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EFFECTIVENESS OF PHYSICAL AND CHEMICAL PRETREATMENTS IN ENHANCING COTTON GIN TRASH *IN VITRO* RUMINANT DIGESTIBILITY

Samuel J. Ray, Lester O. Pordesimo,
Michael J. Buschermohle and John B. Wilkerson
Department of Biosystems Engineering and Environmental Science
John C. Waller
Department of Animal Science
The University of Tennessee
Knoxville, TN

Abstract

Cotton gin trash (CGT) in the raw form has poor ruminant digestibility due to lignocellulosic complexes. These structures must be broken down before adequate digestion can occur. This may be performed by physical and/or chemical means. Two methods for improving digestibility are particle size reduction and/or treatment with sodium hydroxide (NaOH). To evaluate the effectiveness of each method, three experiments were performed in which different CGT types were tested. Each type represented trash from a particular cleaning stage in the cotton ginning process. First, each type was ground with a knife-type grinding mill using screen sizes 0.5, 1.0, and 2.0 mm. For the second experiment, particle size was held constant, and all CGT types were treated with 4 and 6% NaOH (w/w) at room temperature. An agitation cycle of 5 minutes on and 10 minutes off was used, with the total mixing time being 4 hours. Lastly, particle size and chemical concentration were held constant, and treatments were performed at room temperature, 40°C, and 50°C. The total mixing times were 2 and 3 hours for 50 and 40°C, respectively. For all experiments two subsamples of each treatment were tested for *in vitro* ruminant digestibility. From grinding alone, digestibility increased as particle size decreased. Digestibility also improved with a greater NaOH concentration. An average of 70.5% was achieved with 6% NaOH (w/w) treatment, essentially doubling that of the raw CGT. Increasing the reaction temperature did not result in increased digestibility because the mixture dried out and with a consequent reduction in chemical distribution and uniformity in heat transfer. There are still chemical residues in the CGT, and elimination/reduction of these is an issue that needs to be addressed in further research.

Introduction

Finding an economical and practical method of disposing of the large quantities of cotton gin trash (CGT) that accumulate during the ginning process remains a problem for cotton ginning facilities. In the past, incineration has been a widely used means of disposal, but environmental regulations have eliminated this method. Using CGT as a ruminant feed ingredient is one potential option for disposing the material in an environmentally friendly manner. The highest value usage of cotton gin trash is for feeding to ruminant animals. Comparatively, CGT has lower feed value than alfalfa, but higher than prairie hay, bermuda hay, rice hulls, and sorghum stover according to Lalor et al. (1975) (Table 1).

Problems related to utilization of cotton gin trash as a livestock feed/livestock feed ingredient include chemical residues, digestibility, and nutritive value (Buser, 1999). While still a problem, the issue of chemical residues is not as severe as in the past because the levels have decreased since the 1970s and current residues have relatively short lives (personal communication cited by Thomasson et al. (1998)). All these issues can potentially be addressed and ameliorated by engineering physical, chemical, and enzymatic pretreatment and nutrient blending processes for CGT. The strategy is to pre-digest a fraction of the lignocellulosic material in cotton gin trash to facilitate a more complete digestion and utilization by ruminants and then increasing protein content through blending with other ingredients/products. This can be accomplished by characterizing the physico-chemical properties of the gin waste (broadly classified as picker or stripper trash) and then investigating the main effects and interactions of such pretreatment process variables as particle size, moisture content, chemical concentrations, cycled agitation, and reaction time and temperature. While there have been many studies involving the chemical treatment of crop residues for enhanced livestock feeding value, there is very little information on the effects of treatment process variables other than chemical concentration.

Han et al. (1983) stated that in cellulose hydrolysis, direct physical contact between the hydrolytic agents and the cellulose molecules is required and that the rate of hydrolysis is a function of the cellulose surface area accessible to the hydrolytic agent. This fact translates to improved digestion of lignocellulosic crop residues with a decrease in the particle size of the material. Working with rice straw and bagasse, Agrawal et al. (1989) studied the effect of particle size on the *in vitro* digestibility. However, there has been no research directly investigating size reduction of the various CGT material (and crop residues in general) and the effects of this operation in enhancing ruminant digestibility. It has also been proven that treating CGT with sodium hydroxide increases rumen turnover (Conner and Richardson, 1987), but there has been no reported studies on the chemical pretreatment of segregated CGT types, much less the use of agitation and elevated process temperatures. (The term trash type as used in this paper refers to the trash material separated by a particular cleaning stage in the cotton ginning process.) Drymatter digestibilities of crop residues range from 35 to 60% with corn and sorghum plant material generally higher than small grain straws (Klopfenstein, 1980). Thomasson (1980) indicated that raw cotton gin trash had an *in vitro* digestibility of 34%, which falls in the lower end of crop residue digestibility range.

The objective of this study was to determine the effectiveness of particle size reduction and treatment with sodium hydroxide (NaOH) on *in vitro* ruminant digestibility (IVRD) of cotton gin trash. Both of these methods should aid in the breakdown of the lignocellulosic complexes thereby enhancing ruminant digestibility. The effects of CGT type, particle size, chemical concentration, and processing temperature were investigated.

Materials and Methods

Various types of CGT coming from the ginning of stripper and spindle picked cotton were obtained from a gin in West Tennessee. A consolidated sample of CGT cleaned from stripper harvested cotton was obtained from Texas. Listed in Table 2 are different CGT types tested and their moisture contents. Moisture content of all the CGT types were determined following ASTM Standard D 2495 (1987). Types A, B and F, G were mostly non-lint material whereas Types D, E and I, J were mostly lint.

Three experiments were performed in which all CGT types were tested. The effect of various particle sizes on IVRD was evaluated in the first experiment. In the second experiment, the effect of chemical concentration was evaluated while maintaining a constant particle size. In the third experiment, chemical concentration and particle size were held constant while testing the effect of different process temperatures. IVRD was evaluated for all samples using a Daisy II *In Vitro* Incubator (Ankom Technology, Fairport, New York).

Experiment 1

Duplicate samples of the various CGT were ground in a knife mill (Model P15, Glenmills, Inc., Clifton, NJ) using screen sizes 0.5, 1.0, and 2.0 mm in a randomized manner. The CGT type-grinding treatments were applied in the following a completely randomized design. Samples comprising the various type-particle size treatment combinations were then evaluated for *in vitro* ruminant digestibility

Experiment 2

CGT types ground through a 2.0 mm screen were used as the test material. Since greater energy is required to grind material to smaller particle sizes, it was decided that it would be more practical to undertake chemical treatment testing with the larger-sized test material. Each type was treated with 4% and 6% sodium hydroxide (w/w) on a drymatter basis. These concentrations used were based on recommendations from Han et al. (1983) using ryegrass as a test material. They concluded from their research that using these concentrations was the most practical when considering convenience, time, and effectiveness. Additional support for these choices was from Klopfenstein (1978), who noted that the level of treatment for the best response in the animal ranges from 3 to 5% NaOH of residue drymatter.

Chemical treatment was undertaken using a Kitchen Aid Classic stand mixer (Model K45SSWH, KitchenAid, Greenville, OH) as means of providing agitation and greater interaction between the sodium hydroxide solution and the CGT. Four such mixers were used simultaneously in order to speed up the time to accomplish the chemical treatment experiments. For optimum mixing effectiveness, a certain level of fill of material was required in the mixer bowl. It was decided that filling the bowl to one third of its total depth, approximately 8 cm, would allow for effective mixing. Each test was thereby started by pouring ground CGT up to the designated fill level. Since the CGT had different densities, there was therefore a difference in the total mass of material treated in a test. Drymatter of each mixer load was calculated based on the moisture content and the amount of NaOH to make a 4 or 6% treatment was then calculated and weighed. The sodium hydroxide was added to the CGT as an aqueous solution. The amount of water used in the solution was determined by observing the effectiveness of mixing in several test mixes. Visually, using a raw material to water ratio of 1:2 proved to be enough to homogeneously transport the NaOH, but not too much to hinder the handling of the wetted CGT. Based on preliminary testing, a solid to liquid ratio of 1:2 was set for the experiments in order to minimize the amount of water needed for the treatment process and minimize the potential amount of wastewater generated in an actual commercial process. The weighed pure sodium hydroxide was mixed in a beaker with an amount of distilled water equal to twice the weight of the CGT already in the mixer bowl. Since the weight of the solid sodium hydroxide was not considered in determining the weight of water needed, the solid to liquid ratio was actually just fractionally short of being 1:2. The mixer was set on low and mixing was cycled such that the mixer was on for 5 min. and off for 10 min. over a total mix time of 4 hr. The pretreated samples were transferred to airtight sample bags and stored in frozen storage (−17°C) until the remainder of the experimental treatments were completed. The experiment was conducted following a completely randomized design. Samples comprising the various type-NaOH concentration treatment combinations were then evaluated for *in vitro* ruminant digestibility. In undertaking statistical analysis, the results for CGT ground to 2 mm were used as the results for no chemical treatment.

Experiment 3

CGT types ground through a 2.0 mm screen were also used as the test material in this experiment. Each type was treated with 6% NaOH following Experiment 2 procedures with the use of temperature during mixing as a treatment variable [ambient (~25°C), 40°C, 50°C]. Electric rope heaters (Omegalux FR100, Omega Engineering, Inc., Stamford, CT) was coiled around the base of the mixing bowls to serve as the heat source. A light dimmer switch was used to regulate the power for the rope heater in order that the targeted elevated temperatures could be maintained. Temperature measurements were taken at frequent intervals with an infrared thermometer to verify that the targeted temperatures were closely being met. To prevent the material from charring on the bowl surface during processing, the heat was applied only when agitation occurred. Since the water evaporation rate increases with temperature, the total mixing time was reduced to 3 and 2 hr for 40°C and 50°C, respectively. Mixing time was retained as 4 hr for pretreatment at room temperature. The experiment was conducted following a completely randomized design. Pretreated samples were handled as in Experiment 2. Samples comprising the various type-process temperature treatment combinations were thereafter evaluated for *in vitro* ruminant digestibility.

Results and Discussion

Particle Size

As illustrated in Figure 1, IVRD increased as particle size decreased ($P<0.01$), which was expected. Grinding to 0.5 mm resulted in the highest IVRD of the three particle sizes evaluated, with an average digestibility of 47.8%. Grinding to 2.0 mm resulted in the lowest digestibility of 33.8%. It should also be noted that there were considerable differences in digestibility among different grinds (particle sizes) of the different CGT types. Generally, the types with higher fiber or lint content had lower digestibilities. This result was highly significant ($P<0.01$). It is also shown in Figure 1 that trash from the spindle harvested cotton generally had greater digestibilities than trash from the stripper harvested cotton ($P<0.01$). Trash from spindle harvested cotton ground through a 0.5 mm screen had an average digestibility of 58.8% while that from stripper harvested cotton only had an average digestibility of 37.8% (both material obtained from West Tennessee). The CGT from Texas, which was a mixture of all cleanings, had a digestibility of 44.1%.

NaOH Concentration

It is evident from Figure 2 that pretreatment of the CGT with either 4 or 6% NaOH (w/w) was very effective in improving IVRD compared to no chemical treatment ($P<0.01$). Treating the CGT with 6 % NaOH proved to be more effective in improving IVRD than using 4% for all types with an average IVRD of 70.5% compared to 60.6%. These values compare well to the 64% achieved by treating the CGT submerged in a caustic solution in which a superoxide species, e.g. hydrogen peroxide, is incorporated (Thomasson, 1990). The trash types coming from both spindle and stripper harvested cotton having more lint exhibited a greater positive IVRD response to NaOH pretreatment than the non-lint trash types ($P<0.01$).

Process Temperature

In general, applying heat during a chemical reaction increases its rate. Based on this and also because ratio of CGT to water was kept constant at ca. 1:2, the mixing times when mixing/chemical pretreatment was undertaken at elevated temperatures were reduced from the 4 hr used for most of the tests conducted. Preventing charring of the CGT was another reason for this change. It was hypothesized that the elevated process temperatures would counterbalance the reduction in treatment time. As shown in Figure 3, heating the CGT during chemical treatment and agitation resulted in a decrease in IVRD ($P<0.05$). This is explained by the loss of water from the mixtures during the course of processing. Water serves as both the medium for pretreatment chemical transport and a medium for heat transfer, so treatment effectiveness decreases as water evaporates during heating. This result shows that increased process temperature did not make up for the loss of processing time when other process variables were kept constant. At room temperature, the IVRD was 70.5% while at 50°C, IVRD was only 55.4%. It is likely that in order for elevated temperatures to effect improved digestibility, additional water would have to be added to compensate for evaporation during the course of the chemical pretreatment process.

Conclusions

Experiment 1 proved that size reduction was effective in enhancing IVRD of CGT. A concentration of 6% NaOH (w/w) was shown in Experiment 2 to be more effective in improving CGT digestibility than a 4% concentration. Lastly, Experiment 3 showed that undertaking agitated chemical pretreatment at elevated temperatures did not enhance IVRD because water, the medium for chemical transport and heat transfer, was evaporated. The average IVRD is shown in Table 3 for all experiments. For the range of experimental treatment factors studied, the most effective pretreatment of CGT would be to grind the material through a 0.5 mm screen and then treating the CGT with 6% NaOH (w/w) under agitation at room temperature for 4 hours. This certainly may not be the most efficient method when considering cost and practicality under commercial conditions. For instance, the extra power and/or time required to grind material through a 0.5 mm screen may not be worth the degree of IVRD enhancement when compared to IVRD levels for CGT ground through a 2.0 mm screen. An optimal target IVRD needs to be determined considering these factors.

This research study has only addressed the problem of CGT digestibility. The presence of residual pesticides in the CGT has not been investigated in this research. This represents a second hurdle that must be addressed before the use of CGT as a ruminant feed ingredient can be effectively moved forward.

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Table 1. Nutritive value of cotton gin trash.

Nutritional Component	Analysis
Estimated Net Energy Maintenance (MC*/Cwt)	46
Estimated Net Energy Production (MC/Cwt)	15
TDN Ruminant	45
Crude Protein (%)	7.0
Crude Fat (%)	1.5
Crude Fiber (%)	35.0
Ash (%)	10.0
Calcium (%)	0.15
Phosphorous - Total (%)	0.09
Potassium (%)	0.87

Source: Lalor et al., 1975
*MC = million calories

Table 2. Cotton gin trash types tested.

Code	Description	MC (%wb)
stripper harvested cotton – West Tennessee		
A	first stage cleaning – inclined cleaner (essentially burr and stick separator)	9.60
B	second stage cleaning – inclined cleaner	9.66
C	material underneath gin stand	8.21
D	first stage lint cleaner	7.17
E	second stage lint cleaner	5.65
spindle picker harvested cotton – West Tennessee		
F	first stage cleaning – inclined cleaner (essentially burr and stick separator)	8.99
G	second stage cleaning – inclined cleaner	8.75
H	material underneath gin stand	7.26
I	first stage lint cleaner	6.64
J	second stage lint cleaner	6.01
stripper harvested cotton - Texas		
M	mixture of all cleanings	8.76

Table 3. Pretreatment main effects on *in vitro* ruminant digestibility.

	Pretreatment				
Experiment No.	screen size (mm)	NaOH conc. (% w/w)	process temp. (°C)	agitation time (hr)	mean IVRD (%)
1	0.5	0	-	-	47.8
	1.0	0	-	-	37.4
	2.0	0	-	-	33.8
2	2.0	4	~25 (room)	4	60.6
	2.0	6	~25 (room)	4	70.5
3	2.0	6	~25 (room)	4	70.5
	2.0	6	40	3	65.2
	2.0	6	50	2	55.4

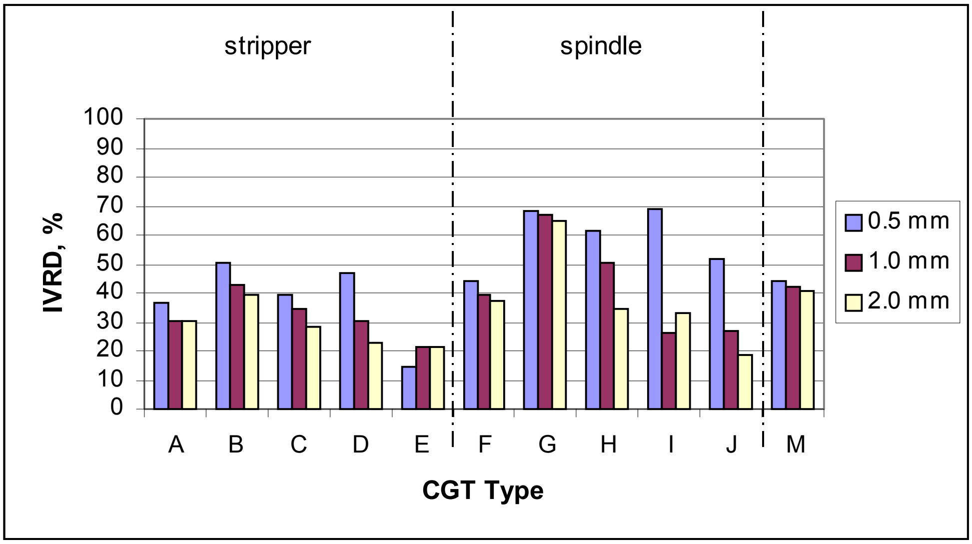

Figure 1. Effect of particle size on *in vitro* ruminant digestibility.

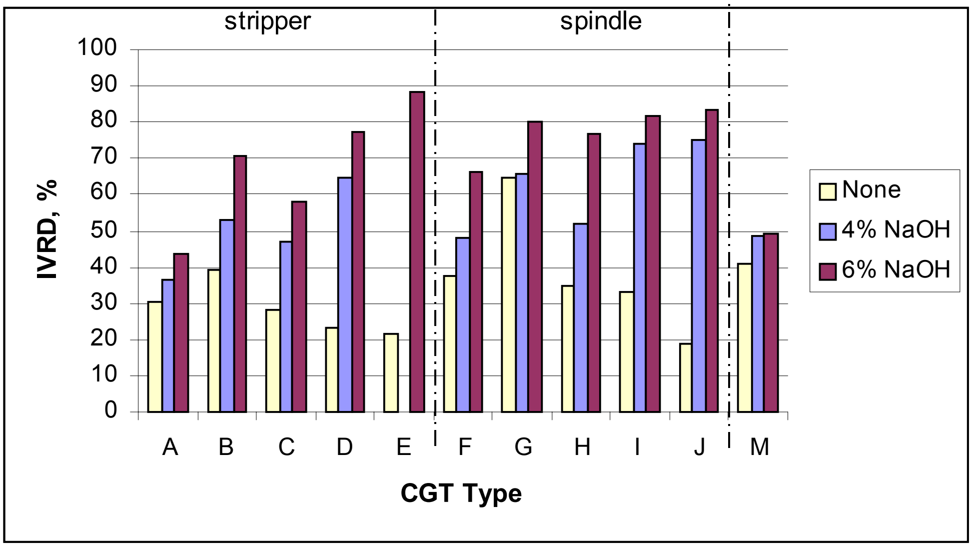

Figure 2. Effect of sodium hydroxide concentration on *in vitro* ruminant digestibility.

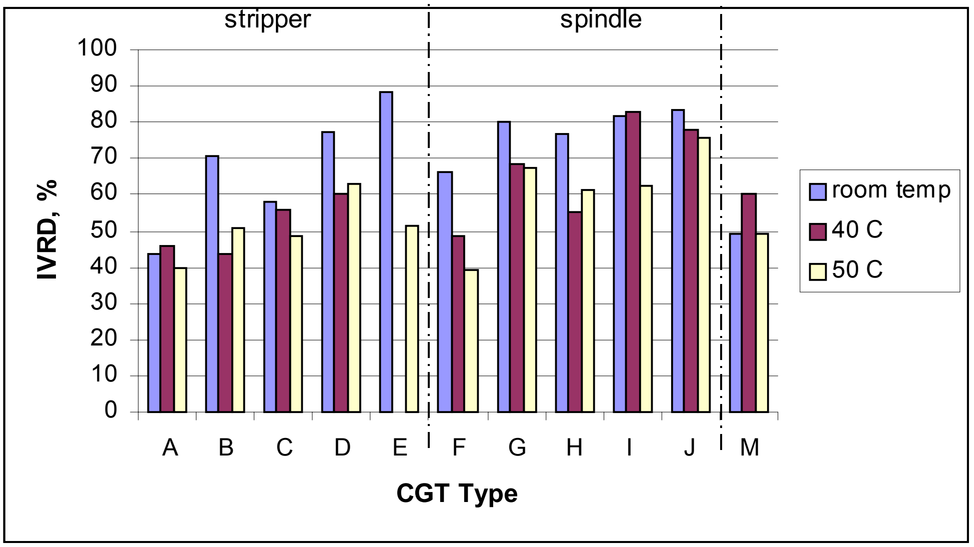

Figure 3. Effect of temperature at mixing on the effectivity of 6% (w/w) sodium hydroxide pretreatment.