWR), T1 = MWR for 1 minute, T2 = MWR for 2 minutes, T3 = MWR for 3 minutes, and T4 = MWR for 4 minutes. Following the treatment, the samples were ground to pass a 1-mm screen before analyzing for chemical properties: dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose, and acid detergent lignin (ADL); and *in vitro* digestibilities of dry matter (IVDMD) and organic matter (IVOMD). In addition, metabolizable energy (MJ/kg feed dry matter, M/D) of the samples was estimated from IVDMD using the formula provided by SCA (l990). Data analysis indicated that MWR affected the samples in three patterns: DM, NDF, and cellulose were not affected by MWR ($P>0.05$). OM, ADF, and hemicellulose were affected ($P<0.05$) by the treatment, but the effects did not follow any pattern related to time of exposure. CP, IVDMD, IVOMD, and M/D increased linearly ($P<0.05$) as the time of MWR increased from 0 to 4 minutes, the increases by 38%, 12%, 9%, and 13%, respectively. ADL decreased ($P<0.067$) by 23% as the time of exposure to MWR increased. This study indicated that application of MWR up to 4 minutes significantly increased the nutritive values of barley straw in terms of improved *in vitro* digestibility and metabolizable energy while lignin content which is recognized as one of anti nutrients in most roughages decreased significantly.

Keywords: microwave radiation, barley straw, chemical composition, *in vitro* digestibility

INTRODUCTION

Even though straw is regarded as a low quality roughage, it has long held an important role as ruminant feed especially at times when a good quality hay/roughage is scarce. Straw has been fed to ruminant animals with varying degree of success. Many studies have shown that although such materials may meet the maintenance requirement of mature animals, they often give poor results when used as a major dietary component for production of meat, milk, and fiber. This is due to the properties of the straw associated with high content of cell walls that are highly lignified. The cell walls are often constitutes up to 80% of the total dry matter of the straw and are mainly built up of structural polysaccharides which may be crystalline with low levels of hydration and cross-linked to lignin. Consequently, proteins and readily available carbohydrates are present in much lower percentages and that present maybe relatively inaccessible inside the cells.

Therefore, before feeding to animals, straw may be processed to overcome anatomical/physical and chemical barriers to digestion. The cell walls must be chemically altered or physically disrupted in order to permit either cellulase or rumen microorganism to have more access to digest it. Various physical treatments have been reported; some types of treatments like grinding/milling procedure followed by a compaction process (pelleting/cubing) are commonly used for this purpose (Winugroho and Chaniago 1984). Exposing straw to treatment either with high steam pressure (Hart *et al*. 1981; Rangnekar *et al*. 1982) or high intensity of gamma irradiation (McManus *et al*. 1974a) increased *in vitro* and *in sacco* digestibility of the straw but the animal intake of these treated materials did not improve (McManus *et al*. 1974b, Hart *et al.* 1981; Rangnekar *et al*. 1982).

Another physical treatment that could be applied is microwave radiation. Studies on wood have demonstrated that intensive microwave radiation applied to wood results in rapid generation of high internal steam pressure in the wood cells which in turn increases permeability of the cells/tissues several thousands fold (Torgovnikov, 1993). Other studies indicated that enzymatic susceptibility of cellulose of samples Pinus densiflora, Fagus crenata, and Phyllostachys was markedly increased by microwave irradiation (Azuma *et al.*, 1984).

The aim of this experiment was to evaluate *in vitro* digestibility of barley straw as a result of exposing the straw to microwave radiation. We wished also to evaluate effects of MWR on the proximate analysis results, particularly where chemical changes may have occurred.

MATERIALS AND METHODS

Straw

Barley straw used in this study was obtained from the 1999 harvest and was provided by the Victorian Institute of Animal Science (VIAS) Werribee. Before microwaving, the straw was separated manually into stem, leaf, and leaf sheath. Only the stem component of the straw was subjected to the microwave treatment in this experiment because it has been recognized that it is the greatest portion of straw, the part that most likely remaining in the field after the grain is harvested, and the part most resistant to rumen degradation compared to the leaf or leaf sheath fractions. Dry matter (DM) content of the straw used in this particular study was around 90%.

Microwave radiation (MWR)

Domestic microwave (MW) (Sharp, model R-4A52) used in this experiment operated with 1.5 kW of electric power and at frequency of 2450 MHz. Before exposing to the MW, the samples were cut into ± 5 cm long segments. Approximately 50 g of the sample was placed in MW container then exposed to MWR according to the treatment. Following the MWR, the sample was ground to pass 1mm screen for further analysis.

The experiment was conducted according to a completely randomized design (Steel and Torrie 1980) consisting of 5 treatments and 4 replications. The treatments were: T0 = control (without MWR), T1 = MWR for 1 minute, T2 = MWR for 2 minutes, T3 = MWR for 3 minutes, and T4 = MWR for 4 minutes.

In this experiment, the longest time for MWR was determined by firstly exposing the straw to the MWR for 30 seconds and then increasing the time of radiation gradually until a maximum time was reached where the straw sample started burning. For these particular straw samples, the longest microwave radiation time (MWRT) that could be applied was 4 minutes.

Laboratory Analysis

Control and MW-treated barley straw samples were analyzed for dry matter (DM), ash, total nitrogen (N), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), cellulose, *in vitro* digestibilities of dry matter (IVDMD) and organic matter (IVOMD). DM content was determined by drying at 100^{o}C in the oven for 24 h. The percentage of ash was determined by combustion of samples for 6 h at 550^{o}C. Organic matter (OM) was calculated as 100-%ash (DM basis). Total N content was determined by the Kjeldahl procedure (AOAC, 1990) and percentage of crude protein (CP) was calculated as total N*6.25. Fibre composition (NDF, ADF, ADL, and cellulose) was analyzed according to the procedure of Goering and Van Soest (1970), while hemicellulose was calculated as NDF–ADF.

IVDMD and IVOMD were determined according to pepsin-cellulase *in vitro* digestibility technique (McLeod and Minson, 1978; 1980). This technique is a two-stage procedure requiring the addition of cellulase in an acid buffer and addition of pepsin in an acetate buffer into the samples incubated at 50^{o} C for a total of 120 hours. Metabolizable energy content of DM (MJ/kg feed DM, M/D) was estimated from IVDMD using the formula: M/D = 0.17 x IVDMD (%) –2.0 (SCA, 1990).

Statistical Analysis

All data were subjected to analysis of variance of a completely randomized design using statistical software package (MINITAB statistical software rel.13.1, Minitab Inc. 2000). The experimental model:

$Y_{ij} = \mu + T_i + \in_{ij}$, where Y_{ij} = observation value, μ = mean, T_i = effects of treatment (i = 1, 2, 3, 4, 5), and $\in_{ij}$ = experimental error (i = 1, 2, 3, 4, 5 and j = 1, 2, 3, 4).

RESULTS

The chemical composition and *in vitro* digestibility of barley straw after MW treatment is presented in table 1.

Table 1. Chemical composition, IVDMD, IVOMD, and estimated M/D of barley straw according to the treatment.

	Treatments					
Nutrients (g/kg DM)	T0	T1	T2	T3	T4	P≤
DM	927.3	928.9	927.9	929.7	931.3	0.426
OM	931.0	929.8	9278.8	926.3	930.8	0.027
CP	6.3	7.2	6.7	7.7	8.7	0.016
NDF	857.7	851.7	847.0	846.0	849.2	0.156
ADF	563.3	562.6	545.7	531.7	540.5	0.000
Cellulose	445.0	442.6	430.3	424.9	443.2	0.112
Hemicellulose	294.4	289.1	301.3	314.3	308.7	0.011
ADL	109.6	109.0	105.7	98.9	83.9	0.067
IVDMD	379.9	388.4	399.8	407.9	424.0	0.000
IVOMD	397.9	401.8	412.2	414.6	433.2	0.002
ME (MJ/kg DM, M/D)	4.6	4.6	4.8	4.9	5.2	0.000

Data analysis indicated that the chemical properties of the straw were affected by MWRT in different patterns. DM, NDF, and cellulose were not affected by MW treatment (P>0.05). DM content of the samples showed no significant changes, from 92.7% (T0) to 93.1% (T4). For NDF content, the range was between 85.8% (T0) and 84.9% (T4). For cellulose, the percentage tended to decrease from 44.5%(T0) to 42.5% (T3), however it increased back to 44.3% for T4.

OM, ADF, and hemicellulose were affected (P<0.05) by the treatment, but the effects did not follow a simple MWRT pattern. Both OM and ADF significantly decreased from 93.0% (T0) to 92.6% (T3) for OM and from 56.3 % to 53.2% for ADF, but for T4 both nutrients increased back to 93.1% and 54.0% respectively for OM and ADF. Even though ADF concentration followed no particular pattern overall it decreased linearly as the MWRT increased following the equation, ADF = 56.6 – 0.896*MWRT (R^2 = 64.4%). Unlike OM and ADF, the concentration of hemicellulose increased from 29.4% (T0) to 31.4% (T3) but decreased to 30.9% for T4.

MW treatment affected CP, ADL, IVDMD, IVOMD, and M/D in linear manner. CP, IVDMD, IVOMD, and M/D increased linearly (P<0.05) as the MWRT increased while ADL decreased linearly (P<0.006) as the MWRT increased. ADL content decreased significantly (P<0.067) by 23%, from 11.0% (T0) to 8.4% (T4) following the linear equation ADL = 11.5 – 0.596*MWRT (R^2 = 42.3%). In contrast, CP increased linearly as MWRT increased. Comparing T0 and T4, CP increased approximately 38% (from 0.63% to 0.87%) and the response represented by a linear regression equation CP = 0.631 + 0.0494* MWRT (R^2=45.2%). Similarly IVDMD, IVOMD, and M/D increased significantly as MWRT increased. IVDMD increased 12% (from 38.0%, T0 to 42.4%, T4), IVOMD increased 9%, from 39.8% (T0) to 43.3% (T4), while M/D increased 13%, from 4.6 to 5.2. Linear regression equations were: IVDMD = 37.8 + 1.06*MWRT (R^2 =67.2%), IVOMD = 39.5 + 0.803*MWRT (R2 = 52%) and M/D = 4.43 + 0.180*MWRT (R^2 = 67.2%).

DISCUSSION

DM content of the straw did not change significantly after MWR even though there was a tendency that it decreased as the level of MWRT increased. One possible reason was that the moisture content of barley straw sample subjected to the treatment was very low (DM = ±90%), therefore the effects of MW on removing the water, especially intracellular and cell wall intra-molecular water of the straw, was limited. Similarly, the concentration of NDF and cellulose did not change significantly.

For other nutrients, MWR was effective in altering the chemical composition of the straw sample. CP increased approximately 38%. Though the increase in the percentage of CP was high, the actual amount of CP of the straw was very low, 6.3 and 8.7 g/kg DM for T0 and T4 respectively. Therefore in terms of quantity, the increase of CP was negligible. What may be of significance is the possible improved exposure of N to microbial activity.

A decrease in lignin as MWRT increased may indicate hydrolysis of lignin-hemicellulose bonds and solubilization of lignin when the molecular frictions occurred during the radiation. Studies on wood have shown that during microwave radiation, the microwave energy causes water and wood substance molecules to disassociate. The molecules of free and bound water, cellulose and lignin are vibrating and rotating to result in molecular frictions (Peyskens *et al.*, 1984). The same explanation may apply to the decrease in ADF even though the pattern for ADF decrease was slightly different from that for ADL; at the highest MWRT the ADF content increased rather than decreased as for ADL. The reason for this was not clear. An increase in hemicellulose content (calculated as NDF-ADF) was primarily an effect of the ADF pattern.

In vitro technique, which is commonly used to evaluate the nutritive value of feeds for ruminant animals, indicated that both IVDMD and IVOMD increased significantly as MWRT increased. There were two possible reasons for this increment. Firstly, MWR altered internal structure area and permeability of the sample for enzymatic digestion. This would be consistent with the observation on wood. Magara *et al.* (1988) reported substantial enhancement in enzymatic hydrolysis of lignocellulose material of ground wood of Fagus crenata pretreated by microwave radiation to 160-220^{0}C before enzymatic hydrolysis. Secondly, MWR decreased lignin content of the straw sample, which in turn increased accessibility of fibre for digestion. Based on IVDMD, the predicted increase in M/D of between 10-20% could be regarded as important when straw is used as an energy/fibre source for ruminants.

In conclusion, application of microwave radiation up to 4 minutes increased the nutritive values of barley straw in terms of improving *in vitro* digestibility and estimated metabolizable energy while the concentration of lignin, which is recognised as an important anti-nutrient for ruminants, decreased quite significantly.

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