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Evaluation of particle board production from cotton gin waste and urea-formaldehyde resin

Evaluación de la producción de tableros de partículas a partir de residuos de desmotadora de algodón y resina de urea-formaldehído

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Abstract. - *The objective of this study is the evaluation of the feasibility of producing particleboard for general use using cotton gin waste generated in Argentina and urea formaldehyde resin. The chemical composition and size distribution of particles of the ginning residue as well as mechanical and physical properties of the particleboards obtained were investigated. The Density and flexural strength of particleboards produced by varying levels of urea-formaldehyde resin between 8.3 and 19.3% (solid to solid ratio) were evaluated. The effect of incorporating jute reinforcement on the mechanical properties of these boards was also analyzed. Particleboards with densities between 530 and 700 kg/m3 and variable flexural strength between 0.30 and 5.85 MPa were obtained, allowing the minimum levels required for low-density boards to be reached. Strength values achieved allow this particleboard to be used in applications without structural requirements, such as door core or insulation.*

Keywords: Cotton gin residue; Urea-formaldehyde resin; Particleboards; Jute.

Resumen. - *El objetivo de este estudio es la evaluación de la factibilidad de producir tableros de partículas para uso general utilizando residuos de desmotadora de algodón generados en Argentina y resina de urea formaldehído. Se investigó la composición química y distribución de tamaño de las partículas del residuo del desmotado, así como las propiedades mecánicas y físicas de los tableros de partículas obtenidos. Se evaluó la densidad y la resistencia a la flexión de los tableros de partículas producidos por niveles variables de resina de urea-formaldehído entre el 8,3 y el 19,3% (proporción de sólido a sólido). También se analizó el efecto de incorporar refuerzo de yute sobre las propiedades mecánicas de estos tableros. Se obtuvieron tableros de partículas con densidades entre 530 y 700 kg / m3 y resistencia a la flexión variable entre 0,30 y 5,85 MPa, lo que permitió alcanzar los niveles mínimos requeridos para los tableros de baja densidad. Los valores de resistencia alcanzados permiten que este tablero de partículas se utilice en aplicaciones sin requisitos estructurales, como el núcleo de la puerta o el aislamiento.*

Palabras clave: Residuos de desmotadora de algodón; Resina de urea-formaldehído; Tableros de partículas; Yute.

1. Introduction

Cotton production in the north of Santa Fe province, is an important productive activity, as in Chaco, Formosa, Santiago del Estero and Corrientes, showing high geographical concentration. This productive activity presents some troubles that should be addressed.

In previous harvests, about 1,000,000 tons of bulk cotton were obtained, leaving behind more than 300,000 tons (approximately 1,195,000 cubic meters) of cotton gin waste (> 30 %), consisting of fibril, carpels, and other components, without any intended destination [1].

In recent decades the use of mechanical harvesting has become widespread, notably improving the profitability of the crop, but producing a greater amount of ginning residue that must be disposed of effectively, generating drawbacks and extraordinary costs to the ginning sector [2].

This waste, which is usually stockpiled in the open air, result in an exceptional habitat for vermin and rodents and, likewise, they are self-igniting, thus representing a danger to nearby communities.

Another characteristic of the ginning sector that is important to bear in mind is that it carries out intensive activities for approximately 100 days a year, in correspondence with harvest-ginning campaigns, and then dedicates itself to maintenance activities or other related activities (processing of seeds) with minimal staff requirements. This situation results in a reduction of personnel or a reduction in working hours (and therefore remuneration) of the local population.
One aspect of cotton production that threatens the implementation of complex technologies in order to reuse ginning waste is the variability of the interannual production, registering in the last decades campaigns that oscillate between 386,676 and 1,032,545 t of raw cotton, according to data from the Ministry of Agroindustry and CCIA [2].

Currently attempts are being made to use ginning residues as livestock feed, although it is very limited because of the low digestibility of the material, which barely exceeds 20 %, a very low value compared to other feed options [3-4].

Another use is composting, which appears to be the most viable solution, although cotton gin waste diffusion as a material to make compost is somewhat limited and of low profitability [5-6].

Unfortunately, in most cases these ginning residues are burned. Because most of the ginning plants are located within the urban zones, they originate serious pollution problems, with any solution proposals, and which cause discomfort among the residents of the surrounding neighborhoods, who fear suffering some kind of illness or respiratory affection. Hence, risks associated with the burning of residues that may be contaminated with toxic agrochemicals must be considered [7-10].

Finally, although other possible uses such as hydrolysis or pyrolysis are identified, the high added value of the obtainable products is offset by the excessive cost of installations and operation, and the requirement for qualified labor.

In this scenario, the possibility of developing innovative construction elements with cotton gin waste could help in addressing both environmental and social problems in this agro-industrial sector, as well as offering new materials for application in building or simple furniture manufacturing. In this direction, possible applications are envisioned in order to improve the habitability conditions of homes, since in the northern region of Santa Fe province, there is a high percentage of constructions with serious problems in their vertical and horizontal enclosures [11].

The production of panels based on lignocellulosic residues constitutes a dry construction technology with thermoacoustic insulating

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characteristics and good resistance to degradation. Numerous studies have been detected that propose the recovery of waste and its application in particleboards, some of them proposing these technologies as substitutes for wood particleboards [12-24]. Some research carried out in our country arouses special interest, aimed at the production of panels based on corn marl [12], used as lightweight, insulating and easy-to-install ceiling plates. This type of element could become a mechanical barrier in order to prevent the attack by the kissing bug and thus reduce the appearance of Chagas disease.

Dr. Mariana Gatani has carried out research work in which peanut shells are used for the development of particleboards intended for the construction of enclosures and ceilings and furniture [14-16].

In the present paper, some research advances are presented on characteristics of the cotton gin waste, its conditioning, the possibility of obtaining particleboards, the properties achieved, and the future perspectives identified in this investigation.

2. Materials and methods

Cotton gin waste used for the particleboards elaboration was obtained from stockpiles of a ginning plant located in Santa Fe province (Argentina). This residue is composed of cotton fiber that cannot be separated in the industrial process, carpels, branches of different sizes, leaves, and dust that is incorporated during collection (Fig. 3).

These residues were chipped in a hammermill (LOYTO N ° 2), equipped with a 16 mm sieve and 8 floating steel hammers. The granulometric characterization of the ground and unmilled ginning residue was carried out, after manual homogenization of the samples and reduction of their size by quartering. Sieves employed were: N° ½” (12.5 mm), N° 3/8” (9.5 mm), N° 4 (4.75mm), N° 8 (2.36 mm), N° 16 (1.18 mm) and N° 30 (0.6 mm), determining the weight of the material retained in each one of them.

pH determinations [25], solubility in 1% NaOH (TAPPI 212 om-02), solubility in cold and hot water (TAPPI 207 om-93) were performed on cotton gin waste. Results of solubility in hot and cold water were corrected according to the ash content. The average of two measurements was reported.

After milling process, all the chips were dried, at oven at 105 ± 2 °C, to 3 % moisture content from a natural moisture level of 16 %.

Subsequently, the ginning residue was manually mixed with the urea formaldehyde resin, with a minimum solid content of 65 %, density of 1.26 g/cm^3, gelation time at 100 ºC of 6 min and viscosity at 25 ºC of 950 cps. Water was added to the resin to achieve solid content of 55 % and a 5 % saturated ammonium sulphate solution was used as a catalyst.

Resin content used for particleboard manufacturing, varied from 8.3 % to 19.3 % (based on oven dry weight of the particles).

After mixture homogenization, it was placed in a mold, pressed until reaching a maximum pressure of 4.75 MPa and then maintained at 70 °C for 30 minutes, obtaining boards with nominal dimensions of 170 x 170 x 10 mm (Figure 1).

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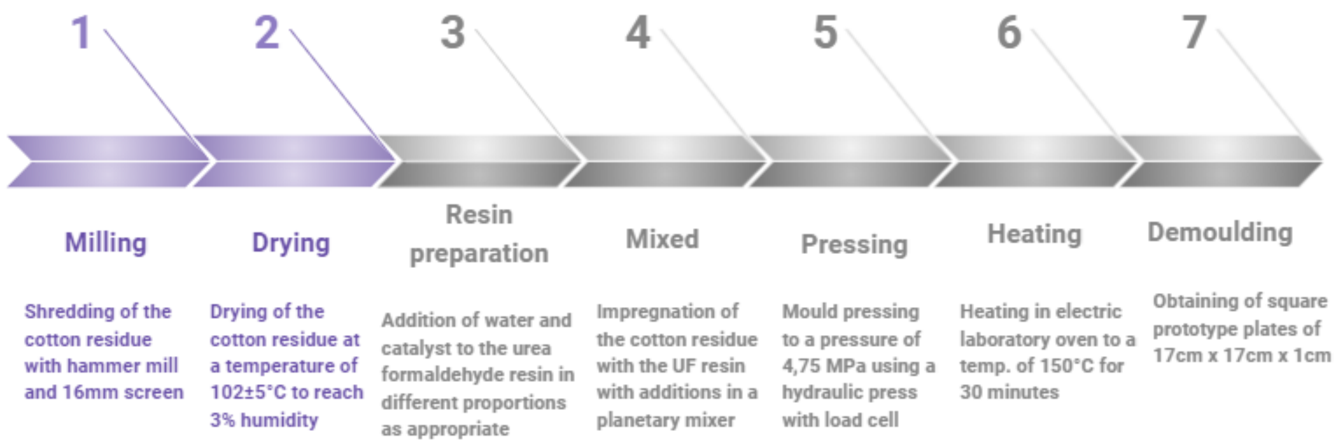

Figure 1. Molding scheme

The use of bidirectional jute fabric with a surface density of 252 g/m^2 was evaluated as a reinforcement (Figure 2). It was impregnated with the same proportion of resin as the ginning residue [20].

On particleboards obtained, determinations of density, bending strength and modulus of elasticity were made.

Density was determined according to IRAM 9705 procedure.

Bending strength was carried out according to the guidelines of IRAM 9706, maintaining a specimen length of 160 mm. Molded samples were cut into 4 specimens of nominal dimensions 160 x 40 x 10 mm. These specimens were conditioned for 48 to 72 hours prior to the test, in a controlled environment at 20 ± 2 °C and 65 ± 5 % relative humidity. The load was applied in the center of the span (140 mm), at a constant deformation rate of 12 mm/min, until the failure of the specimen was verified.

Figure 2. Bidirectional jute fabric

3. Results and discussion

Natural cotton gin waste has concave shapes, which makes impossible to achieve an adequate adhesion between particles. For this reason, it was decided to grind this material, achieving greater uniformity in particle size and improving its morphological characteristics.

Table 1 shows the amount of residue particles retained on each sieve, both for the residue in its natural condition and for the chipped material. It is noted that the fraction greater than 4.75 mm is drastically reduced by grinding, corresponding to 95.85 % for the natural residue, while in the chipped material it reaches 54.8 %.

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For chipped residue the amount of particles smaller than 600 µm is 8.86 %, and it is constituted by very fine remains of particles and dust, which must be discarded in order to manufacture particleboards due to its great adhesive demand.

Table 1. Particle size distribution in cotton gin waste

Sieve		Individual retained (%)	
No.	Sieve size (mm)	Natural waste	Chipped waste
1/2”	12.50	- - - -	24.28
3/8”	9.50	- - - -	8.86
4	4.75	95.85	21.66
8	2.36	- - - -	17.05
16	1.18	1.93	13.16
30	0.60	- - - -	6.13
100	0.15	1.04	- - - -
Bottom		1.18	8.86

It can be appreciated a diversity of particle sizes between 12.6 and 0.6 mm in the ground material, since there are significant percentages retained in each sieve. Consequently, length to thickness ratio varies from 3 to 18. From the photographs of each fraction retained on sieves (Figure 3), different particle morphologies can be observed, the most irregular ones corresponding to the larger sizes and the flatter ones to the smaller sizes. Brumbaugh [31] studied the effect of wood flake size and indicated MOR values increased as the length to thickness ratio increased to 250 and remained constant at higher ratios, significantly different from cotton gin particles used in this investigation.

The results of solubility in 1% NaOH, in cold and hot water of the residue are shown in table 2. pH of the residue resulted equals to 5 for cold water determination and 6,4 for hot water determination. Cold water procedure constitutes a measure of components such as tannins, gums, sugars and coloring materials. Hot water procedure also measures the starch, while the NaOH extractions show the presence of low molecular weight carbohydrates, mainly hemicelluloses present in the sample.

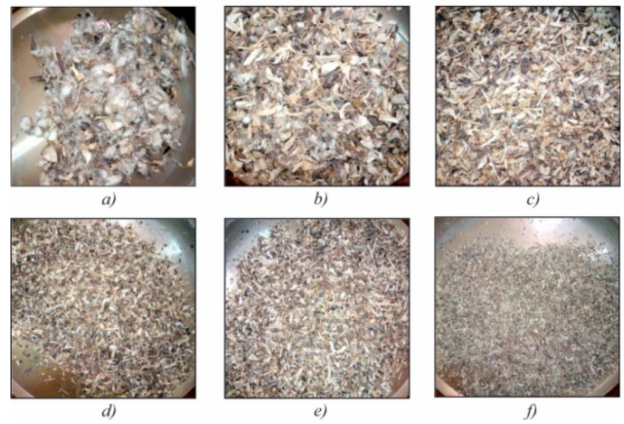

Figure 3. Morphology of chipped cotton gin waste retained in sieves: a) retained over ½”; b) passing ½”, ret. 3/8”; c) passing 3/8”, ret. 4.75 mm; d) passing 4.75 mm, ret. 2.36 mm; e) passing 2.36 mm, ret. 1.18mm; f) passing 1.18 mm, ret. 0.6 mm.

The comparison of the soluble components presents in the ginning residue, with respect to other materials such as hard and soft woods, cereal stubble, and shells from other crops, such as peanut and hazelnut shells, indicates values higher than most of the species used in other investigations, with the sole exception of hazelnut shells [27-29]. In previous works [32] it was found that by soaking ginning residue under ambient conditions for 48 hours, it was possible to reduce soluble components content at the same time that residue wettability was improved. This improvement cotton carpels also verified by HakkiAlma et al. [30] as boards made with cotton carpels soaked for 2 weeks under ambient conditions showed less thickness swelling and higher levels of bending strength. These changes in the wettability of the residue could explain the poor adhesion between the urea formaldehyde resin and the residue in its natural state. At the same time, inequity of pH of residue and resin can hinder good bonding between them and hardening of resin [34-35]. Level of pH of cotton gin waste is 5 to 6.4, and the resin presents a pH value of 8, resulting relatively different.

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Table 2. Cotton gin waste chemical analysis.

Chemical component	Percent
1 % NaOH solubility	46.0
Hot water solubility	16.1
Cold water solubility	11.9
pH in cold water	5.0
pH in hot water	6.4

Table 3 shows the average values of density, bending strength (MOR) and modulus of elasticity (MOE) obtained for the particleboards made of cotton gin waste. Samples produced without reinforcement are called N and those with incorporation of bidirectional jute sheet on each face are identified as N + Y. Bidirectional jute sheets bonded to the particleboard covered the total surface of each of the 170 x 170 mm faces (Figure 4).

Figure 4. Panels obtained in the mouldings: (a) without incorporation of reinforcement; (b) with incorporation of bidirectional jute sheeting

Table 3. Physical and mechanical properties of cotton gin waste particleboards.

Sample	Pressure (MPa)	Adhesive (%)	Density (kg/m^3)	MOR (MPa)	MOE (MPa)
V-N	4.75	8.3	530	0.30	15
V-N+Y	4.75	8.3	600	1.04	62
U-N	4.75	11.9	610	1.62	138
U-N+Y	4.75	11.9	600	3.06	160
R-N	4.75	15.1	630	3.15	269
R-N+Y	4.75	15.1	700	5.53	358
S-N	4.75	19.3	630	3.05	324
S-N+Y	4.75	19.3	670	5.85	390

Particleboard density varies between 0.53 g/cm^3 to 0.63 g/cm^3 for those that do not incorporate reinforcement (N) and between 0.60 g/cm^3 to 0.70 g/ cm^3 for the N + Y samples. In figure 5 it can be seen that as the resin content increases, there is an increase in density. This behavior is similar for all particleboards, regardless of the presence of reinforcement (Fig. 5) up to a content of 15.1 %.

Density values obtained place unreinforced particleboards in the low density (LD) classification according to the ANSI A208.1 standard [33], which establishes an upper limit of 640 kg/m^3. At the same time, the incorporation of bidirectional jute reinforcement increases the density values, reaching, for the highest percentage of resin, the classification of medium density (M) according to ANSI A208.1 (640 to 800 kg/m^3) [33].

Commercial particleboards available in the area present density values between 610 and 690 kg/m^3, which are similar to those corresponding to the experimental boards obtained. For these commercial boards bending strength is between 8.5 to 19 MPa, modulus of elasticity between 1200 to 2300 MPa and the adhesive consumption generally varies from 2.5 to 10 % of the weight of the board. As can be appreciated resin content levels are much lower than that required when using cotton gin residue [28,36].

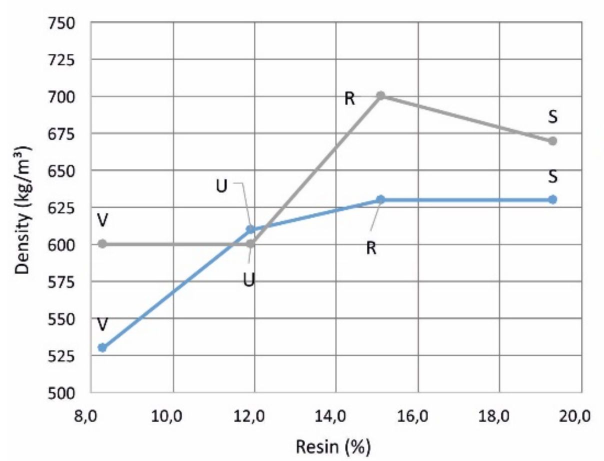

Figure 5. Particleboard's density

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Results of bending strength (MOR) of particleboards produced (Table 3) indicate that the increase in the resin content allows increasing bending strength values, both in the case of plane panels as well as for panels with jute reinforcement. ANSI A208.1 [33] establishes a minimum bending strength value of 3 N/mm^2 for LD-1 panels and 5 N/mm^2 for those classified as LD-2. In the case of medium density panels (M), the required bending strength value corresponds to 11 N/mm^2. According to this standard, the panels classified as low density (LD-1 and LD-2) are reserved for their application doors insides, while those classified as medium density (M) can be used in commercial, industrial and construction applications. It can be seen that, in the case of samples without reinforcement, it is only possible to reach the minimum value of bending strength for resin contents of 19.3 %. The particleboards that incorporate reinforcement reach a minimum of 3 N/mm^2 and 5 N/mm^2, for resin contents of 11.9 % and 15.1 %, respectively.

Results obtained indicate that the increase in the density of the material and the resin content have a positive effect on the development of strength (Figure 6) as well as on the stiffness, evidenced by the increase in the modulus of elasticity (MOE) (Figure 7).

In Figure 8 it can be observed that as the resin content increases, the strength difference between samples with and without jute reinforcement increases. It can be explained given that the adhesion between jute and cotton gin waste also increases. When adding jute fabric, although the density does not change significantly, bending strength of particleboards increases, since the jute acts as a mechanical reinforcement, about 3 MPa for 19.3 % of resin, allowing boards to achieve values established by the ANSI A208.1 standard [33]. This effect is not very significant for lower resin contents, since up to 11.90 % resin content it is appreciated that this reinforcement tends to detach from the panel when the failure approaches (Figure 9a). On the contrary, for resin contents of 15.1 and 19.3 % the jute remains adhered and the breakage of its fibers is observed, showing an effective collaboration that improves mechanical behavior.

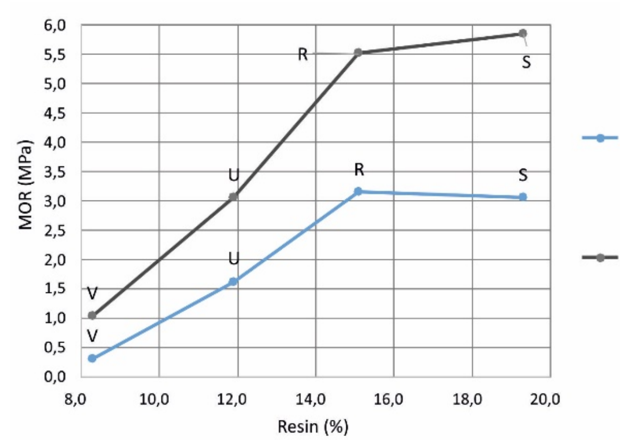

Figure 6. Particleboards bending strength

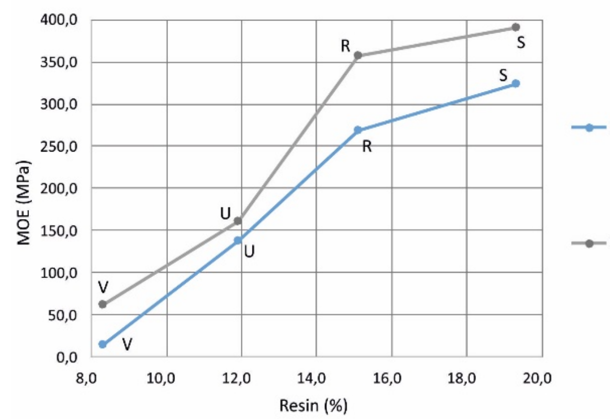

Figure 7. Particleboard's modulus of elasticity

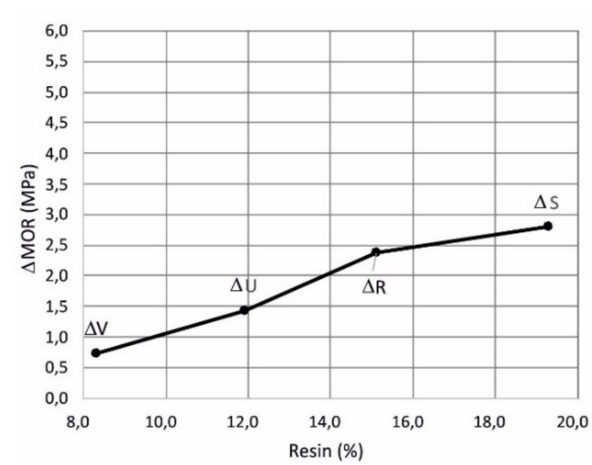

Figure 8. Differential increment in bending strength due to reinforcement incorporation

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a) b) c)

Figure 9. Particleboards with jute reinforcementfailure: a) samples U (N+Y); b) samples R (N+Y); c) samples S (N+Y).

Although no other investigations using complete ginning residue have been detected, it has been possible to identify works from other authors working with stalks of cotton plants and carpels, respectively [17, 26-27, 29, 31]. Güller used stalks from cotton plants to make particleboards with urea formaldehyde resin contents of 8 % for the central layer and 10 % for the outer layers. For these particleboards, he obtained densities of 600 and 800 kg/m^3 and bending strength of 11.4 and 15.67 MPa, respectively [17].

This author obtained, for particleboards from cotton stalks and urea formaldehyde resin, variable strength values depending on the resin content of the internal (ML) and external (OL) layers and the final density of 4.38 MPa (density 400 kg/m^3 – 10 % ML – 12 % OL), 8.79 MPa (density 500 kg/m^3 – 10 % ML – 12 % OL), 12.36 MPa (density 600 kg/m^3 – 10 % ML – 12 % OL) and 16.79 MPa (density 700 kg/m^3 – 10 % ML – 12 % OL) [16]. HakkiAlma et al. made particleboards with cotton carpels with urea formaldehyde resin contents of 9 % for the central layer and 11 % for the outer layers. For these boards, he obtained densities of 668 to 693 kg/m^3 and bending strength of approximately 10.5 (unsoaked chips) and 11.5 MPa (chips soaked for 2 weeks) [30].

Results of modulus of elasticity (MOE) are much lower than those achieved by Güller [17], which reached 2004 and 2705 MPa for panels with urea formaldehyde resin contents of 8 % for the central layer and 10 % for the outer layers. Pirayesh et al [21] obtained for walnut shell agglomerates and 9 to 11 % urea formaldehyde resin content, bending strength values of 6.63 MPa and MOE of 1208.9 MPa.

It is evident that strength level obtained for the particleboards made with the complete ginning residue is affected by its heterogeneity and the presence of particles of different shapes and sizes such as carpels, branches of various sizes and leaves, since the development of adherence between these components is very complex. Thus, it is also diminished by the presence of cotton fibers, which, due to their high surface area and knotting, complicates a complete and uniform impregnation with resin, generating poorly bonded resin-fiber cores where the strength decreases considerably.

4. Conclusions

From the results obtained in the research, it can be concluded that:

- It is possible to produce particleboards from cotton gin waste and urea-formaldehyde resin with properties close to those of low-density commercial boards, complying with the minimum requirements demanded by the standards. Incorporation of jute reinforcements significantly increases bending strength of particleboards, reaching levels required for low density boards by the ANSI 208.1 standard, without incorporating complex steps in the productive process.
- Finding this type of new application area for cotton gin residue can lead to decreasing pressure on the forests, alleviation of raw material shortage of wood industry in developing countries and provide a second income for this crop along with environmental benefits.
- The characteristics of the residue cause important demands for resin to achieve acceptable

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physical and mechanical behavior of the particleboards, which translates into higher production costs. Simultaneously, high contents of urea-formaldehyde resin are related to considerable formaldehyde emissions that could be harmful to health.

- From the above arises the need to evaluate alternative of replacement of urea-formaldehyde resin for another one with greater compatibility with cotton gin waste in order to increase strength levels, or the incorporation of formaldehyde sequestering additives to reduce emission levels of this compound.

5. Acknowledgements

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6.- Authorship and Contribution

Agustina Trevisan: Methodology; validation; formal analysis; research; data curation; writing original draft; writing: revision and editing; visualization. *Luciano Gabriel Massons:* Methodology; validation; research; data curation; writing original draft; writing: revision and editing; visualization. *Florencia Benítez:* Validation; research; data curation; writing original draft; writing: revision and editing; visualization. *María Fernanda Carrasco:* Methodology; validation; formal analysis; resources; writing original draft; writing: revision and editing; visualization; supervision; project administration, acquisition of funds. *Rubén Marcos Grether:* validation; data curation; visualization; supervision. *Ariel Anselmo González:* Validation; data curation; writing original draft; writing: revision and editing.

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