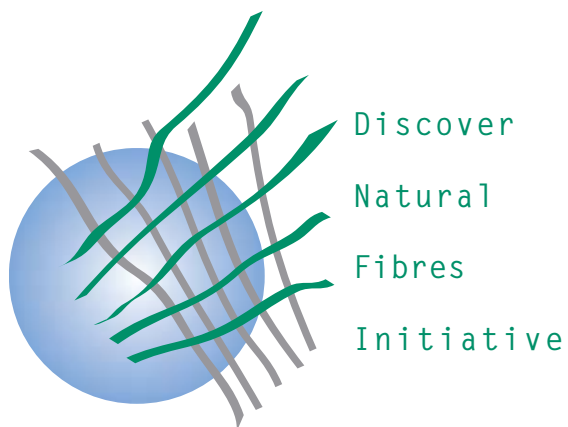




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Introduction

Gossypols were isolated from cotton seeds for the first time in 1886. The cotton plant has many cotton seed pigments, and gossypols make up 35-50% of total intra-glandular pigments. The varieties that could be of great interest to breeders are those whose gossypol glands are few or completely absent in the embryos, but other plant parts have normal gossypols. Research conducted in many countries has demonstrated that the presence of gossypol slows insect multiplication. The World Health Organization recommended that free gossypol and total gossypol may not constitute more than 0.06% and 1.2% of cotton flour respectively, if cotton flour is to be consumed by humans. The Food and Drug Administration of the USA has set a gossypol limit of 0.045% or 450 ppm in cotton flour for human consumption. Some biotech approaches, including one carried out by Cotton Incorporated in the USA, shows that RNAi-mediated gossypol reduction is restricted to the developing embryo and the kernel in mature seed. Thus, the defensive capabilities offered by the remaining plant organs stemming from gossypol and related terpenoids, were not compromised in RNAi lines. Extensive lab testing and field trials are underway to select one event that has the least amount of gossypol in the seed without any loss of gossypol in other parts of the plant. It is yet to be confirmed that the final event has no negative effect on yield, fiber quality or other aspects of even an agronomic nature. The first article is focused on producing low-gossypol or gossypol-free cotton seed while maintaining normal glands in the aerial parts of the plant.

The next two articles are on utilization of cotton stalks for making particle boards. Cotton stalks are rich in cellulose and have a composition and fiber structure comparable to that of many hardwood plants. There are many reasons to utilize cotton stalks more efficiently than just burning them in fields or mulching them into the soil. The Central Institute for Research on Cotton Technology, India, has been working on the use of cotton stalks for many years. The Common Fund for Commodities (CFC) approved a four-year project on Utilization of Cotton By-produce for Value-added Products in October 2004. The project CFC/ICAC 20 was designed to

demonstrate commercial feasibility by installing and operating a pilot plant capable of producing one ton of particle board per day. The Central Institute for Research on Cotton Technology of the Indian Council of Agricultural Research implemented the project. The article 'Particle Boards from Cotton Stalks' describes the need and quality of boards made from cotton stalks. The data show that cotton stalks can be used to make particle board of a quality rivaling board made from wood, which is the most common raw material used by the particle board and plywood industries. The last article is more specific to the CFC/ICAC 20 project. As the technology to make particle board from cotton stalks progress, there is also a need to create demand for these materials at the end-use level. This can only happen if cotton-stalk board is at least equivalent in quality to the boards available in the market. The challenges to expanding demand for boards made from cotton stalks are: high level of consistency, minimal density variation and close thickness tolerances topped with superior surfaces.

10th Meeting of the Southern and Eastern African Cotton Forum (SEACF)

The 10th Meeting of the Southern and Eastern African Cotton Forum (SEACF) was held in Lusaka, Zambia from 9-10 March 2010. Delegates from Ethiopia, Kenya, Mozambique, Namibia, South Africa, Tanzania, Zambia, Zimbabwe, CABI and ICAC attended the meeting. The business meeting of SEACF took place on 9 March and a workshop on "Integrated Pest Management" on March 10, 2010. During the business meeting, country representatives provided updates on recent developments and changes in cotton production research in their respective countries. The meeting elected Mr. West K. Chitah as the Chairman of SEACF.

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Dr. Graham Thompson <GThompson@arc.agric.za> will continue his contributions to SEACF as Forum Coordinator, and the Institute of Industrial Crops will continue hosting the SEACF secretariat. For many years, Dr. Annette Swanepoel of South Africa <aswanepoel@agri.ncape.gov.za> provided great support in strengthening the SEACF and helped to organize many meetings of SEACF. The meeting in Lusaka acknowledged Dr. Swanepoel's contributions and wished her success in her new job. All documents of the meeting are available on the ICAC web page at <http://www.icac.org/tis/regional_networks/africa_forum.html>.

11th Meeting of the Latin American Association for Cotton Research and Development - ALIDA

The 11th Meeting of the Latin American Association for Cotton Research and Development (ALIDA) will be held in Resistencia, Chaco, Argentina from June 22-25, 2010. Preparations are underway, and all information is posted on the ICAC web page at <<http://alida-algodon.org>>. Participation in ALIDA meetings is open to all countries; ALIDA meetings are conducted in Spanish. The ICAC is sponsoring the meeting and encourages researchers from the region to attend the meeting. The Government of Argentina has nominated Ing. Agr. Diana Piedra as the Coordinator of the meeting. She can be reached at the following address.

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9th Joint International Conference CLOTECH' 2010

The 9th Joint International Conference CLOTECH'2010 on Innovative Materials and Technology in Made-up Textile Articles and Footwear will be held from May 27-28, 2010 at the Technical University of Radom, Poland. Registration is already open, and additional information can be obtained as follows:

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World Cotton Research Conference-5

The Indian Society for Cotton Improvement has decided to organize the World Cotton Research Conference-5 in Mumbai from November 7-11, 2011. Pre registration will open soon and additional information will also be posted at <http://www.icac.org/Meetings/WCRC/english.html>.

Gossypol in Cotton Seed

The cotton plant may or may not have gossypols. But, if gossypol is present, it is present in all parts of the plant, including the seeds. Gossypols are desirable in some plant parts, particularly the leaves and floral buds, because serves as a toxicant against some insects. However, gossypol is undesirable in seeds because large quantities of gossypol are toxic to non-ruminants and so cannot be used as animal food. The cotton plant has many cottonseed pigments, and gossypol makes up 35-50% of total intra-glandular pigments. This article is focused on producing low-gossypol or gossypol-free cottonseed while maintaining normal glands in the aerial parts of the plant. Gossypol must be removed or modified in cottonseed oil when the original seeds contained gossypol, but this aspect is not discussed in this article.

Species Differences for Gossypol Glands

Gossypol was isolated from cottonseeds for the first time by the English chemist J.J. Longmore in 1886 (Afzal and Ali, 1983). Munro (1987) quotes Paul Fryxell as giving credit for recognizing the importance of gossypols to F.G.C. Alefeld, which at the time he referred to as *punctae*. Other forms of intra-glandular pigments are gossypurpurin, gossyfulvin and gossycaerulin. According to Afzal and Ali (1983), gossypurpurin was first isolated from the red crystals, also called red gossypol, obtained from the chloroform extracts of cottonseed kernels in 1955. Gossyfulvin was first isolated in 1944 from a cottonseed extract. Gossyfulvin exhibits an orange color that becomes more intense with storage of the seed under humid conditions. Gossycaerulin is a blue pigment

that was first reported in 1861. Some of the literature suggests that gossycaerulin is linked to the absence of gossypol in the seed, but there is no strong evidence to support that contention. No significant work has been undertaken to analyze the cotton plant and study its hereditary characteristics with a view to producing varieties free of pigments like gossypurpurin, gossyfulvin and gossycaerulin.

Gossypol is present in all cultivated species and in most known species of *Gossypium*. Gossypol-carrying glands are often large enough to be visible to the naked eye on the calyx, and although always there, the calyx glands may also be few and, sometimes, not prominent at all. Interspecies and intraspecies differences are well known. According to Fryxell (1984), gossypol glands are often found in the petals. In certain species, however (e.g. *G. incanum* and *G. cunninghamii*), the petals lack glands altogether or have only a few. Most species have gossypol embedded as dark spots in the carpel layer. Fryxell's work is well known in the world, particularly with regard to his description of *Gossypium* species. He reported that in some species the gossypol might appear as a raised area on the carpel layer while on others gossypol might appear as a depression in that layer. The species that could be of great interest to breeders are those whose gossypol glands are few or completely absent in the embryos (*G. bickii*, *G. australe*, *G. sturtianum*), despite being generally present in other plant parts.

Punitha and colleagues at the Tamil Nadu Agricultural University, Coimbatore, India studied gossypol content in eight wild species, 6 colored fiber lines, 19 white fiber varieties and 2 hybrids. Shade-dried leaves, squares, bolls and seed were analyzed for gossypol content. They observed higher gossypol content in wild species, in general, compared to colored and white lint cultivated varieties. The range of gossypol content varied between 0.8% in *G. triphyllum* to 7.10% in *G. davidsonii*. Gossypol content was highly significant in the leaves of *G. trilobum*, and in the squares and bolls of *G. davidsonii* and *G. raimondii*. *G. barbadense* showed the highest gossypol content of all cultivated species. Another interesting finding they reported was that the seeds generally had lower gossypol content than the squares and bolls.

Gossypol Extraction

Gossypol is toxic to non-ruminant animals such as poultry, swine and to humans. This is why high concentrations of cottonseed meal cannot be used in feed rations for those animals, and cottonseed flour cannot be eaten by humans. Ruminants, such as cattle, have the ability to detoxify gossypol because the microorganisms in the rumen bind that so, it can't be absorbed along with the food. Cattle will not normally be affected at recommended cottonseed feed levels. In normal feeding situations, the amount of cottonseed that can be fed

is about 0.5% of body weight for mature cows and lower percentages of body weight in calves. A mature cow on the average can be fed two kg of cottonseed per day. High gossypol consumption by cattle can lower their feed consumption, as well as reduce their liver, cardiac and reproductive functions when fed at excessive levels for extended periods of time.

Gossypol is a sesquiterpenoid aldehyde (Percy and Kohel, 1999). Sesquiterpenes are a class of highly reactive chemical terpenes. Gossypol is a phenol compound with a molecular formula $C_{30}H_{30}O_8$ (Pons Jr., 1976 and Afzal and Ali, 1983). Gossypol in the seed kernel is capable of liberating gossypol that can be extracted comparatively easily. There are other gossypol types that react with amino acid groups of proteins and peptides during conventional cooking/pressing and can be called 'bound gossypol.' The World Health Organization recommended that free gossypol and total gossypol may not constitute more than 0.06% and 1.2% respectively, if cottonseed flour is to be consumed by humans. The Food and Drug Administration of the United States has set a gossypol limit of 0.045%, or 450 ppm, in cotton flour for human consumption.

There is no single morphological plant character that can be directly correlated to gossypol content in seed and thus be used as a criterion by breeders to select for any given range of gossypol in the seed. Researchers have to rely on morphological as well as chemical analysis to quantify the actual gossypol content in seed. The method has to be efficient and cost effective. Of the many methods that have been tried, it seems that high performance liquid chromatography (HPLC) can best meet both requirements. HPLC can determine the gossypol content in a single seed. This, and its reliability with respect to repeatability and sensitivity, is why HPLC is recommended, particularly for measuring low quantities of gossypol. Like many other researchers, Benbouza *et al.* (2002) strove to find a physical character to establish a correlation between gossypol in seed with the number of glands on the kernel. They cut each seed into two longitudinal sections after removal of the teguments to assess the number of glands per section, its section area, and the size of the glands. Gland number and size was measured under a microscope. The gossypol glands were distributed in three classes according to their size: small glands ($<2700 \mu m^2$), medium glands ($2700-7549 \mu m^2$) and large glands ($>7549 \mu m^2$). The total numbers of glands of each class were counted, and the mean gossypol surface was determined by multiplying the number of gossypol points by the mean size of gossypol glands. Benbouza *et al.* (2002) concluded that the results could be used to quantify the contents of gossypol in single seeds belonging to the genotypes studied. They also used HPLC with some modifications to analyze single seeds, against which the physical evaluation was compared, but while the results could be genotype specific, it is not practical to count the number of glands and come up with a near actual mean size using a microscope.

Varietal Differences and Breeding for Glandless Seed

Upland cotton seeds usually contain from 0.6 to 2% gossypol. Gossypol glands are not uniformly distributed on plant parts and vary greatly by genotype and growing conditions. Researchers in Israel (Zur *et al.*, 2009) studied the dynamics of the gossypol content of the cotyledons and true leaves of 12 high-gossypol cotton strains, commercial cultivar Acala SJ1, and the glandless strain Acala 63–74. They planted all genotypes at different growing periods and observed that certain strains had the highest gossypol contents at all stages of development. Acala SJ1 had the lowest gossypol content among all glanded strains. The so-called glandless strain had the least amount of gossypol. In all strains tested, the highest gossypol concentration was found in the cotyledons. The highest concentration in all cases occurred during the flowering period. The weight gain of 10–20-mg *Spodoptera littoralis* larvae after a 5-day feeding on cotyledons was the highest on the glandless strain and the lowest on strains that showed the highest amount of gossypol glands.

Intraspecific crosses within *hirsutum* have produced either glanded or glandless plants, including seed: if the plant is glanded, the seeds will be glanded; if the plant is glandless, the seeds will be gossypol free. Many people have tried to transfer the glandless character from non-cultivated species to upland cotton and to express the character only in the seed, but they have not been successful. Researchers at Gembloux Agricultural University (recently incorporated in the University of Liège), Belgium transferred a character exclusively for gossypol-free seed from diploid C and G genome species. Benbouza *et al.* (2010) reported that workers in Australia had reported that a glanded plant and glandless seed character existed naturally in some wild Australian species. Benbouza *et al.* (2010) bridged crosses involving upland, *G. Raimondi* and *G. sturtianum* parents wherein the latter species served as a donor for the target character (glanded plants having seeds with the fewest gossypol glands). DNA molecular markers were able to identify chromosomal regions that carried the character of interest, facilitating marker-assisted selection of desirable genotypes. Being a donor, *G. sturtianum*, was repeatedly used as a parent, and in each generation plants with the least number of gossypol glands in the seed and the highest number of glands on other plant parts were selected for the next generation. Special efforts were made to ensure fertilization and to produce viable seed at early back crossing. Later generations automatically produced more viable seed. Research was conducted on a small scale, and plants were grown under lab conditions. Researchers concluded that selection pressure based on a reduced level of visible glands on the seed kernel wall would, in every back cross and selfed generation derived from a cross of three species [*(Gossypium hirsutum* × *G. raimondii*)² × *G. sturtianum*], provide the variability to select self-fertile plants that produced nearly glandless seed while maintaining normal gossypol glands on

the aerial plant parts. A great deal of work has yet to be done, but the indications are that it may be possible for genes from uncultivated species that control the desired trait (separating the plant and seed for gland expression) to be marked and utilized.

The interspecific sterility problems are obvious. Apart from Benbouza *et al.* (2010), many other researchers have also tried to introgress glandless-seed from *G. sturtianum* with the glanded-plant-trait into upland cotton. However, so far the interspecific sterility problem has prohibited the release of any commercial varieties. Ovule culture was tried by some researchers to proceed beyond the first backcross, but that option was not very successful either.

As far as upland varieties are concerned, it has been claimed that a fully glanded variety with genotypic composition of $Gl_2Gl_2Gl_3Gl_3$ may have the highest quantity of gossypol glands; on the other hand, a genotype with the gossypol gene in $gl_2gl_2gl_3gl_3$ condition will be glandless. Studies have shown that as the number of dominant alleles in the genotype decreased, so did the gossypol in the seed. According to Romano and Scheffler (2008) several studies have reported that $gl_2gl_2Gl_3Gl_3$ had a greater effect on reducing seed glands than $Gl_2Gl_2gl_3gl_3$, but the degree to which other plant organs were affected was not clear.

Since the antibiosis and biocidal properties of gossypol was recognized, breeders have been trying to develop and commercialize a target variety that would circumvent those drawbacks, but without success so far. The problem has been that the presence of Gl_2 and gl_3 genes could not be conditioned to the absence of glands in the seed kernel. Partial success was reported by many sources. Romano and Scheffler (2008) adopted a conventional breeding technique to lower gossypol glands in the cotyledon by crossing glanded upland varieties with glandless varieties and selecting for low gossypol in the cotyledon with high gland level (glanded parent level) in all other plant parts. They crossed parents from three glanded adapted lines with a glandless parent. They evaluated F_7 and F_8 generation progenies visually for the presence and abundance of glands in vegetative and reproductive organs and ran HPLC assays for percent total gossypol in the seed. The correlation between seed gossypol content and glands on the boll was moderate enough in all populations to allow selection of genotypes with seed gossypol reduced by 50% to 80% compared to the glanded parent. Romano and Scheffler (2008) reported plants in F_7 progeny that had <0.3% total gossypol in the seed. These lines have normal glands on stems and stigmas and near-normal glands on the bolls and calyces. Leaves show a reduction in gland numbers from the onset of flowering through maturity, but the number of glands on the veins and leaf margins are retained throughout the season.

Romano and Scheffler (2008) found that the new lines should make it possible to double the amount of whole cottonseed in feed for ruminant animals without detrimental effects. It might also be possible to include cottonseed in fish or poultry

rations, further expanding the use of cottonseed meal. Their work done in 2004 showed that plants with glandless stems and stigmas had 0% gossypol in the seed. Plants having glands on the stem and stigma showed a variable amount of gossypol glands ranging from 0.1% to 2.0% in almost homozygous plants at F_7 . The variation was almost the same in the next generation, which indicated that stem and stigma glands were not good predictors of glands in the seed or gossypol in the seed kernel. Glands on the boll had only a moderate correlation with gossypol in the seed—highly marked and dense glands on the boll do not always mean higher gossypol in the seed. The results showed that if breeders wish to exclude gossypol-free-seed plants from segregating populations, they can look for the absence of glands on the main stem and stigma and eliminate these plants from the population.

A number of researchers have found that in certain cases, the gossypol content of the hybrid population surpassed either of the parents, thus showing a transgressive inheritance. The argument given in this support is the complimentary genes from the low glanded/glandless parent though the variation could be due to seasonal effects. But, there is disagreement among the research community that $gl_2gl_2gl_3gl_3$ gene constitution is a glandless condition.

Gossypol Resistance to Insects

Many researchers have demonstrated the effect of gossypol on bollworm control, particularly the tobacco budworm *Heliothis virescens*, African cotton leafworm/Egyptian cotton leafworm *Spodoptera littoralis*, spiny bollworm *Earias insulana* and pink bollworm *Pectinophora gossypiella*. Gossypol is also reported to be toxic to aphids, *Aphis gossypii*, lygaeid bugs (milkweed bug) *Oncopeltus fasciatus* and the boll weevil, *Anthonomus grandis*. However, the mechanisms of the toxic action of gossypol and compounds related to it have not been fully explained. Gossypol is reported to serve as an inhibitor of digestive enzymes in the insect. The literature also reports findings by some researchers indicating that the negative effect of gossypol on insect populations, in certain cases, might be due to other chemicals or other factors, and not exclusively to the effects of gossypol.

Wilson and Shaver (1975) placed larvae of tobacco budworm on seedlings and fed them on detached fresh flower buds (squares) of four parents, carrying all true breeding combinations of the duplicate gland-determining alleles Gl_2 , gl_2 , Gl_3^{rat} , and gl_3 , and F_1 hybrids, including reciprocals. They showed that gland density and gossypol content were highly correlated with the number of gland-determining alleles present and with each other. Both were highly negatively correlated with larval seedling preference and larval weight. Diallel analysis showed that most of the genetic variance in gland density, gossypol content, and larval response was additive. Reciprocal and maternal effects were generally small and non-significant. The impact of gossypol in flowering parts, particularly flower buds and bolls, will be more significant than gossypol in stems and/or woody branches because of the nature of the attack from

the tobacco budworm and pink bollworm, but the antibiosis nature of the gossypol content is confirmed.

Gossypol is one of those special characters, like okra leaf, frego bract, red color of the plant, leaf hairiness, etc., that has been difficult to utilize because of its general biocidal properties. Calyx glands have been shown to protect flower buds from certain budworms. So, it is important to have glands on the calyx while trying to get rid of glands/gossypols in the seed. It is typical for upland cotton varieties to have glands throughout the calyx, but not on the calyx crown. There are, however, certain unique upland lines that have glands throughout the calyx, including the crown, and those genotypes were found to have enhanced resistance to insects. The gl_2 and gl_3 gene combination, which removes all gossypol contents from plant parts, has been used to produce glandless cotton cultivars. Glandless varieties have been developed in the USA and grown on a small scale (Percy and Kohel, 1999). Glandless/gossypol-free varieties have also been developed by CIRAD, and they were grown on a commercial scale in West Africa, but only for a few years. The reasons for abandoning gossypol-free cotton in West Africa are partially dependent on non-scientific factors, although the literature shows that gossypol-free cotton was attacked by several insect species, which had not previously been recorded as cotton pests.

Because of the biocidal properties of gossypol glands on the flower buds, efforts have also been made to develop high gossypol cotton varieties, despite the decline in the feed value of the seed. Conventional breeding and the quest for transgressive genotypes with high gossypol content in the segregating population resulted in high gossypol content germplasm. Jenkins (1989) reported the earliest development of high-gossypol germplasm with equally high yield as commercial cultivars. Each of the high gossypol germplasm lines was superior in yield to a commercial cultivar when grown under high infestation of *Heliothis*, and was competitive in yield when insects were controlled through insecticides. The high gossypol germplasm not only reduced damage to fruit, but the live larvae count was also lower than on normal gossypol cultivars.

Biotechnological Solution

Research is currently under way on this subject in some countries, but the published literature indicates that so far only Cotton Incorporated, USA has achieved a breakthrough in producing cotton plants with ultra low levels of gossypol glands in the seed while maintaining normal levels in other plant parts. The research was done at Texas A&M University, College Station, USA, but with the financial support provided by Cotton Incorporated. Rathore (2007) reported that various terpenoids are derived from the primary sesquiterpene skeleton, (+)- δ -cadinene. This enzyme, (+)- δ -cadinene synthase (δ -CS), is a cyclase enzyme that catalyzes the conversion of farnesyl diphosphate to (+)- δ -cadinene, the first committed step in the biosynthesis of gossypol and related terpenoids. The ability to block this committed step solely in seeds could

produce plants with reduced gossypol levels only in the seed. According to the sources quoted by Rathore (2007), attempts to use the antisense gene suppression mechanism targeting δ -CS to eliminate gossypol from cotton seeds were either unsuccessful, or resulted in only a small reduction in gossypol levels, or yielded ambiguous results. Rathore (2007) believed that a more powerful gene silencing mechanism and a strong, highly seed-specific promoter were required to achieve a meaningful reduction in seed-gossypol. So, there was a need for a promoter targeting the δ -CS gene in cotton. Sunilkumar *et al.* (2006) were able to use RNA interference (RNAi)-mediated suppression of the δ -cadinene synthase (δ -CS) gene to disrupt gossypol biosynthesis in the seed. More details on the process involving a triggering sequence are given in both papers.

Gossypols were not altogether eliminated from the seed but were reduced to ultra low levels. More importantly, the character was heritable. As mentioned above, the US Food and Drug Administration, the Food and Agriculture Organization of the United Nations, and the World Health Organization (FAO/WHO) permit a free gossypol content of 0.45 $\mu\text{g}/\text{mg}$ (450 ppm) and 0.6 $\mu\text{g}/\text{mg}$ (600 ppm), respectively, in edible cottonseed products. The *Agrobacterium*-mediated transformation method was used to develop several lines with low quantities of gossypol in the seed. The most recent reports from Cotton Incorporated (personal communications) indicate that researchers have narrowed the lines to 5-7 potential events. Rathore (2007) reported that one line produced seeds with gossypol levels as low as 0.2 $\mu\text{g}/\text{mg}$, showing approximately a 98% reduction in the level of the toxin. Normal seeds of a Coker 312 variety contained as high as approximately 10 μg gossypol/mg of kernel. The results suggested that RNAi-mediated gossypol reduction is restricted to the developing embryo and the kernel in mature seed. Thus, the defensive capabilities offered by the remaining plant organs and stemming from gossypol and related terpenoids, were not compromised in RNAi lines. Extensive lab testing and field trials are underway to select one event that has the least amount of gossypol in the seed without any loss of gossypol in other parts of the plant. Researchers are making sure that the final event has no negative effect on yield, fiber quality or any aspect of an agronomic nature.

Conclusion

Studies conducted around the world on lowering gossypol content have shown that gossypol quantities can be lowered to acceptable levels in the seed while maintaining near-normal levels in other plant parts. It is achievable by utilization of both intraspecific and interspecific hybridization and biotechnology approaches. Upland crosses can lower gossypols, but not successfully enough to achieve acceptable levels in the seed. In other approaches, the main issues are how to overcome sterility problems in the case of interspecific combinations (involving diploid species), and impacts on other characteristics in the case of biotech cotton.

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Particle Boards from Cotton Stalks

An article entitled 'Utilization of Cotton Plant By-produce for Value Added Products' was published in the December 2007 issue of the *ICAC RECORDER*. The article described the CFC/ICAC project 'Utilization of cotton by-produce for value-added products,' which is sponsored by the ICAC and funded by the Common Fund for Commodities (CFC). The Central Institute for Research on Cotton Technology, Mumbai of the Indian Council of Agricultural Research is executing the project. The Government of India through the Council contributed 58% of the cost of the project in the form of available and additional resources required to implement the project. The project was initiated in October 2004 and was concluded in December 2009. The main thrust of the project was to utilize cotton stalks for making particleboards and binderless boards on a commercial scale. The Central Institute for Research on Cotton Technology, India has been working on the utilization of cotton stalks for many years but the current project was designed to demonstrate commercial feasibility by installing and operating a pilot plant capable of producing one ton of particle-boards every day. While the above-referred article provides background information on project objectives and plan of work, including work done until mid-2007, this article is focused on commercial uses for cotton stalks and project results in general. More specific results of the project work are given in the next article of this issue.

One of the objectives of the project was to disseminate project results to other countries. Since the project work had already been completed by November 2009, the Central Institute for Research on Cotton Technology organized an international workshop in Nagpur from November 9-11, 2009 to disseminate project results. Delegates from many Asian and African countries and representatives of CFC and ICAC attended the workshop. Experience showed that up-gradation to a pilot plant involved important issues that were not perceived at the time of development of the project. Farmers cannot receive good price for cotton stalks unless there is a system to buy stalks from growers, chip stalks into the proper size for easy transportation to a factory and proper storage of stalks before they are used for making boards of various kinds and sizes.

Why Cotton Stalks and Why Now?

Taking an average area of 33 millions hectares planted to cotton in the world, close to 80 million tons of cotton stalks are produced every year. Cotton stalk yield under rainfed conditions is about one ton/ha but irrigated conditions could produce over three tons/ha. Harvested stalks stored in the field serve as storehouse for insects, particularly various kinds of pests when cotton is not available in the field. Entomologists strongly recommend that no un-opened bolls should be left on the branches, and stalks must be removed from the field soon after picking. Sometimes cotton stalks are mulched in the soil that requires heavy machinery and some additional

fertilizer has to be added to enhance the stalk decaying process. Rotavating stalks in the field enhance organic matter and thus improve soil fertility and permeability. However, while the mulching and soil incorporation process involves energy and cost, decaying of crop residue releases carbon into the air. The effect on soil structure and consequently on soil fertility cannot be challenged, but greenhouse gas emissions are an important issue. No quantitative data are available on the economic benefits of soil incorporation versus long-term environmental consequences.

Even if soil incorporation overrides the environmental consequences, burning of cotton stalks in the field, which is still common and has been an official recommendation as a part of integrated pest management, particularly prior to extensive use of insecticides, is an environmentally destructive solution. The third major use of cotton stalks in many developing countries is as firewood, which is desirable from the point of view as a substitute of forest wood.

Cotton stalks are rich in cellulose and have a composition and fiber structure comparable to many hardwood plants. There are many factors that drive the need to utilize cotton stalks better than burning in the field and where technologies are either not available or it is too expensive to mulch them in the field. Three important ones are:

- Farmers are not getting value from cotton stalks. The cost of production is rising, and farmers need additional income to compensate for the high cost of production. A market for cotton stalks will bring additional income to cotton growers.
- Suitable technologies were not available in the past to process crop residues for making particle boards. According to Pandey and Sujatha (2009) crop residues could not be used with conventional formaldehydes based resins due to the fact that fiber cells are surrounded by a layer of wax/silica. This layer prevented the water based formaldehydes resins, which are widely used in the plywood industry, from forming a strong bond among fibers. New technologies enable destruction of the wax/silica layer by using mechanical high shear forces accompanied by a thermal and chemical treatment. The combined effect of the chemi-thermo-mechanical process allows the formaldehyde resins to penetrate and bond particles even with wax/silica coatings.
- Environmental risks are better understood today than before. Carbon pollution is recognized as a serious issue. The growing demand for forest-based raw materials is resulting in loss of precious forests. There is a need for additional land to grow more food crops, but environmental concerns do not suggest making more land available by cutting forests for the sake of producing particle boards. Cotton stalks, like other agricultural crop

residue, provide an alternate source of raw material for making particle boards.

Quality of Particle Boards

Whatever may be the urgency and demand for particle boards, consensus will not compromise on inferior quality boards. If secondary agricultural produce like rice husks, cotton stalks, wheat straw, etc., are to be used for making commercially viable particle boards they must at least match the quality produced by the wood based industry. The table below is compiled from Pandey and Sujatha (2009) and Shaikh (2009). The sources of data for the boards from all materials except cotton are not known, but the data for cotton boards is independent of the other data and was produced by the CFC/ICAC project. The data shows that cotton stalks can be used to make particle boards with quality as good as that provided from wood, which is the most common raw material used by the particle board and plywood industry.

Bagasse is the most commonly used crop residue used for making particle boards. Sugar-cane bagasse is a fibrous waste product of the sugar refining industry, along with ethanol vapors. Bagasse is used on a large scale to produce ethanol in Brazil. Part of the waste is recycled as a raw material for paper manufacturing. Most of the bagasse is not processed and is either burnt or allowed to rot. The presence of pith in bagasse negatively affects the quality of particle boards. Rice husks, wheat straw and corn/maize stalks are the most abundantly available crop residues in the world.

Rice – Rice husks have 15-22% silica, which is in contagious association with cellulose and pentosan. The Indian Plywood Industries Research and Training Institute have developed a technology to overcome the high silica problem.

Jute – Jute composites can be used to make partitioning boards, false ceiling, etc., but jute is planted on only about 1.2 million hectares in the world.

Wheat – Wheat straw is available in abundance but in most developing countries straw already has a value as hay for

livestock. In countries where it is not used as hay, collection from the field, transportation and storage is a big issue.

Cotton – Cotton stalks too have collection, chipping and storage issues that were addressed in the project and will be discussed in this article and the next article of this issue of the *ICAC RECORDER*.

Corn/maize – Corn fibrous husks and stalks can be used to form a structural composite board that is considered to be stronger and harder than wood-fiber composites. However, corn husks and stalks have a value as animal feed and, unlike cotton stalks, are used for this purpose in many countries. In most developing countries where corn is grown, green/fresh corn stalks are used as fodder after cobs have been removed.

Many other agricultural residues like groundnut, coir, coconut husk, sisal, banana leaf sheath and others have been tried but the volume of production is too low compared to cotton stalks.

Private Sector Experience with Cotton Stalks

Bagasse was the most popular raw material for particle boards. The rise in prices of bagasse in India in the last few years has compelled the private sector to look for an alternate raw material. A bagasse based particle board factory commissioned in 2006 faced severe economic problems due to a steep rise in bagasse prices, which almost doubled in three years. Bagasse prices rose to US\$ 45-55 per ton. The factory decided to try cotton stalk and was able to acquire chipped cotton stalks at US\$32-45 per ton. They started making boards using various mixes of cotton chips and bagasse but according to the paper presented at the November meeting (Deshpande, 2009), they could not use more than 40% of the cotton stalks as a raw material because the appearance of the boards changed, which is not acceptable for the photo-lamination industry. In addition, the board required sanding which was not available at the factory. In the next page, the table shows what the factory has used for the mixes.

Comparison of Cotton Stalk Made Particle Boards With Boards from Other Raw Materials

Property	Raw Material Used in Making Boards						Cotton Stalks (Made by the Project)
	Wood	Rice Husk	Bamboo Mat (Overlaid with Rice Husk)	Wheat Straw	Groundnut Husk	Bagasse	
Density kg/m ³	755	790	845	800-900	700	683	750
Water Absorption %							
Two hour soaking	7.5	16	7	-	-	20.7	20
Four hour soaking	16	30	15.5	61	-	60.4	40
Swelling Thickness %	6.5	7.4	3.3	25	23.7	9	9
Modulus of Rupture N/mm ²	16.6	14.5	32.9	25.7	11.8	21	17.6
Modulus of Elasticity N/mm ²	2,800	2,290	3,700	3,169	1,396	2,617	-
Internal Bond Strength N/mm ²							
Dry	0.55	0.37	0.39	0.37	0.3	0.52	0.51
Wet	0.18	0.12	0.13	-	0.15	0.13	-
Screw Withdrawal Strength N/mm ²							
Face	1,475	1,375	2,200	-	-	2,220	1,400
Edge	950	1,100	1,275	-	-	977	860
Nail Withdrawal Strength N/mm ²	-	-	-	-	-	-	1,300
Swelling to Surface Absorption %	-	-	-	-	-	-	6

Boards Produced With Bagasse and Cotton Stalks		
Board Thickness	Face Bagasse	Core Cotton Stalk Chips
9 mm	75%	25%
12 mm	70%	30%
18 mm	55-60%	45-40%

The factory was able to produce particle boards that met the specifications of the Bureau of Indian Standards. Wheat straw and soybean pod covers were also tried but resin absorption was not satisfactory with those raw materials. In addition, a constant/assured supply of raw material was another issue that inhibited the use of these raw materials. The factory also experimented with filler boards where cotton stalks could be successfully used. The good thing about the use of cotton stalks was that they were available abundantly in cotton growing areas and have no other uses. The company paid Rs. 500 (US\$11) per ton of stalks to farmers but the total cost of chipped stalks delivered to the factory increased to US\$41/ton.

Processes Involved in Making Particle Boards from Cotton Stalks

After cotton is picked from plants, the plants may carry leaves (dry or some partially dry leaves), burrs and some fiber left in un-picked or in partially open bolls. There could still be some green bolls that may open after the final picking has been made. Stalks to be used for making boards must be devoid of leaves, burrs and fiber. While harvesting stalks, no dirt/soil should be carried along with stalks. Contamination of stalks with leaves, burrs, fiber and dirt/soil deteriorate the quality of raw material and will result in poor resin absorption and board quality. The cleaning loss depends on the undesirable material on the stalk, but it is estimated that the cleaning loss including small branches, could go as high as 20-25%. Stalks must be chipped when they have 15-25% moisture so as to have the best geometry and minimum dust emission. Chipping loss is estimated at 10%. Chips should be stored under roof with proper ventilation and should not be allowed to gain additional moisture.

The size and quality of the chipped material could effect board properties in terms of surface smoothness and hardness, modulus of rupture, internal bond strength, thickness swelling, water absorption, screw holding, nail holding and moisture content (Geevarghese, 2009). Chips are milled into finer particles in an attrition mill and dried to the level of 3-5% moisture. The dried chips are sieved into three categories; face, core and oversize particles. The oversized particles are further milled to convert them all into face and core size. The face and core material are stored in separate silos.

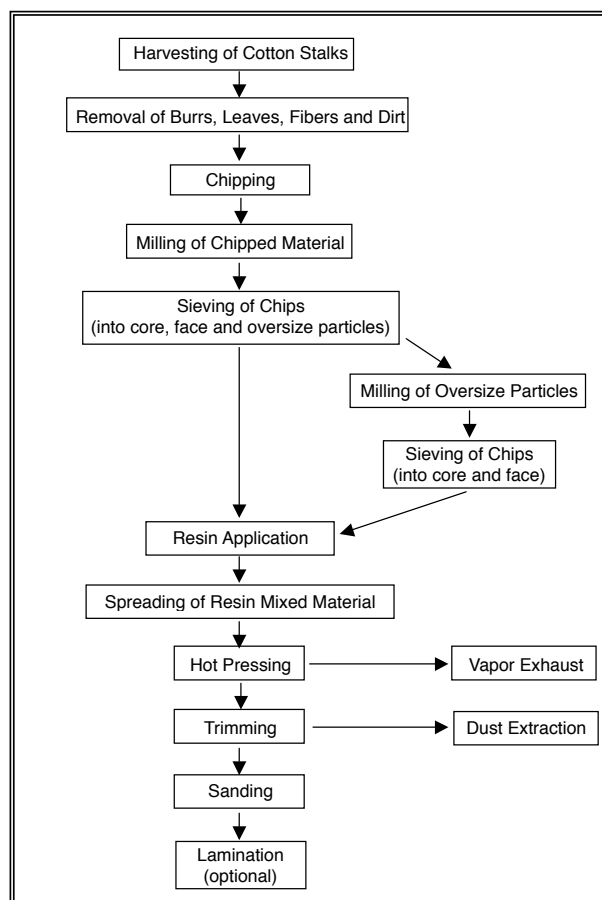
The most important and expensive process at the manufacturing plant is gluing the chipped material. It is recommended that 12% resin should be used for the face and 7% for the core

on a bone-dry basis. Lower percentages of resin will affect gluing quality, while extra amounts of resin will increase the cost with no reward for an expensive chemical. Along with the resin, other chemicals to avoid termites, fungus, and other pests, could be added as required depending upon the end use of the board. Resin must be blended with the raw material properly for uniform board strength.

Glued fibers are fed into the spreading machines. There can be two or three spreading machines. In the case of two machines, there will be one face and one core, the trolley with hauls plates moves to and from to get a three-layer formation. But in the case of three spreading, two faces and one core, the trolley moves in one direction only. The three layers formation first takes the face layer, then the core and finally other face layer. There are other types of spreading machines with wind sifting facility, which are not required for small capacity plants.

As the cotton stalk fibers are of very low bulk density, the mat height will be 5 to 6 times the height of the finished boards. Pre-pressing reduces the thickness of the mat to almost 1/3rd and holds the mat together with tackiness. The consolidated mats are pressed at high temperature and pressure in a multi daylight hot press. The temperature and time of pressing cycle depends upon the type of resin used and the thickness of the board. The hot pressed boards are allowed to cool to the ambient temperature.

Flow Chart of Particle Boards from Cotton Stalks



The next step is trimming the edges to the required dimensions and sanding with calibrating and finishing heads. The calibrator sands the board to the required standard thickness, and the finishing head makes the surface smooth. The plain particle boards can be overlaid with wood veneers, decorative kraft papers, and melamine impregnated papers, which will make the boards more durable and enhance their face value. The laminated boards can be sold at almost double the price of plain particle board, the additional cost for laminating is negligible. The laminated cotton stalk boards can be used in false ceiling, partitions, doors and panels, flush doors, wall paneling, tabletops, cupboards, kitchen cabinets, flooring, wardrobes, and various kinds of furniture. It is estimated that three tons of cotton stalks will produce about 1.3 tons of clean chipped material with about 10% moisture. One ton of chipped material will produce about 675 kg of particle boards with about 6% moisture. The series of processes involved in particle board making are shown in the flow chart on previous page.

Other Uses of Cotton Stalks

Cotton stalks comprise about 75-82% holocellulose, 24-26% lignin, 12-14% moisture and 6-8% ether extractives. The focus of the project was to use this valuable crop residue for making particle boards but cotton stalks can also be used to make soft boards, hard boards and medium density fiber boards. The main problem with cotton stalks lies in its high transportation and storage cost due to low bulk density. Stalk waste at a particle board factory can be used for briquetting (densification). The optimum moisture content for agricultural residues to be briquetted ranges from 8-15%, which fresh cotton stalks attain after one week of storage in open air. This implies that these residues can be briquetted one week after harvest without any additional costs for drying. The cotton stalk briquettes can serve as raw material for generation of bio energy. The condensed briquettes will also enable cost effective transportation.

Cotton stalks possess fiber dimension comparable to most commonly available species of hardwood. It can therefore be used for preparation of pulp and paper, hard board and corrugated boards and boxes. The Central Institute for Research on Cotton Technology, India has standardized a biological anaerobic treatment for preparation of paper grade kraft pulp from cotton plant stalks. The technology is developed and patented indicating that the process of anaerobic digestion is technically feasible and economically viable. Paper quality was at par with that from conventional processes.

The Central Institute for Research on Cotton Technology has also used cotton plant stalks as a substitute for wood in the manufacture of corrugated fiber board boxes for packaging fruit. Uniform chipping of stalks and a kraft liquor concentration of 18% produced kraft paper with desired properties. The techno-economic feasibility worked out by conducting large-scale trials in a mill indicated that the box prepared from cotton

plant stalk kraft would be cheaper than that of commercially available boxes. Corrugated boxes were lighter in weight than wooden boxes and hence more corrugated fiber board boxes could be transported thus reducing freight per box. The corrugated fiber board boxes prepared from cotton plant stalk kraft paper possessed desirable bursting and compressive strength. Lamination of boxes with polypropylene film from the outer side further improved strength and the ability of the boxes to withstand moisture during prolonged cool storage under high humidity conditions.

Work done in Egypt compared properties of pulps made from cotton stalks of *hirsutum* and *barbadense* species. Researchers used a soda-anthraquinone process to prepare pulp. The pulp was bleached using oxygen and hydrogen peroxide. Bleached and unbleached pulps were refined and tested for strength. Egyptian cotton stalks produced better unbleached pulps, higher yields, and better strength. The upland cotton stalks pulp had better bleachability. The strength of the bleached pulps from both stalk types was the same, with values slightly lower than mixed hardwood pulp (Ali, 2001). The work done in the USA showed that wheat straw and wine shoot produced the best and worst quality paper, respectively. In addition to wheat straw and wine shoots the other crop residues trials were olive tree fellings, cotton stalks and sunflower stalks (Jimenez *et al.*, 2001). Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production has been studied in Greece, which showed that lignin and cellulose content depends on tissue maturity, but does not change significantly within each species. A lot of work has also been done in Spain, Turkey and other countries. A review of the work done and ongoing in cotton stalks are not the main thrust of this article. The main purpose is to highlight the project results and increased focus on uses of cotton stalks. There is an interest in using crop residue as a raw material for making various types of products, and cotton is a good candidate for such a raw material.

Conclusion

Bagasse is the first crop residue based raw material that has been commercially used for making particle boards. The problem as mentioned above is the price variation and unreliable supply. While the price will continue to be determined by market forces, the price for raw material must be determined in relation to the cost of production of boards and their market value, otherwise the crop residue based industry cannot flourish. Seasonal supply limitations affect all agricultural crop residues. Cotton stalks are just entering the market as a commercial raw material. Cotton and sugarcane are harvested at the same time and will compete against each other. Low bulk density and thin spread over a large area are already issues in cotton stalks. However, price hikes should not affect opportunities for this raw material to gain momentum. As the technological aspect makes progress, so should the marketing aspect to make cotton stalk particle boards popular at the end use level. It can only happen if cotton boards are at least

equivalent in quality to the boards available in the market. The challenges for the boards made from cotton stalks are to achieve a high level of consistency, minimal density variation and close thickness tolerances and superior surfaces.

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Utilization of Cotton Stalk for the Production of Particle Board

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Cotton cultivation in recent years in India and other Afro-Asian countries has become insufficiently remunerative due to high input costs, low productivity and fluctuating market prices. Therefore, there is a need to look for alternate means of revenue for farmers. In this connection, judicious utilization of cotton by-produce for value added products gains relevance.

In India, about 23 million tons of cotton stalks are generated every year. Most of the stalks are treated as waste; some are being used as fuel by the rural population, while the bulk of the stalk is burnt off in the field after harvest of the cotton crop.

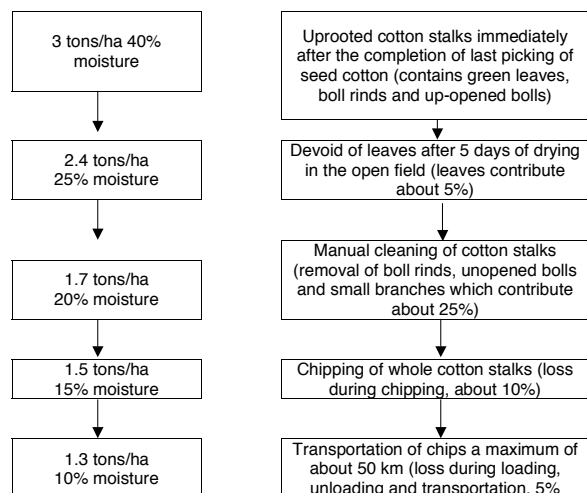
Cotton stalk is rich in cellulose and is of comparable composition and fiber structure to many hard wood species. CIRCOT (Central Institute for Research on Cotton Technology) has developed a technology for preparation of particle boards from cotton stalks, thereby providing an avenue for the farmer to sell stalks for enhancing his income. However, this technology needed refinement in an experimental plant and scaling up in an established board manufacturing industry to demonstrate the techno-economic feasibility for commercial adoption. CIRCOT-ICAC-CFC Project on utilization of cotton by-produce for value added products accomplished the above objectives.

The economics of board manufacturing and acceptance of cotton stalk by industry depends on the cost of raw material in

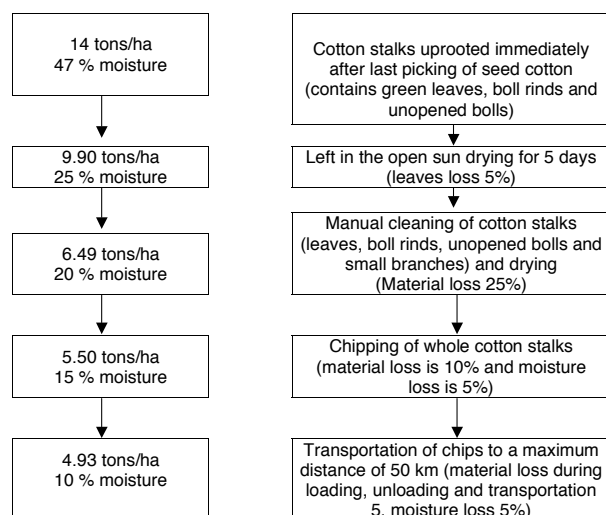
an usable form at the industry gate. Therefore, the logistics of collection of cotton stalks, chipping and transportation from field to industry and its proper storage in different forms at various centers are crucial issues in deciding the economic viability of this raw material. The present paper discusses in detail the systematic study carried out by CIRCOT for the last three years on these aspects. Data collected and analyzed to evaluate the economics of cotton stalk collection, pre-processing, storage, chipping and transportation have been presented and discussed.

From the study carried out by CIRCOT, it has emerged that among the various options the most suitable logistics of cotton stalks comprises uprooting of stalk, storage, manual cleaning, chipping using a tractor driven chipper at a centralized chipping center not farther than 5 km from the field and transportation of chips to the factory within 50 km distance by truck. On average, about 1.3 tons of cleaned chips are obtained per ha of land under rainfed conditions, while about 5 tons of chips could be obtained per ha under irrigated conditions. Transporting cotton stalks beyond 5 km before chipping and beyond 50 km after chipping would not be an economically feasible endeavor. On average, the cost of cleaned and chipped stalks to be made available at the factory gate situated not more than 50 km away from the production center (farm) would workout between Rs.1,500-2,000 (US\$33 – 44) per ton of the raw material with 10% of moisture.

Flow chart on the Availability of Cotton Stalks in Nagpur District, Maharashtra, India (Rainfed)



Flow chart on the Availability of Cotton Stalks in Sirsa District, Haryana, India (Irrigated)



Cost of Logistics of Cotton Stalk Collection, Chipping & Transportation

Labor Charges Paid for Cotton Stalk Procurement

	In US\$/ha
Uprooting and cleaning	11.1
Chipping	5.1
Tractor Hiring	8.0
Total	24.2

Cost of Ready-to-Use Cotton Stalk Chips at Factory Site

		In US\$/ha
1	Labor charges for uprooting, cleaning and chipping	24.2
2	Transportation charges	7.1
3	Loading and unloading charges	1.1
4	Raw material cost	11.1
Total		43.5

Further, a systematic study was carried out for proper storage of stalks. From the various trials undertaken it was concluded that storage of cotton stalks in chip form under a shade or in a covered shed in pyramid form is the most ideal method. The stalk neither deteriorated in quality nor was infested by insects and pests, even after storing over a period of about one year.

The quality of particle boards is affected by the presence of impurities in the stalks. Therefore, the second component of the project deals with development of a cleaning system to remove undesirable impurities like leaves, boll rinds, burrs, lint, etc. from cotton stalk. As an R & D exercise, a stalk-cleaning machine was fabricated. The machine is comprised of a scratching system (peeler) conveyor, air blowing chamber and air suction chamber.

The efficiency of the machine was evaluated by conducting cleaning trials. The results indicated that the machine is quite effective and could clean or remove about 90% of impurities from the stalk. However, not suitable for adoption at field level, this machine can be used effectively in the particleboard industry.

Performance Evaluation of Cotton Stalk Cleaning System*

Initial Weight of Cotton Stalks (Kg)	Moisture Content (%)	Weight of Stalks after Passing the system (Kg)	Moisture Content of cleaned Stalks (%)	Weight of Removed Material (Kg)			Moisture Content of peeled Material (%)
				1	2	3	
100	10.5	77	11.0	16.0	0.6	6.2	6.0

* Performance is based on 5 trials

1. Material Collected in the first unit
2. Material Collected in cyclone
3. Material Collected at the end of conveyor

PS: Moisture content of stalk is around 11%, whereas that of wastes (boll rinds, leaves, lint and small branches) is around 6%

The third component pertains to setting up of a one-ton-per-day (TPD) capacity pilot plant for particle board manufacturing and fine tuning of the technology of board making followed by industrial trials to work out the techno-economic feasibility.

A one TPD plant has been set up at the Ginning Training Center (GTC) of CIRCOT, Nagpur, India and the technology of board manufacture perfected on the pilot plant. Production trials were conducted to prepare boards of different surface finishes by using different eco friendly resins. Research trials were also conducted to blend cotton stalk with other materials like bagasse and mulberry stalks. Good quality boards can be

prepared after blending with other raw materials. Industrial trials were also conducted at M/s. EcoBoard Industries Ltd., Velapur, M/s. Aurobindo Laminations, Nagpur, M/s. Archid Ply Industries, Mysore, etc., and the techno-economic feasibility has been worked out. Properties of boards prepared are presented below:

Properties of Three Layered Particle Boards from Cotton Plant Stalks

Sr. No.	Properties	Unit	IS 3087-1985		CIRCOT Board
			Type I	Type II	
1)	Density	Kg/m ³	500-900	---	750
2)	Average Moisture Content	%	5-15	---	11
3)	Water Absorption	%			
	i) 2 h. soaking		10	40	20
	ii) 24 h. soaking		20	80	40
4)	Swelling Thickness	%	8	12	9
5)	Swelling due to surface absorption	%	6	9	6
6)	Modulus of Rupture	N/mm ²			
	i) Up to 20 mm		15.0	11.0	17.6
7)	Internal bond strength	N/mm ²			
	i) Up to 20 mm thickness		0.45	0.3	0.51
8)	Screw withdrawal strength	N			
	Face		1250	1250	1400
	Edge		850	700	860
9)	Nail withdrawal strength	N	1250	---	1300

The fourth component of the project pertains to undertaking commercial trials to prepare binderless boards using cotton stalk.

Three large-scale trials were conducted to prepare binderless boards at M/s. Jolly Board, Miraj and at M/s. Western India Plywood Industries Ltd., at Kannur, Kerala. The trials were conducted with 100% cotton stalks as well as after blending with bagasse and wood. Good quality binderless boards were prepared, and the process was found to be technically feasible and economically viable.

In addition, efforts were made in dissemination of the technology developed and creating awareness about utility of cotton stalk as an industrial raw material amongst farmers, and entrepreneurs. Cost-economics of a 10 TPD particleboard plant was worked out and the same is presented below:

Cost Estimation & Profitability

Production Capacity:	10 TPD (384 boards of 8'x4'x12 mm)
To process:	15 Tons/day of cleaned cotton stalk
No. of shifts/day:	3
No. of hr./shift :	8

A. Capital Investment

Sr. No.	Land & building	US\$
1.	Land (About 1 hectare)*	50,000
2.	Building cost* (Area: About 10,000 sq. ft., 929m ² , Raw material storage)	90,000
	<i>Total Land and Building Cost</i>	<i>140,000</i>
3.	Plant and machinery cost, and commissioning, freight, insurance, duties etc.	844,000
4.	Fire fighting equipment, office furniture etc., water treatment plant, transformer, weighing machines etc.	30,000
5.	Preliminary and Pre-operative Expenses cost	30,000
6.	Technology Fees	40,000
7.	Contingency Provision cost	50,000
8.	Margin money for working capital cost	47,000
	Total Project cost	1,181,000

*Cost in India

B (I). Total Manufacturing Cost:

	US\$
Raw materials cost (Cotton stalks, glue, surface finishing, chemicals & additives)	280,000
Utilities cost (power, coal & process water etc.)	130,000
Labor & Supervision cost	70,200
Maintenance, Repairs & Overheads cost	56,000
Manufacturing Cost	536,200

B (II). General Expenses:

Administrative overheads, Distribution & Selling cost : 35,000 US\$

B (III). Depreciation & Interest: 204,000 US\$

	US\$
Total Cost of Production (BI+BII+BIII)	775,200
Cost of Production per kg Board	0.26
Cost of Production per sq. ft. Board	0.21
Cost of Production per m² Board	2.27

C) Profitability

I) Selling price per unit (8'x4'x12mm)	:	US\$8.70
II) Gross annual income	:	US\$995,320
III) Annual cost of production	:	US\$775,200
IV) Annual Returns	:	US\$220,120
V) Return on Investment	:	19%

The major achievements of the project are listed below:

- A cost effective supply chain mechanism has been developed for collection, cleaning, chipping, storage and transportation of cotton stalk from the field to the factory at an affordable price to the industry.
- Awareness has been created amongst farmers about the utility of cotton plant stalks as an industrial raw material.
- As an R & D exercise, a cotton stalk cleaning system was developed and evaluated.
- The process of particle board manufacture was standardized in the pilot plant. New eco friendly resins were developed. Boards having termite resistance, fire retardance water repellent properties were prepared.
- Industrial trials were undertaken to work out the techno-economic feasibility. Good quality boards suitable for lamination can be manufactured using cotton stalks without any major modifications in existing plants and machinery.
- Industry has been convinced of the utility of cotton stalk as raw material for particle board and hard board manufacturing and the industry is ready to use it provided cleaned, chipped cotton stalks are made available to them at factory gate at an affordable price.
- Awareness is also created amongst prospective entrepreneurs, NGO,s financial institutions and governmental agencies about cotton stalk as an industrial raw material for particle board manufacture.

Future Action Plan for success of the project:

- It is essential that a few supply chain centers are established in clusters of cotton growing areas for collection, chipping and supply of cotton stalks from the field to the factory. Initially, these centers need to be set up with financial assistance from project or governmental assistance and can serve as demonstration centers which subsequently can be taken over by private entrepreneurs as a rural enterprise.
- Use of cotton stalks as a raw material for the particle board industry would fetch an additional income of about 5% to farmers. In addition, this would have a positive impact on the environment by reducing the use of wood for particle board manufacture and thereby contributing significantly to the slowing of the deforestation process.
- As part of the dissemination activity, an international workshop was organized between 9-11 November 2009, at Nagpur, India wherein the achievements of the project were highlighted to national and international audience and invitees with a view to build entrepreneurship not only in India and also in other cotton growing countries.

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