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The effect of heating and NaOH treatments on the nutritive value of nonlinted whole cottonseeds

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ABSTRACT

The effect of treating nonlinted whole Pima cottonseeds (WCS) with heat, NaOH, or their combination on digestive tract digestibility in dairy cows, was studied using the mobile dacron bag technique. NaOH treatment increased ruminal DM disappearance from WCS. For DM there was an interaction, between heat treatment and incubation time. Interactions of NaOH x heat and heat x incubation time were found for ruminal CP disappearance. Heat treatment decreased ruminal CP disappearance. With WCS which was heat-treated in the presence of NaOH, ruminal CP disappearance decreased. NaOH and heat treatments of WCS, respectively, increased and decreased intestinal DM disappearance. These respective treatments also increased and decreased intestinal CP disappearance. NaOH and heat treatments of WCS, respectively, increased and decreased total tract DM and CP disappearance. It was concluded that a combination of NaOH and heat treatments may protect nonlinted WCS from excessive ruminal CP degradation and deliver more nutrients to the intestine.

KEY WORDS: cattle, heat, mobile bag technique, NaOH, whole cottonseeds

INTRODUCTION

Whole cottonseed (WCS) is an important industrial by-product and feedstuff in subtropical regions. Owing to its high protein and energy contents WCS may be successfully incorporated into ruminant diets (Coppock et al., 1987). Whereas high linted dietary WCS is well digested by ruminants, digestibility of delinted

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cottonseed is lower. In lactating dairy cows, about 11% of consumed whole acid-delinted seeds are excreted in the faeces (Coppock et al., 1985). Similar proportions of naturally nonlinted WCS of the Pima variety have been found in the faeces of lactating dairy cows (Sullivan et al., 1993). The lower digestion of nonlinted than of linted WCS is apparently related to its higher density, leading to reduced mastication and favouring its passage from the rumen in an unaltered form. With cracked WCS, feed efficiency of dairy cows increased (Sullivan et al., 1993), though grinding Pima cottonseed may decrease microbial growth and net ruminal protein efficiency (Zinn, 1995). These findings emphasize the potential biological value of nonlinted WCS for ruminants. An alternative means of increasing availability of the nutrients enclosed within the hard coat of the WCS is by breaking the lignocellulose linkage by treating the seeds with alkali (Van Soest, 1994). A significant advantage of this type of treatment is that because of its high fat content, alkali-treated WCS can be stored longer than its cracked counterpart.

While alkali treatment of highly lignocellulosic feedstuffs may improve overall nutrient digestion in the rumen, the response can vary between different nutrients. Thus, whereas an increase in carbohydrate digestion from WCS in the rumen may be desirable, excess ruminal crude protein (CP) degradation should be avoided. To protect the treated WCS from excessive CP degradation in the rumen heat can be applied, thereby increasing intestinal input of undegradable CP from WCS (Pena et al., 1986; Smith and Vosloo, 1994).

Information on the combination of heat and alkali treatments for WCS utilization in ruminant diets is lacking. We studied the effect of treating WCS of the Pima variety with heat, NaOH, or their combination on ruminal and total digestive tract digestibility in dairy cows.

MATERIAL AND METHODS

WCS treatments

Commercial WCS of the Pima variety were treated as follows: non-treated (CONT), soaked for 15 min in 15% NaOH and then air-dried (NaOH), heat treated at 150°C for 2 h (HEAT), or treated with NaOH and immediately heat treated as above (COMB). Treatment of heat was applied in a forced air oven in which WCS were spread on trays in 2 cm layers.

In sacco trial

In sacco incubation was performed by suspending polyester bags in three cows provided with ruminal and duodenal cannulas. The cows were in mid lactation and were maintained on a concentrate diet (34% NDF) which included 2 kg WCS. Intact WCS (3g) was weighed into each of the 12 x 6 cm polyester bags (mean pore size of 45 μm). In each cow, bags were introduced into the rumen in four replicates per treatment and per incubation time and kept there for 48, 24 or 12 h. All the polyester bags were removed from the rumen together and immediately rinsed with cold tap water. After incubation, two bags were rinsed and dried. The other two bags were inserted through the duodenal cannula, as described by Arieli et al. (1989). Eight bags per day, from the different treatments, were inserted randomly at a rate of two bags per h to the duodenal cannula. Bags collected from the faeces after excretion were rinsed and dried. Ash and CP levels were determined in the undigested residual.

Chemical analysis

Chemical analysis were performed on dry, 2-mm milled samples. Dry matter (DM) was assayed after drying at 105^{0}C for 12 h. Organic matter (OM) was determined after ashing at 600^{0}C for 3 h. CP was analyzed using a Kjeldahl autoanalyzer. NDF was determined according to the method of Van Soest et al. (1991).

Calculations and statistics

Digestibility of DM, OM, and CP in the rumen and intestine was determined in two replicates per treatment and per incubation time, by assuming that ruminal digestibility values were similar between bags that were passed on to the intestine and their counterparts analyzed after being recovered from the rumen.

Three-way analysis of variance (SAS, 1985) was used to separate differences in ruminal, intestinal and total tract digestibility values of DM, OM and CP, due to treatments of NaOH, heat and rumen incubation time, and their interactions. Significance was declared at $P<0.05$. When interactions with incubation time were found to be significant, analysis of treatments was performed for each time point separately.

RESULTS

WCS composition

The treatments effected some changes in WCS composition (Table 1). Treatment with NaOH was associated with a 6% increase in ash content. In the absence of alkali, heat treatment was associated with a 10% increase in NDF, which appeared to be entirely related to an increase in hemicellulose (as reflected by the difference between NDF and ADF contents; Table 1).

In sacco trial

Treatment with NaOH was associated with a 10% increase in ruminal DM disappearance and a 7% increase in ruminal OM disappearance from WCS (Table 2). For both DM and OM disappearance there was an interaction between heat treatment and incubation time. Thus at 12, 24 and 48 h, WCS heating increased ruminal DM disappearance by 10, 6 and −6%, respectively, and ruminal OM disappearance by 6, 3, and −6%, respectively.

Interactions of NaOH x heat and heat x incubation time were found for ruminal CP disappearance. Heat treatment in the absence of NaOH was followed by decrease in ruminal CP disappearance of 2, 8 and 7% at ruminal incubation times of 12, 24 and 48 h, respectively. With WCS which was heat-treated in the presence of NaOH ruminal CP disappearance decreased by 9, 11 and 38% at ruminal incubation times of 12, 24 and 48 h, respectively.

The NaOH and heat treatments of WCS were respectively associated with an 8% increase and 12% decrease in intestinal DM disappearance (Table 3). There was an NaOH x heat x incubation time interaction with regard to intestinal, OM disappearance: at 12 h, treating WCS with NaOH resulted in a 14% increase; at 24 and 48 h treating WCS with heat resulted in respective decreases of 19 and 15%. The NaOH and heat treatments of WCS were respectively associated with a 12% increase and 32% decrease in intestinal CP disappearance.

The NaOH and heat treatments of WCS were associated, respectively, with a 13% increase and a 7% decrease in total tract DM disappearance (Table 4). Longer ruminal incubation times were associated with an increase in total tract DM and OM disappearance: 46% at 12 h, 50% at 24 h and 58% at 48 h for DM,

TABLE 1

Chemical composition of whole cottonseed used in trials, DM basis

Treatment	CONT	NaOH	HEAT	COMB
Dry matter	89.9	82.0	99.1	98.8
Ash	4.5	11.6	4.5	11.3
Crude protein	22.6	20.4	23.2	21.5
Fat	22.4	22.9	22.9	23.0
NDF	38.3	33.6	48.6	41.0
ADF	25.9	22.7	26.5	26.9
ADL	14.5	11.1	13.3	12.0

[1] treatments are: control, NaOH, heat, and their combination

TABLE 2

Ruminal disappearance of DM, OM, and CP from WCS at various incubation times, %

Treatment	CONT	NaOH	HEAT	COMB
DM[2]				
12 h	4.9	14.2	15.1	23.2
24 h	12.8	22.0	18.5	29.0
48 h	31.8	44.2	27.0	37.0
SEM 4.18				
OM[3]				
12 h	3.8	8.0	9.3	15.1
24 h	10.9	18.4	12.6	23.0
48 h	30.6	36.2	22.2	33.5
SEM 2.17				
CP[4]				
12 h	5.5	13.0	3.5	3.8
24 h	16.2	25.5	7.8	14.5
48 h	40.8	57.1	33.7	19.0
SEM 4.95				

[1] treatments are: control, NaOH, heat, and their combination

[2] NaOH effect ($P<0.001$), incubation time effect ($P<0.001$), incubation time x heat effect ($P<0.05$)

[3] NaOH effect ($P<0.001$), incubation time effect ($P<0.001$)

[4] heat effect ($P<0.001$), NaOH x heat effect ($P<0.05$), incubation time effect ($P<0.001$)

TABLE 3

Intestinal disappearance of DM, OM and CP from WCS after various ruminal incubation times, %

Treatment	CONT	NaOH	HEAT	COMB
DM[3]				
12 h	38.2	45.2	27.4	39.1
24 h	43.2	48.7	25.9	31.1
48 h	39.1	42.6	24.0	38.6
SEM 4.99				
OM[4]				
12 h	37.8	46.0	25.8	46.4
24 h	49.3	42.1	24.7	29.1
48 h	35.0	38.0	20.6	31.0
SEM 5.74				
CP				
12 h	70.3	73.5	35.9	51.7
24 h	60.6	74.8	44.4	31.3
48 h	63.4	71.5	8.4	51.1
SEM 8.66				

[1] percentages of the amounts passed to the intestine

[2] treatments are: control, NaOH, heat, and their combination

[3] NaOH effect ($P<0.05$), heat effect ($P<0.001$)

[4] NaOH effect ($P<0.05$), heat effect ($P<0.001$), NaOH x heat x incubation time effect ($P<0.05$)

TABLE 4
Total tract disappearance of DM, OM and CP from WCS at various ruminal incubation times, %

Treatment	CONT	NaOH	HEAT	COMB
DM[2]				
12 h	41.1	53.1	37.6	53.5
24 h	50.6	60.0	39.4	51.0
48 h	58.5	68.0	44.0	61.3
SEM 5.57				
OM[3]				
12 h	40.2	50.6	32.6	54.7
24 h	54.9	52.8	33.8	45.7
48 h	55.0	60.6	38.4	54.4
SEM 4.62				
CP[3]				
12 h	72.2	76.8	37.3	54.6
24 h	67.2	81.7	48.1	42.0
48 h	78.0	87.9	38.8	60.7
SEM 7.56				

[1] treatments are: control, NaOH, heat, and their combination
[2] NaOH effect ($P<0.001$), heat effect ($P<0.01$), incubation time effect ($P<0.05$)
[3] NaOH effect ($P<0.001$), heat effect ($P<0.01$), NaOH x heat effect ($P<0.05$)
[4] NaOH effect ($P<0.05$), heat effect ($P<0.001$)

and 44% at 12 h, 47% at 24 h and 52% at 48 h, for OM respectively. A NaOH x heat interaction was found with regard to total tract OM disappearance. In the absence of NaOH, treating WCS with heat was associated with a 15% decrease in total tract OM disappearance, a 3% decrease in the presence of NaOH. The NaOH and heat treatments of WCS were respectively associated with an 11% increase and 30% decrease in total tract CP disappearance.

DISCUSSION

The nonlinted WCS used in the present study is less digested in the rumen than linted WCS (Coppock et al., 1985). Its lower digestibility may be related to its rapid sedimentation in the rumen. In line with this reasoning was the low *in sacco* digestion of CP in the rumen found with control whole seeds (Table 2), being less than half of that found for ground WCS (Arieli et al., 1989).

Heat treatment reduces the degradation of CP supplements in the rumen (Satter, 1986). This effect partly related to blocking of reactive sites for microbial proteolytic enzymes, and partly to reduction of protein solubility (Broderick and Craig, 1980). Heating of WCS has been followed by increased *in vivo* CP flow into the intestine and absorption of total amino acids in dairy cows (Pena et al., 1986). There is an optimal effect of heat intensity on intestinal digestion. For linted WCS, using the mobile dacron bag technique, the optimal heat treatment was shown to be achieved when the product of heating duration times temperature increment above 130°C was 45 h x °C (Arieli et al., 1989).

The effect of heating on CP degradation was time-dependent (Table 2). Most of the reduction in ruminal CP degradation from WCS, about 8%, had already occurred after 24 h incubation in the rumen. A much larger reduction, of 35%, was found in intestinal CP degradation of heated WCS (Table 3). Similarly, degradation of CP in the total tract was reduced by 31% with heated WCS (Table 4). It is likely that excess denaturation was caused by heating the WCS at 150°C for 2 h, and that this was associated with the reduction in rumen degradation and with inferior intestinal CP degradation.

It should be noted that in dairy cows rumina only some of the Pima WCS passes into the intestine non-chewed. Hence, in these animals the predicted digestibility would be higher than that found *in sacco*. Collectively, these results suggest that heating of nonlinted WCS has the potential to increase absorbable CP, provided that this CP is subjected to proper enzymatic exposure in the rumen and in the intestine.

Accessibility of nutrients within the hard WCS coat to digestive enzymatic action may be increased by grinding (Zinn,1995) or by using alkali, which acts by hydrolyzing the seed coat lignin and mainly its hemicellulose (Van Soest, 1994). In some cases, NDF content of forages may increase with alkali treatment, presumably via the leaching of solubles or due to the Maillard reaction (Canale et al., 1990). The appearance of Maillard products in alkali-treated forages results from heat exposure of the forage rather than from the alkali itself. From the composition of treated WCS (Table 1), NaOH treatment in the present study does not appear to be associated with a decrease in WCS quality. In NaOH-treated WCS an increase of 10, 5 and 10% in DM digestion in the rumen, intestine and total tract, respectively, was found. A similar trend, but of lower magnitude, was found with OM digestion (Tables 2, 3, 4). An increase in OM digestion in the rumen may be beneficial for microbial protein synthesis, provided the additional energy comes from carbohydrates rather than fat.

With NaOH treatment of WCS, increases of 11, 9 and 11% in CP, digestion in the rumen, intestine and total tract were found, respectively (Tables 2, 3, 4). Comparable data concerning the effect of NaOH on CP utilization of WCS are not available. When other feedstuffs were treated with NaOH, various results of CP digestion were obtained: NaOH treatment of soyabean did not affect ruminal CP degradation in one case (Waltz and Stern, 1989), but in another ruminal CP disappearance was reduced (Mir et al., 1984). Total tract CP digestion from barley in sheep was reduced by NaOH treatment (Beams et al., 1986). It thus appears that the effect of NaOH on WCS digestion is an overall response to its indirect effect on coat detachment and its direct effect on CP digestion.

Whereas NaOH treatment was associated with an increase in rumen CP digestion, and heating was associated with a decrease in rumen CP digestion, the effect of their interaction was associated with a decrease in ruminal CP digestion. At 48 h the ruminal CP digestion in COMB was even lower than that in either HEAT or NaOH treatments. Perhaps penetration of heat through the perforated WCS coat was excessive in terms of ruminal CP degradation.

CONCLUSION

Treating nonlinted whole Pima cottonseed with NaOH and heat affected differentially the disappearance of ruminal and intestinal OM and CP. Interactions were found between heat and NaOH treatments on digestibility of OM and CP at various section of the digestive tract. It was concluded that the mobile bag technique may serve as a useful tool for monitoring and determining the treatment combination needed to achieve maximal biological effect.

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STRESZCZENIE

Wpływ ogrzewania i traktowania NaOH na wartość pokarmową nierozdrobnionych całych nasion bawełny

Badano wpływ ogrzewania i traktowania NaOH całych, nierozdrobnionych nasion bawełny (WCS), na strawność składników pokarmowych u krów mlecznych metodą mobilnych woreczków. Traktowanie NaOH zwiększało ubytek suchej masy (SM) WCS ze żwacza. Dla SM stwierdzono interakcję pomiędzy ogrzewaniem i czasem inkubacji. Stwierdzono także interakcję pomiędzy NaOH a ogrzewaniem oraz ogrzewaniem a czasem inkubacji dla ubytku białka ogólnego (CP). Ogrzewanie zmniejszało stopień rozkładu CP w żwaczu. Stopień rozkładu białka nasion ogrzewanych w obecności NaOH był mniejszy niż nasion nie traktowanych. Traktowanie NaOH i ogrzewanie WCS zwiększało lub zmniejszało, odpowiednio, ubytek SM. Traktowanie nasion NaOH zwiększało, a ogrzewanie zmniejszało stopień rozkładu CP w jelitach. Podobne wyniki otrzymano dla stopnia trawienia SM i CP w całym przewodzie pokarmowym.

Stwierdzono, że kombinacja NaOH i ogrzewania nie rozdrobnionych WCS może chronić przed nadmierną degradacją CP w żwaczu i dostarczać większej ilości składników pokarmowych do jelit.