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Utilization of byproducts from the tequila industry: part 1: agave bagasse as a raw material for animal feeding and fiberboard production

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Abstract

Agave bagasse was successfully separated into fractions that were used in sheep feeding trials. Agave bagasse can be substituted for corn stubble in the sheep's diet which resulted in improved weight gain. Agave bagasse was also processed into long and short fiber fractions with a hammermill and fiberboards of medium and high specific gravities being produced. Medium specific gravity agave fiberboards had moisture and mechanical properties comparable to medium specific gravity fiberboards made using aspen fiber. All high specific gravity agave fiberboards made from short or long fibers were stronger in bending than the ANSI standard for hardboards. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Agave bagasse is the residual fiber remaining after cooked agave heads are shredded, milled and the sugars water-extracted. The bagasse is primarily the rind and fibrovascular bundles dispersed throughout the interior of the agave head. It represents about 40% of the total weight of the milled agave on a wet weight basis. Bagasse is available all year in only two main regions of the tequila producing areas in Mexico: the Tequila region and the Jalisco Highlands. Bagasse is composed of fiber and pith. The fiber is thick walled and long (10–12 cm). Some bagasse is mixed with clay and used to make bricks. More bagasse finds its way, after mechanical pith separation and sun-drying, into mattresses, furniture and packing materials, but most of it is treated as waste and returned to the fields. In recent years, the tequila market has grown and gained international recognition. Market growth is expected to continue due to the recently recognized "tequila origin denomination" by the European Union, which means more tequila will be produced with a substantial improvement of the process and tequila quality. This will mean even more bagasse, increasing the disposal problems €or the tequila companies.

Research work on the use of agro-industrial waste is needed because of the serious economic and environmental problems caused by the disposal of these resources. The possibility of utilizing at least part of agave bagasse as an efficient ruminant feed could have a major impact on livestock production practices in areas where tequila is produced. The availability of energy to the ruminant animal from this source, as well from other lignocellulosic agricultural by-products, is limited by the close physical and chemical association between structural carbohydrates and lignin and the crystalline arrangement of the cellulose polymer in plant cell walls (Morris and Bacon, 1977; Hartley and Jones, 1978; Scalbert et al., 1985). Lignin is the most important factor limiting degradation of cellulose by microorganisms (Gould, 1984). There is also an increasing trend towards the use of lignocellulosic agricultural by-products in useful products, such as sound-proofing, thermal insulation and false ceilings (Sampathrajan et al., 1992; Raj and Kokta, 1991; Maldas and Kokta, 1990). The bagasse fiber could also be used to produce a wide variety of other products such as filters, sorbents, geotextiles,

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fiberboards, packaging, molded products or in combination with other resources. The purpose of the present study was to investigate the use of agave bagasse pith as a possible animal feed and the fiber for fiberboard production.

2. Methods

2.1. Pith separation

Initial fiber-pith separation trials were carried out in a small cylindrical depither similar to a hammer mill provided with circular sieve 45 cm high with a diameter of 35 cm. The sieves used had an opening of 9 and 12.7 cm. The hammers adhered to a vertical central shaft and were driven by a 45 Hp motor assembly. The depither was a top feeding apparatus allowing the fiber to fall freely to the bottom and the separated pith to be collected from the lateral cylinder wall. Besides the initial separation evaluation of the pith, mechanical separation also was carried out on pith separation using a screen opening size of 12.7 cm. For feeding trials, pith separation was carried out manually with a metallic sieve with an opening of 12.7 cm.

Large scale fiber-pith separation trials were carried out with a mechanical separator constructed for that purpose. The fiber-pith separator consisted of a steel horizontal static cylinder with a diameter of 60 cm and 2.65 m long with an influent hopper hole of 34 x 32 cm and effluent hole of 20 x 15 cm, placed in each end of the cylinder. Half of the cylinder (lower part) was constituted by three interchangeable sieves (63 cm width). The central part of the cylinder was constituted by a shaft driven by a 30 Hp motor assembly (SyPPA, S.A. de C.V. Fray Antonio de Segovia 1239, Col Atlas, Guadalajara, Jalisco, México). Two bearings were used to support the shaft to the framework beneath the separator. The unit was placed on a frame in order to obtain sufficient height to allow to load it. Around the shaft six array blades (eight blades per array) were united in a perpendicular fashion to insure adequate movement of the agave bagasse. Pith-fiber separation tests were carried out in this separator using several sieve openings and agave bagasse from different tequila factories. Separated fiber from “Sauza” tequila factory was used for fiberboard study.

2.2. Feeding trials

Pith separation was carried out manually with a metallic sieve with an opening size of 12.7 cm. The first feeding trial was conducted with 36 Pelibuey crossbred male sheep (average initial weight 18.8 kg). Animals were randomly assigned to one of 12 pens (three sheep per pen). Each pen was randomly assigned to one of three diets so that each dietary treatment was fed to four pens of sheep. Diets were based on (dry basis): (a) 79.3% ground corn, (b) 63.2% agave bagasse pith and (c) 63.2% ground corn stubble. The ingredient and chemical composition of experimental diets fed to sheep are shown in Table 1. Animals were fed ad libitum throughout a 56 day period. Water was made available ad libitum. Average daily gain was calculated from individual sheep weights obtained for each 14 day interval for 56 days. Feed intakes were measured and summarized for each pen of sheep with subsequent calculations of the feed:gain ratios.

A second feeding trial was conducted with 15 Pelibuey crossbred male sheep (average initial weight 23.2 kg). Animals were randomly assigned to one of five pens (three sheep per pen). Diet was based on agave bagasse pith. The ingredient and chemical composition of experimental diet fed to sheep are shown in Table 1. Animals were fed ad libitum throughout a 42 day period. Water was available ad libitum. Average daily gain was calculated from individual sheep weights obtained for each 14 day interval for 42 days. Feed intakes were measured and summarized for each pen of sheep with subsequent calculations of the feed:gain ratios as described for the first feeding trial.

Table 1
Ingredients of experimental rations fed to sheep

Ingredient (%)	Diet (Experiment 1)			Diet (Experiment 2)
	1	2	3	
% dry matter				
Sorghum grain, ground	–	–	–	20.0
Ground corn	79.3	–	–	22.0
Agave bagasse pith	–	63.2	–	28.0
Corn stubble	–	–	63.2	–
Dehydrated alfalfa, ground	15.0	15.0	15.0	12.0
Cane molasses	5.0	5.0	5.0	15.0
Fish meal	–	–	–	2.0
Soybean meal	–	15.6	15.6	–
Limestone	0.1	–	–	–
Calcium phosphate	–	0.2	0.2	–
Potassium carbonate	–	0.4	0.4	–
Urea	0.5	0.5	0.5	1.0
Vitamin premix	0.1	0.1	0.1	–
Chemical composition (%)[a]				
Dry matter (%)	87.4	45.6	90.0	47.0
Crude protein	12.5	12.7	15.6	12.6
NDF[b]	36.8	42.3	63.1	45.0
ADF[c]	8.8	36.5	36.6	25.2
Ash	4.8	9.0	8.5	5.0

[a] Dry basis.
[b] Nitrogen detergent fiber.
[c] Acid detergent fiber.

2.3. Chemical analyses

Dry matter, and ash were determined by AOAC (1984) procedures. Total nitrogen (N) was determined by the Kjeldahl procedure (AOAC, 1984). A factor of 6.25 was used to convert nitrogen to crude protein. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by methods described by Goering and Van Soest (1970).

2.4. Statistical analyses

Animal feeding data were subjected to analysis of variance for a completely randomized design using analysis of variance obtained from the SAS General Linear Models procedure (SAS User's Guide, 1979). Significance was declared at $P < 0.05$.

2.5. Fiber processing and fiberboard production

Dry processing of agave bagasse fiber for fiberboard production was done using three different procedures. Fiber was hammermilled using a screen size of 25.4 mm (Method A), hammermilled initially with a screen size of 12.7 mm followed by a screen size of 9.53 mm (Method B), or hammermilled using a screen size of 19.1 mm (Method C). Bagasse hammermilled using the methods B and C was separated into five fractions (dry remaining pith, long fiber, short fiber, fines and dust) using a commercial screener with screen sizes of 1.6 and 0.4 mm. Dry remaining pith and long fibers which did not pass the screen size of 1.6 were separated manually and weighed. Short fiber and fines were the fiber fractions which passed screen size of 1.6 but not the screen size of 0.4. Short fiber and fines were separated manually and weighed. Dust was the fraction which passed the 0.4 mm screen size.

Either the long or short fiber fractions (4.4 and 1.7 cm length) recovered from bagasse hammermilled using method C were used to form fiberboards with an approximate density of 1.0 and 0.64. Fibers were sprayed in a laboratory blender with a water soluble, 50% solid content, liquid phenolic resin. A resin level of 8% was used based on the oven-dry weight of each fiberboard. Long or short bagasse fiber, were hand-formed into a 30 cm × 30 cm randomly oriented mat and pressed at 190°C for 8 min.

Bagasse hammermilled using method A was sprayed in a laboratory blender with an 8% (based on oven-dry weight of the fiber) water soluble, 50% solid content, liquid phenolic resin. After resin application, the fiber (9 cm length) was allowed to dry and made into mats using a pilot scale Rando Webber airlaid mat-making machine (Rando Machine Corporation, The Commons, Macedon, New York 14502). Agave fiber mat was cut into pieces of 30 cm long. Fiberboards with an approximate specific gravity of 1.0 and 0.64 were manually formed into a 30 cm × 30 cm randomly oriented mat and pressed at 190°C for 8 min.

2.6. Strength tests

Static Bending tests were conducted on single fiberboard specimens (51 × 203 mm) conditioned to 65% relative humidity (RH), according to American Society for Testing and Materials standard D 1037 (ASTM, 1982) using a 150 mm span. From the bending data, modulus of rupture (MOR) and modulus of elasticity (MOE) were determined. Ten specimens from each fiberboard were tested and the results averaged. Tensile strength parallel to the board surface was conducted on board specimens (50.8 × 254 mm) conditioned to 65% relative humidity (RH) according to American Society for Testing and Materials standard D 1037 (ASTM, 1982). Ten specimens from each fiberboard were tested and the results averaged.

2.7. Humidity and water soaking tests

For RH tests oven-dried, weighed specimens from each fiberboard (5 × 5 cm) were placed in constant humidity rooms at 30%, 65% and 90% RH and 27°C. After 31 days, the specimens were weighed to determine the equilibrium moisture content and thickness measured to determine thickness swelling. After the EMC had been determined at 90% RH, the specimens were placed back in the 30% RH humidity room for an additional 31 days and EMC and swelling determined again. Five specimens from each fiberboard type were tested and the results averaged.

For water soaking tests oven-dried, preweighed specimens from each fiberboard (5 × 5 cm) were placed in a 28 × 26 cm container, 5 cm deep. Thickness measurements were taken using a flatbed micrometer. Water was added to the container and the board thickness recorded as a function of time. Measurements were taken in time increments up to 3 days, Each specimen was again oven-dried for 24 h at 105°C and weight and thickness determined. Five specimens from each fiberboard type were tested and the results averaged.

3. Results and discussion

The ingredients in the experimental design of the feeding trials and the chemical analysis of the feed are provided in Table 1. The results of the separation trials as well as the dry matter content of the agave bagasse and the various fractions collected are shown in Table 2. Using a sieve of 9 mm in the depither, the total yield of separated pith was 13.7%. This was too low a yield to be considered for animal feeding trials. Using a sieve of

Table 2
Results of agave bagasse separation

Item	Screen opening size (mm)	Fraction collected (%)[a]	Dry matter (%)
Agave bagasse		100	34.8
Separated pith	9	13.7	29.3
Agave fiber	9	86.3	35.1
Agave bagasse		100	29.9
Separated pith	12.7	53.6	31.1
Agave fiber	12.7	46.4	42.5
Agave bagasse		100	35.0
Separated pith	12.7	46.0[b]	29.3
Agave fiber	12.7	54.0	35.5

[a] Mean of three replicates.
[b] By hand.

12.7 mm in the depither, the yield of separated pith increased to 53.6% with 46.4% fiber left on the screen. The separated pith fraction was 31.1% dry solids while the fiber left on the screen was 42.5% dry solids. If the separation was done manually with the 12.7 mm screen, the yield of separated pith fraction was 46% with 64% fiber left on the screen. The separated pith fraction was 29.3% dry solids and the fiber remaining on the screen was 35.5% dry solids.

It was observed that in the machine separation, there was considerable mechanical breakup of the fiber, which ended up in the pith fraction. Since it is the pith fraction that is desirable to feed to animals, we did not want to include part of the fiber fraction in the feeding trails. For this reason, we chose to use the hand fractionated pith for feed trials since it contained a smaller fiber fraction.

The results for pith recovered from five different tequila factories using a specially designed bagasse separating system are shown in Table 3. The system uses three sets of separating screens as the raw bagasse moves though the separator. The first screen has openings of 2.54 cm, the second has openings of 2.54 cm while the third screen has openings of 1.9 cm (except for the Camichines plant where 2.54 cm screen was used in all three screens). As the raw bagasse moves through the separator, the pith is removed from the fiber. As can be seen in Table 3, the amount of recovered pith depends on the manner in which agave heads were processed for fermentable sugar extraction. For example, there was a significant difference ($P < 0.05$) between yield of recovered pith from the agave heads processed in "La Rojeña", Sauza and Camichines tequila factories. In the La Rojeña tequila factory, the bagasse comes from cooked, shredded and pressed agave heads in mills to extract the sugars. In the Sauza factory, the bagasse comes from shredded agave heads before cooking and sugars extraction in pressing mills. In the Camichines tequila factory, the bagasse comes from shredded agave heads, subjected to a sugars extraction process using hot water and in the processing mills. The extracted juice is cooked in a later step.

3.1. Feeding trials

In the first feeding trial, corn stubble was selected as a reference substrate (Table 1) to compare with agave bagasse pith. Corn stubble is one of the principal ingredients in animal feeding with a well-defined monetary and nutritional value in the regions where agave bagasse is produced.

The comparison of weight gain for sheep when fed on diets based on corn, agave bagasse pith and corn stubble are shown in Table 4. There were no significant differences ($P > 0.05$) in the average daily dry matter intake for animals fed on experimental diets. Average daily gain was higher (179 g) for animals fed on a diet based

Table 4
Comparison of sheep performance fed diets based on corn, agave bagasse pith and corn stubble

Item	Diet[a]			SEM[b]
	1	2	3	
Average daily gain (g)	179.0[c]	96.4[d]	72.1[d]	14.826
Dry matter intake (g/day)	783.0[c]	774.0[c]	772.0[c]	12.339
Feed/gain	4.4[c]	8.32[d]	11.12[c]	0.926

[a] For composition see Table 1.
[b] Standard error of the mean.
[c,d,e] Means in the same row with different superscripts differ ($P < 0.05$).

Table 3
Effects of screen mesh size on separation of agave bagasse from different sources

Tequila factory	Agave bagasse processed (kg)	Screen opening size (cm)[a] Screen			Recovered pith (%)
		1	2	3	
La Rojeña	100	2.54	2.54	1.90	36.0[a]
Sauza	100	2.54	2.54	1.90	56.0[a]
Orendain	100	2.54	2.54	1.90	45.3[a]
Viuda de Romero	100	2.54	2.54	1.90	43.5[a]
Camichines	100	2.54	2.54	2.54	38.3[b]

[a] Mean of five runs.
[b] Mean of eight runs.

Table 5
Sheep performance fed diet based on agave bagasse pith[a]

Item	Value[b]	SEM[c]
Average daily gain (g)	186.0	12.617
Dry matter intake (g/day)	1.077	0.056
Feed/gain	5.87	0.417

[a] For composition see Table I.
[b] Represents the mean of five pens with three animals per pen.
[c] Standard error of the mean.

Table 6
Effects of screen mesh size on separation of different agave bagasse fractions after grinding bagasse in hammermill with a screen size of 12.7 mm following with a screen size of 9.53 mm

Screen opening size (mm)	Recovered fraction (%)				
	Dry pith	Long fiber	Short fiber	Fines	Dust
1.6	12.2	13.0			
0.4			46.5	18.1	
Passing 0.4					10.2

on corn but there were no significant differences ($P > 0.05$) in the average weight gains between animals fed on the diet based on agave bagasse pith compared to those fed on the diet based on corn stubble. When the feed to gain ratio is considered, agave bagasse is more efficient in converting feed to weight gain than is corn stubble. An important aspect shown in this research is that agave bagasse pith could have the same economic value as corn stubble, with the advantage that agave bagasse pith is available all year and corn stubble only after corn harvesting.

The results of a second feeding experiment are shown in Table 5. Using the diet shown in Table 1 (last column), the average daily gain, dry matter intake and feed:gain ratio were 186 g, 1077 g/day and 5.87, respectively (Table 5). Data from previous experiments (Iñiguez et al., 1996 using a number 2 diet (Table 1) containing 28% corn stubble in place of agave bagasse pith show an average daily gain of 150 g, with a dry matter intake of 796 g/day and a feed:gain ratio 5.33 over a period of 56 days with an average initial sheep weight of 19 kg. Using the same diet the following data were obtained from a second experiment: average daily gain was 191 g, dry matter intake 1110 g/day and feed:gain ratio 5.9 in a period of 42 days with average initial sheep weight of 21 kg (Iñiguez et al., 1990).

Using the past data and the data collected in our latest experiment, it can be calculated that if 28% agave bagasse pith was used (on a dry weight basis) in place of corn stubble in the animal feed (50% on a wet basis) and animals consumed 2 kg of wet feed per day, then it is possible that a tequila factory such as Rojeña, producing 68 ton/day, with 36% pith recovered (Table 3), could feed 24,480 animals daily.

Table 7
Effects of screen mesh size on separation of different agave bagasse fractions after grinding bagasse in hammermill with a screen size of 19 mm

Screen opening size (mm)	Recovered fraction (%)				
	Dry pith	Long fiber	Short fiber	Fines	Dust
1.6	13.1	39.5			
0.4			23.6	14.1	
Passing 0.4					

Table 8
Equilibrium moisture content (EMC) and thickness swelling (TSw) at various relative humidities of agave fiberboards

Fiberboard	30% RH		65% RH		90% RH		90–30% RH			
	EMC	TSw	EMC	TSw	EMC	TSw	EMC	TSw	EMC	TSw
Medium sp gr short fiber[a]	3.2	0	6.6	0	15.2	6.35	15.2	6.17	4.6	1.48
High sp. gr. short fiber[b]	2.8	0	10.1	0	14.1	9.45	14.5	9.91	4.4	3.60
High sp. gr. long fiber[c]	3.1	0	6.6	0	15.7	11.35	15.7	9.89	4.5	4.00
High sp. gr. long fiber Rando mat[d]	3.1	0	6.6	0	15.5	15.91	15.2	14.85	4.4	6.11
Medium sp. gr. long fiber Rando mat[e]	3.1	0	6.7	0	16.5	11.06	15.4	10.92	4.4	5.17
Aspen fiberboard[f]	3.3	1.0	7.2	3.1	19.8	11.2	N.D.[g]	N.D.	N.D.	N.D.

[a] Average of five fiberboards with one sample per fiberboard, short fiber, specific gravity of 0.64.
[b] Average of six fiberboards with one sample per fiberboard, short fiber, specific gravity of 1.00.
[c] Average of five fiberboards with one sample per fiberboard, long fiber, specific gravity of 1.00.
[d] Average of five fiberboards with one sample per fiberboard, Rando mat, specific gravity of 1.00.
[e] Average of five fiberboards with one sample per fiberboard, Rando mat, specific gravity of 0.64.
[f] Average of five fiberboards using 8% phenolic resin, specific gravity of 0.64 (data from Rowell et at., 1991).
[g] N.D.: not determined.

3.2. Fiberboard production

The relative amounts of fiber sizes after processing the raw agave bagasse with a hammermill are shown in Tables 6 and 7. The data in Table 6 are from hammermilling the raw bagasse through two screens: 12.7 and 9.53 mm and then collecting long fiber on the 1.6 mm screen and short fiber on the 0.4 mm screen. The dry pith is the material that did not go through the 1.6 mm screen and was separated by hand from the long fiber. The fines were separated by hand from the short fiber and the dust passed through the 0.4 mm screen. The data in Table 7 are from hammermilling the raw bagasse through one screen of 19 mm. The same separations were done as described in Table 6. The long fiber fraction and the short fiber fraction were used to make fiberboards of different specific gravities.

The results of the RH testing of the fiberboards are shown in Table 8. As expected, the EMC values for all fiberboards were approximately the same at all relative humidities tested but the amount of swelling each board underwent at a given moisture content was different. The largest swelling was seen in the high specific gravity fiberboards made using the Rando forming equipment with the long fiber. The medium specific gravity fiberboard made using short fiber only swelled 6.4% at 90% RH. Cycling the 90% RH specimens back to 30% RH resulted in slightly higher EMC value for each fiberboard than was first obtained after the initial 30% test. This may be due to a more open structure that allows easier moisture access after initial swelling to 90% RH. Data previously published on medium specific gravity aspen fiberboards are included in the table to illustrate the relative differences between these fiberboards and those made from agave bagasse (Rowel1 et al., 1991), None of the agave fiberboards exhibited any swelling at both 30% and 65% RH but the aspen fiberboards did exhibit swelling at these relative humidities.

The results of the rate and extent of water swelling are shown in Table 9. The composite made using the high specific gravity long fiber from a Rando forming machine swelled faster and to a greater extent than any of the other fiberboards. The slowest rate and extent of swelling was in the medium specific gravity fiberboards made from short fibers. The weight loss in the fiberboards after water soaking varies from 4.4% to 7.7%. The lowest weight loss was in the high specific gravity fiberboards made from long fiber. The least amount of swelling after the water soaking test was in the medium specific gravity fiberboards made with short fiber. The rate and extent of swelling for medium specific gravity aspen fiberboards is also included for comparison. The aspen fiberboards exhibited a similar rate and extent of swelling as the medium specific gravity short fiber agave fiberboards. All of the agave fiberboards lost approximately 4–8% weight at the end of the test. The medium

Table 9
Rate and extent of thickness swelling of agave fiberboards

Fiberboard	Thickness gain (%)					Thickness gain (%)			Oven drying after 3 days	
	15 min	30 min	45 min	1 h	2 h	1 day	2 days	3 days	Weight loss (%)	Thickness gain (%)
Medium sp gr. short fiber[a]	14.6 (14.7)[b]	16.3 (13.8)	16.9 (18.3)	16.9 (17.6)	16.9 (16.3)	18.1 (17.4)[b]	18.3 (16.8)	19.0 (18.9)	6.1 (11.9)	9.0 (20.4)
High sp. gr. short fiber[c]	17.0 (40.5)	20.3 (35.9)	20.8 (35.2)	22.0 (35.1)	24.4 (33.9)	25.4 (35.4)	27.7 (34.2)	28.2 (31.0)	4.4 (8.1)	19.9 (62.6)
High sp. gr. long fiber[d]	20.3 (16.1)	25.2 (12.7)	27.8 (12.9)	29.0 (15.4)	30.4 (13.0)	35.6 (12.7)	38.6 (14.6)	40.6 (11.6)	6.5 (10.4)	30.2 (21.3)
High sp. gr. long fiber Rando mat[e]	33.0 (18.0)	40.6 (13.4)	41.2 (16.0)	44.7 (10.2)	43.3 (15.9)	48.3 (9.7)	49.3 (10.0)	50.8 (12.9)	7.7 (6.1)	41.3 (20.5)
Medium sp. gr. long fiber Rando mat[f]	30.3 (25.2)	30.3 (27.6)	32.6 (26.4)	33.2 (23.5)	32.8 (23.5)	34.4 (24.9)	35.5 (25.3)	35.8 (24.2)	6.8 (24.5)	26.2 (22.7)
Aspen fiberboard[g]	14.0	14.3	15.7	15.8	16.3	19.9	20.3	21.0	N.D.[h]	N.D.

[a] Average of five fiberboards with one sample per fiberboard, short fiber, specific gravity of 0.64.
[b] Coefficient of variation (%).
[c] Average of six fiberboards with one sample per fiberboard, short fiber, specific gravity of 1.00.
[d] Average of five fiberboards with one sample per fiberboard, long fiber, specific gravity of 1.00.
[e] Average of five fiberboards with one sample per fiberboard, Rando mat, specific gravity of 1.00.
[f] Average of five fiberboards with one sample per fiberboard, Rando mat, specific gravity of 0.64.
[g] Average of five fiberboards using 8% phenolic resin, specific gravity of 0.64 (data from Rowell et al., 1991).
[h] N.D.: not determined.

Table 10
Mechanical properties of agave fiberboards

Property fiberboard	Three point bendings		Tensions
	MOR (MPa)[a]	MOE (GPa)[b]	MOE (GPa)
Medium specific gravity short fiber	21.6 (11.9)[c]	1.31 (14.0)[d]	1.25 (18.3)[d]
High specific gravity short fiber	36.2 (9.0)	2.55 (10.1)[e]	2.12 (12.7)[f]
High specific gravity long fiber	36.7 (3.7)	2.17 (3.2)g	2.31 (19.1)[h]
High specific gravity long fiber Rando mat	40.9 (12.4)	2.28 (20.4)[i]	1.53 (13.8)[j]
Medium specific gravity long fiber Rando mat	15.5 (30.9)	1.09 (30.8)[k]	1.12(21.9)[k]
Aspen fiberboard[l]	17.2	1.45	–
ANSI Standard[m]	31.0	–	–

[a] MOE, modulus of elasticity.
[b] MOR, modulus of rupture.
[c] Coefficient of variation (%).
[d] Average of four fiberboards with one sample per fiberboard, short fiber, specific gravity of 0.64.
[e] Average of six fiberboards with one sample per fiberboard, short fiber, specific gravity of 1.00.
[f] Average of two fiberboards with one sample per fiberboard short fiber, specific gravity of 1.00.
[g] Average of four fiberboards with one sample per fiberboard, long fiber, specific gravity of 1.00.
[h] Average of three fiberboards with one sample per fiberboard, Rando mat, specific gravity of 1.00.
[i] Average of four fiberboards with one sample per fiberboard, Rando mat, specific gravity of 1.00. In MOR test one specimen went over max load.
[j] Average of two fiberboards with one sample per fiberboard, Rando mat with a specific gravity of 1.00. One specimen went over full scale range
[k] Average of four fiberboards with one sample per fiberboard, Rando mat, specific gravity of 0.64.
[l] Average of five fiberboards using 8% phenolic resin, specific gravity of 0.64 (data from Rowell et al.. 1991).
[m] American National Standard. Basic Hardboard, ANSI Standard ANSI/AHA 135.4.

specific gravity fiberboard made from short fiber exhibited the least amount of permanent swelling after the water swelling test (9.0%). The high specific density fiberboards made from long fiber Rando mats exhibited the greatest permanent spelling after the water swelling test (41.3%).

The results of the mechanical test on the agave fiberboards are shown in Table 10. The fiberboards with the highest MOR in bending were the high specific gravity boards made using the Rando forming machine and long fiber. The highest MOE in bending was in the high specific gravity fiberboards made using short fiber. The highest MOE in tension were the high specific gravity agave fiberboards made using short fiber. Medium specific gravity aspen fiberboards have an MOR in bending of 17.2 which is about the same as the medium specific gravity agave fiberboards. The ANSI standard value for MOR in bending for hardboard is 3 1.1 MPa so several of the fiberboards made from agave have higher MOR strength in bending than the standard (ANSI, 1982).

4. Conclusions

Agave bagasse was successfully separated into fractions that were used in animal feeding trials. Agave bagasse can be substituted for corn stubble which results in improved weight gain in sheep. Given that agave bagasse is slightly better than corn stubble in the diet of sheep, agave bagasse could have a commercial value equal to that of corn stubble. Agave bagasse, hammer-milled into long and short fiber fractions and medium specific gravity fiberboards had similar moisture and mechanical properties as compared to medium specific gravity fiberboards made using aspen fiber. All high specific gravity agave fiberboards made from short or long fibers were stronger in bending than the ANSI standard for hardboards. The results of this research show that new, cost effective uses are available for agave bagasse which is, at present, a low value waste by-product of the tequila industry.

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