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Contents

Introduction

A number of biotech insect resistant cottons are available, and farmers have a choice to utilize the technology they want to employ against the target insects in their areas. Although all technologies are not approved for commercial use in every country, some countries have more than one form of insect resistant biotech cotton approved for commercial planting. Similar tough competition does not exist for herbicide resistant biotech cotton, because Roundup Ready biotech cotton is dominating the market in the USA and elsewhere where herbicide genes have been approved for use. Each insect resistant technology has its own benefits and different technology fees. The first article 'Bollgard® II versus WideStrike™ Biotech Cotton' compares two prominent insect resistant biotech cottons commercially grown in the USA. Bollgard® II was deregulated by the U.S. Environmental Protection Agency in December 2002 while WideStrike™ was approved for commercial production almost two years later in September 2004. They are both better than Bollgard®. Bollgard® II produces two proteins that provide effective control of the major Lepidopteran insect pests of cotton, including the cotton bollworm *Helicoverpa zea*, tobacco budworm, *Heliothis virescens*, pink bollworm *Pectinophora gossypiella*, and beet armyworm *Spodoptera exigua*. WideStrike™ is also a dual action biotech cotton, but the technologies differ in the biotech genes they carry. However, it is clear that the combination of two proteins (Cry 1Ac and Cry 1F) in WideStrike™ is highly effective against fall armyworm. The Cr 1Ac and Cry 2Ab (in Bollgard II) together also provide good control of fall armyworm but not as good as WideStrike™. More aspects of the two technologies are given in the first article.

The U.S. has the most successful boll weevil *(Anthonomus grandis)* control program among all countries that have suffered from this pest. The program is successful because it has a different philosophy/approach from the other pests that affect cotton in the country. It was realized almost three decades ago that boll weevil control requires a different approach than just insecticide use. Thus, an approach called the Boll Weevil Eradication Program was devised and implemented in stages throughout the cotton belt in the country. The elimination is based on two fundamental principles: 1) permit only a minimum population to go into hibernation to diapause, and 2) kill the maximum number of weevils that emerge from diapause. Continuous and area wide use of the strategy has successfully eliminated boll weevil from most of the cotton belt in the USA. Some estimates suggest that the boll weevil eradication program may be completed, and all the cotton area in the USA may move to the post-eradication stage in 2009. The boll weevil destroyed cotton industry in Central America and, it is the most damaging cotton pest in Argentina, Bolivia, Brazil, Colombia, Mexico, Paraguay, Peru and Venezuela. Unfortunately, the approach still followed relies on insecticide use. There is a need to learn from the U.S. experience and change the approach from control to elimination. The second article talks about boll weevil biology and the eradication program in the USA.

The ICAC Secretariat estimates that the share of cotton among all fibers consumed at the end use level was 40% in 2006, as opposed to 68% in 1960. There are many ways to reverse this trend and one very convincing approach is to find more uses of cotton. The third article is entitled 'Future of Cotton in Nonwovens'. Cotton has several positive attributes, such as absorbency, dyeability, dissipation of moisture resulting in wear comfort, static-freedom, sustainability, biodegradability, and many more. Unfortunately, petroleum based synthetic fibers are more extensively used in making nonwovens. The article discusses why cotton is not yet used extensively in nonwovens. The article also highlights the advantages of using cotton in nonwovens. Dr. Sawhney and Dr. Condon of the Southern Regional Research Center, New Orleans, USA estimate that cotton has a future in nonwovens, and the nonwoven market is expected to reach US$25 billion in 2009. The technologies used in nonwovens have changed in favor of cotton.

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Emerging Trends in Production, Processing and Utilization of Natural Fibers

The Indian Society for Cotton Improvement and the Indian Fibre Society will jointly organize an international seminar on 'Emerging Trends in Production, Processing and Utilization of Natural Fibers' in Mumbai, India from April 16-18, 2009. The Seminar will be held under the auspices of the Indian Council of Agricultural Research (ICAR), which is the apex body on agricultural research in the country. The Seminar will discuss various aspects of fiber production, processing, diversified product manufacturing, marketing and by-product utilization and policy planning of all natural fibers. It may be remembered that the United Nations has declared 2009 as the International Year of Natural Fibres. The objective of the high recognition for natural fibers is to raise awareness of natural fibers, promote efficiency and sustainability of natural fibers, and foster an effective international partnership among various natural fibers industries. The registration fee for international participants is US$250, and the last date to submit papers is November 30, 2008. For additional information, contact the organizers at the address below.

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Bollgard® II versus WideStrike™ Biotech Cotton

Biotech varieties were grown on 95% of the area planted to Upland cotton in the USA in 2008/09. Biotech varieties include single gene and stacked gene insect resistance, in addition to herbicide resistance. The insect resistant events approved in the USA are Bollgard®, Bollgard® II and WideStrike™. Bollgard® carrying the Cry 1Ac gene was commercialized in 1996/97, Bollgard® II, with the Cry 1Ac and Cry 2Ab genes, in 2003/04 and WideStrike™, with Cry 1Ac+Cry 1F, in 2005/06. The purposes of adding a second gene to Bollgard® II and WideStrike™ were to enhance the spectrum of pests controlled and delay the development of resistance, a danger that is more likely when there is a single type of toxin. It is estimated that over 90% of the Upland cotton area in the US in 2008/09 was planted to Bollgard®+ Bollgard® II varieties and only 1-2 % to WideStrike™ varieties, both in the single gene and the stacked gene forms to add the herbicide resistance characteristic.

In the USA, losses due to various pests are estimated every year. The report presented at the 2008 Beltwide Cotton Conferences showed that the bollworm/budworm complex caused more damage to cotton in 2007 than other insects (Williams, 2008). According to Williams (2008) the average cotton yield in 2007/08 in the USA was lower by 0.913% because of Heliothines. The Lygus bug was number two, lowering yield by 0.683%; thrips were third with 0.578%, cotton fleahoppers were forth with 0.477% and aphids were fifth with a yield reduction of 0.320%. All the sucking pests together caused more than double the yield loss caused by the budworm/bollworm complex, but against them farmers have to rely on chemical controls, while biotech cotton is the main defense against budworms and bollworms. Cotton was planted on 4.3 million hectares in the USA in 2007/08, and the average yield was 985 kg/ha. The 0.913% yield loss caused by Heliothines comes to nine kilograms of lint per hectare which is equal to US$61.4 million at the average Cotlook A Index price of US$1.61/kg for 2007/08. It is not possible to eliminate losses as long as budworms and bollworms exist as pests on cotton; it is, however, definitely possible to lower those losses. *Helicoverpa zea* is the most important of the Heliothines affecting cotton in the USA, and WideStrike™ and Bollgard® II insect resistant technologies are supposed to minimize those losses. Yield losses to bud and bollworm attacks were estimated at 3.7% from 1985 to 1995 (Gianessi and Carpenter, 1999). Thence the need to stack another gene or find a stronger one; this and many more aspects of WideStrike™ and Bollgard® II technologies are compared in this article.

Bollgard® II Technology

Monsanto developed Bollgard® II Event 15985 by re-transformation of Bollgard® cotton Event 513. Bollgard® II produces two proteins that provide effective control of the major Lepidopteran pests of cotton, including the cotton bollworm *Helicoverpa zea*, tobacco budworm, *Heliothis virescens*, pink bollworm *Pectinophora gossypiella*, and beet armyworm *Spodoptera exigua*. Bollgard® II also produces the β-D-glucoronidase (GUS) marker protein. The GUS protein has no insecticidal properties and is used as a marker to facilitate the detection of plants capable of producing Cry 2Ab. The GUS produced in Bollgard® II is extremely safe. In fact, GUS is present in intestinal epithelial cells, intestinal microflora bacteria and numerous foods. Cry 2Ab is also designated as Cry 2Ab2, Cry IIB, Cry B2 and Cry IIAb. Bollgard® II provides greater control of tobacco budworm, pink bollworm and cotton bollworm than Bollgard®, plus it provides additional control of secondary lepidopteron insects such as beet armyworm *Spodoptera exigua* and fall armyworm *Spodoptera frugiperda*. The fall armyworm feeds on foliage and developing fruit forms. In cotton, the damage is severe when the larvae feed on developing bolls. The beet armyworm damages seedlings, growing tips in young plants and small bolls. The young larvae make a loose web over the feeding site for protection. Older larvae chew irregular holes in leaves and also feed on squares, flowers, and bolls. Square damage by the beet armyworm differs from bollworm damage in that the surrounding bracts and foliage are often damaged by the beet armyworm but not by bollworm. However, the beet armyworm primarily feeds on plant leaves. It is known (ICAC, 2008) that there is variability in the expression of Bt toxin in various plant parts and at various stages of plant development. Toxin expression declines in the terminal leaves throughout the season, as well as within individual leaves, as they age. Thus, it was feared that the target insects would encounter progressively lower protein levels as they moved downward on the plant thereby increasing their chances of survival for a little longer or of escaping altogether. During this period, pest damage would continue. Both types of armyworm can cause sever losses in yields, so it became necessary to have more effective control, similar to the control of the tobacco budworm and other insects against which Bollgard® is effective.

WideStrike™ Technology

WideStrike™® has two genes, Cry 1F and Cry 1Ac, also derived from *Bacillus thuringiensis (Bt)*. Dow AgroSciences developed the technology to control early and late season insects mostly controlled by Bollgard® II as well. To be effective, the Cry proteins must be ingested by the target lepidoteran insects affecting cotton . The target pests have a high pH in the midgut and the protein is dissolved triggering a chain of reactions that ultimately results in the death of a target pest. The Cry 1Ac and Cry 1F genes bind to specific receptor molecules on the midgut epithelial cells of the target pests. Once bound, the receptor produces in the midgut cells, leading to lysis, cessation of feeding and death. The overlap among receptors is incomplete. Cry 1Ac binds to at least three receptors while Cry 1F binds to at least two receptors in the tobacco budworm. In the cotton bollworm, Cry 1Ac and Cry 1F each bind to at least four receptors, of which two are shared. Data submitted by Dow AgroSciences to the US Environmental Protection Agency for approval of WideStrike™ reported that in cotton bollworm approximately 60% of Cry 1Ac binding is to receptors that also bind Cry 1F, and the remaining 40% of Cry 1Ac binding is to receptors that do not bind Cry 1F. Incomplete shared binding is expected to delay cross-resistance when resistance is mediated by receptor changes.

Bollgard® II was deregulated by the U.S. Environmental Protection Agency in December 2002 while WideStrike™ was approved for commercial production in September 2004, almost two years later. WideStrike™ technology is available only through PhytoGen Cottonseed varieties. PhytoGen Cottonseed was established in 1980, but only 3.3% of the cotton area was planted to Phytogen varieties in the USA in 2007/08, compared to 42.9% to Deltapine 29.3% to Bayer CropScience Fibermax varieties and 15.4% to varieties developed by Stoneville Pedigree Seed Company (Anonymous, 2007). The Delta and Pine Land Company, Bayer CropScience and Stoneville Pedigree Seed Company were using Monsanto's Bollgard® technology and only PhytoGen Cottonseed was using WideStrike™ technology. This is also one of the reasons that WideStrike™ is approved only in the USA. In June 2007 when Monsanto bought Delta and Pine Land Company, Monsanto had to sell the Stoneville Pedigree Seed Company. Bayer CropScience now owns Stoneville Pedigree Seed Company and there is a possibility that the area currently planted to WideStrike™ varieties may increase within the next few years. In January 2006, the Dow AgroSciences and Monsanto Company made an agreement on cross-licensed intellectual property rights. The impact with respect to the WideStrike™ character is yet to be seen.

Interaction Between Two Toxins

The Cry protein (Anonymous, 2003) names are assigned according to the similarity in amino acid sequences. In this nomenclature, Cry proteins with the same Arabic numeral i.e. Cry 2, share at least a 45% of amino acid sequence identity. The Cry proteins with same Arabic numeral and uppercase letter, such as Cry 2A share at least a 75% sequence identity. And, the Cry proteins with the same number, uppercase letter and a lowercase letter (for example Cry 2Ab in the case of Bollgard® II) share more than a 95% amino acid sequence identity.

Cry 1Ac and Cry 2Ab are protein toxins that can interact and affect the performance of one or both toxins. Monsanto has already undertaken studies on this subject, and Greenplate *et al* (2002) reported that there is no interaction between the two Cry proteins. The researchers designed a study to quantify the bio-efficacy of Cry 1Ac/Cry 2Ab (Bollgard® II) cotton and compared it with Cry 1Ac (Bollgard®) in the tobacco budworm *Heliothis virescens* bioassay. Three isolines of a variety having Cry 1Ac only, Cry 2Ab only and Cry 1Ac+Cry 2Ab were used to examine the relative contribution of each toxin to the total efficacy of Bollgard® II, in addition to studying the nature of the interaction (synergistic/antagonistic or additive) of the individual toxins in the 2-gene cotton. Purified Cry 1Ac was used as a standard for comparison. The studies proved that both genes work independently of each other and that there is no interaction between them.

Efficacy of WideStrike™ against other Technologies

There is no doubt that in terms of insect control, both Bollgard® II and WideStrike™ are superior to Bollgard®. Differences, if any, are all due to the 2nd Bt gene and the host genotypes. The two-gene biotech cottons have a broader spectrum of activity and increased efficacy. However, the potential for caterpillar damage remains, and both technologies may require treatment against target insects. Adamczyk *et al.* (2008) compared WideStrike™ with Bollgard® and Bollgard® II to assess their ability kill the beet armyworm and fall armyworm. Experiments were conducted in 2005/06 and 2007/08 in the field and lab. The field sites varied in 2005/06 and 2007/08. All Lepidopteran insects used in the experiments were lab-reared colonies. In 2005, bioassays were conducted using only fall armyworm larvae. For undertaking bioassay studies using larvae, a single larva was placed in individual petri dishes containing a moistened filter paper and a single lower leaf obtained from all plots for a total of 32 larvae/variety. Leaves were collected when the crop was at peak bloom. The petri dishes were covered and after five days surviving larvae were carefully transferred to new petri dishes containing fresh filter paper and new leaf. This procedure continued until pupation. Live larvae were counted at seven and 10 days. Petri dishes were checked daily for presence of pupae starting from 15 days. In 2007, the beet armyworm larvae were placed in a dish containing a terminal (upper canopy) leaf or a mid-canopy leaf (10 dishes/variety) for a total of 50 larvae/variety. Fall armyworm bioassays were conducted identically, except that only mid-canopy leaves were used. Leaves were also collected at various stages during the growing season. Percent mortality was counted after five days.

Bioassay studies on egg masses were undertaken in the field in 2007/08. Inoculations with beet and fall armyworm egg masses were done using various sections of the plant. Eggs were spread on a piece of nylon cloth and same-size samples were pinned to the underside of a leaf for all traits and covered with a cage that consisted of a condiment cup covered with a hard plastic lid. Five days after inoculation, the infested leaves and the corresponding cages were harvested and transported to the laboratory. Leaf damage was classified on a scale of 0-5, 0 being no damage and 5 being 100% damage.

The results showed that in 2005/06 and 2007/08, WideStrike™ and Bollgard® II performed significantly better than Bollgard® against fall armyworm larvae. Adamczyk *et al.* (2008) observed that in both 2005 and 2007, WideStrike™ had typically higher efficacy than Bollgard® II. They also noted that fall armyworm larvae developed successfully to pupation when fed Bollgard® or Bollgard® II, but not WideStrike™. They related WideStrike™'s greater efficacy against the fall armyworm to the Cry 1F protein. The beet armyworm survived equally well on Bollgard® II and WideStrike™ when mid-canopy leaves were fed to larvae. Late in the season, however, when beet armyworms were fed leaves located in the upper part of the plant (i.e. upper-canopy leaves), larval survival on WideStrike™ was very high (>60%). This means that when WideStrike™ cotton is close to maturity, Cry 1F expression is low in young terminal leaves. Furthermore, beet armyworm mortality on WideStrike™ terminal leaves at over 109 days after planting was similar to that observed on Bollgard®. This means that WideStrike™ may require supplemental insecticide applications to control beet armyworms feeding on younger leaves late in the season. Results of tests using egg masses and cages support the observations and conclusions above.

VipCot™ (Vegetable Insecticidal Protein) lines utilize a single protein (Vip3A). Syngenta discovered this protein 1994. The Syngenta technology has been extensively tested in the USA but not commercialized yet. Although derived from the bacteria *Bacillus thuringiensis* (Bt), Vip is structurally and functionally different from the d-endotoxins employed in current traits. Vip is expressed throughout the entire plant and provides good protection against the cotton bollworm, American bollworm, native bollworm, tobacco budworm, pink bollworm, beet armyworm, fall armyworm, cabbage looper and soybean looper.

Bacheler and Mott (2004) tested WideStrike™, Bollgard® and Vip lines for their efficacy against the cotton bollworm, *Helicoverpa zea*. However, in 2004, Monsanto regulations prohibited direct comparison of these lines using the same test in adjacent fields. So, Bacheler and Mott (2004) evaluated each technology in separate, but adjacent tests within the same field border. The location of the trials normally has high bollworm pressure. The results indicated that under adverse conditions, each of the technologies evaluated may, at times, require protection from bollworms. Additionally, the VipCot™ cotton line sustained European corn borer damage to bolls. Although low (2%) European corn borer may indicate a certain susceptibility in the Vip3A gene. The WideStrike™, VipCot™, and the Bollgard® II lines showed bollworm damage to bolls of 15, 14, and 6%, respectively, at the peak boll damage scouting assessment. Yield differences appeared to correlate with these boll damage trends. The parathyroid-protected counterparts of these same lines showed yield increases of 158, 327, and 207 kg lint/hectare for the WideStrike™, VipCot™ and Bollgard® II lines, respectively. Stink bug levels were extremely low, thus supporting the inference that these yield differences appeared to have been caused by bollworms.

Cook *et al.* (2008) compared two WideStrike™ varieties with one Bollgard® II variety and two non-Bt varieties without supplemental insecticide applications. Treatment efficacy was determined by examining 25 squares per plot for evidence of heliothine feeding on both the biotech and non biotech varieties at 67, 75, 80, 91 and 97 days of planting. Similarly, boll damage was assessed by examining 25 bolls per plot on the same dates. In another trial , two WideStrike™ varieties were compared with one Bollgard® II variety stacked with Roundup Ready Flex, with and without supplemental insecticide applications against heliothine insects. To check for the presence of heliothines, 25 squares were examined at 75, 80, 91 and 98 days after planting. Bollworm damage was also assessed in the 2nd experiment in the same way as in the first trial. The results showed that both the WideStrike™ and Bollgard® II technologies had significantly fewer damaged squares and bolls compared to Roundup Ready Flex non-insect resistant biotech cotton varieties.

Hardke *et al*. (2008) conducted laboratory studies to test the efficacy of various types of insect resistant technologies against fall armyworm. They selected one conventional/

non-biotech variety each of Bollgard® cotton, Bollgard® II, WideStrike™ and VipCot. Freshly harvested flower buds from all varieties were placed in petri dishes and lab-reared L3 larvae of the fall armyworm were released in the petri dishes to feed exclusively on the flower buds. The supply of flower buds was replenished every 2-3 days or whenever necessary. A minimum of two replicates, each with a total of 30 larvae, produced a total sample size of 60 larvae per variety/line. Dead larvae were counted every 2-3 days. The results showed that the fall armyworm larvae continued feeding on non-biotech squares and by the cut-off point, which was 12 days after initiating the experiment, 100% mortality had not been achieved. Larval mortality on conventional variety flower buds ranged from 1.7% at two days after treatment to 41.6% at 12 days after treatment. On Bollgard® cotton, the mortality rate ranged from 0% at two days after treatment to 65% at 12 days after treatment. Thus, there was not 100% mortality on Bollgard® cotton at the end of the treatment, i.e., 12 days. While only 1. 7% of the larvae had died on Bollgard® II cotton at two days after treatment, the mortality rate had increased to 85% on the 7th day and 88.3% at 12 days after treatment. All the fall armyworm larvae feeding on WideStrike™ variety flower buds were dead at seven days after treatment. VipCot squares produced results similar to that of WideStrike™ technology, and complete mortality was observed at the end of the treatment. Hardke *et al*. (2008) intend to repeat the experiment in the 2008/09.

Many factors determine the survival of lepidopteran pests on biotech cottons. Toxin expression is influenced by genotypes, growing conditions, stage of crop development, plants parts, etc., so all the impact seen on a particular variety/line cannot be directly attributed to the Cry gene or any other biotech gene. Interestingly, larvae of the target pests also behave differently depending on the previous host. Jackson *et al.* (2007) compared two colonies of the fall armyworm on the same variety. They collected late instars of fall armyworm from Bt and non-Bt sweet corn to establish two separate colonies. Two-day old and 5-day old F_1 larvae from each colony were confined to white flowers of two non-Bt cotton varieties, a WideStrike™ variety, and a Bollgard® II variety with cloth cages to evaluate damage potential. The results showed that the Bt corn strain of fall armyworm damaged significantly fewer bolls, because of the previous host crop, compared to the non-Bt corn strain. No differences were detected between strains with respect to boll damage levels caused by 2-day old larvae in WideStrike™ or Bollgard® II cottons. Assessement of 5-day old larvae of the fall armyworm showed that in one out of three replications the damage caused by the Bt corn strain to non-Bt cotton was significantly less than that of the non-Bt strain. Among strains of Bollgard® II and WideStrike™ cottons, no differences were detected in damage levels caused by 5-day old larvae. Leaf tissue bioassays were also conducted to compare survival of two fall armyworm strains that originated from either non-Bt or Bollgard® II cotton. No differences were detected in the survival rates of 3-day old larvae feeding on either non-Bt or Bollgard® II cotton. Results from these studies suggest that there may be some fitness cost associated with fall armyworm development on Bt sweet corn. Because this same phenomenon was not associated with development on Bt cotton, further studies should be conducted to examine the impact of Bt crops on fall armyworm populations.

The above results conflict with some earlier work which showed that F_1 progeny from a fall armyworm strain collected from a Bt corn field were more vigorous in the presence of non-Bt cotton than those from a strain from a non-Bt corn field . This incidence may be explained by a higher expression of the Cry 1Ab protein in Bt sweet corn compared to a strain from a Bt corn field. However, it is clear that the combination of two proteins (Cry 1Ac and Cry 1F) in WideStrike™ is highly effective against fall armyworm in field and laboratory tests. The Cr 1Ac and Cry 2Ab genes together also provide good control of fall armyworm but not as good as WideStrike™.

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The Boll Weevil Eradication Program in the USA

The boll weevil, *Anthonomus grandis,* is a serious cotton pest in Argentina, Bolivia, Brazil, Colombia, Mexico, Paraguay, Peru, Venezuela and the USA. The Central American countries of Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua planted cotton on 467,000 hectares in 1977/78, and 119,000 hectares in 1987/88, but almost no cotton was planted in these countries in 1997/98. In 1977/78, at the time when cotton area was at its peak in the Central American countries, the average yield for the region was 770 kg/ha, i.e., almost double the world average and 132% of the average yield in the USA. There were some individual countries with higher yields than the Central American region in 1977/78, but as a region, Central America was the highest yielding in the world. Ten years later, the average cotton yield for the region was 812 kg/ha, compared with the world average of 554 kg/ha. The average yield in Guatemala in 1987/88 was only 33 kg/ha less than Australia, and Guatemala was the third highest yielding country in the world after Israel and Australia. Guatemala and Nicaragua were the last countries in the region to abandon cotton production. When they ultimately stopped producing cotton in the early 1990s, yields in both countries were still higher than the world average. In fact, yields never dropped significantly in Central America, but the cost of production escalated due to insecticide applications against the boll weevil. The Central American countries were not able to find an economical way to control the boll weevil and so had to give up cotton production. Thus, unless economically feasible means are available to control it, the boll weevil is so serious that it can force countries to stop producing cotton.

Introduction of the Boll Weevil into Various Countries

The boll weevil entered the USA in 1892 from Mexico and this is why it is also sometimes called the Mexican boll weevil. Some reports show that the pest crossed the Río Grande, near Brownsville, Texas, to enter the U.S. and reached southeastern Alabama in 1915. The boll weevil was already present in Mississippi in 1914, and by 1922 it had spread throughout the eastern cotton growing states all the way to Virginia. Thus, in about 20-25 years, the boll weevil had infested all cotton growing regions in the U.S. Some calculations suggest that the boll weevil spread at an average rate of about 92 kilometers per year. Within Mississippi, the boll weevil spread to all cotton areas in about seven years.

The boll weevil invasion continued not only in the USA but also into other countries in South America. The boll weevil was detected in Venezuela in 1949 and in Colombia in 1950. The Amazon Rainforest was considered by some to be a barrier against the boll weevil, but it was ultimately found in Brazil in 1983. In just a few years the boll weevil spread to almost all the coastal area of the country. From Brazil, the boll weevil moved to Paraguay, and in 1993 it was also found in Argentina in the area bordering Paraguay.

The Bolivian Committee for the Prevention and Elimination of the Boll Weevil, the National Association of Cotton Producers (Asociación Nacional de Productores de Algodón – ADEPA) and the National Association of Cotton Ginners reported on June 23, 1999, that the Bolivian Ministry of Agriculture had detected the boll weevil in an area close to the border with Brazil thanks to a monitoring program that had been in place for many years. Catches in traps indicated the presence of boll weevil inside the borders of Bolivia. The area where the boll weevil was detected was about 600-700 kilometers away from the actual cotton area in Brazil. The pest could easily move and settle in the cotton area because a large number of fields were not cleaned after the final picking. Cotton plants remaining in fields, together with relatively mild weather during the winter helped the boll weevil establish a foothold in Bolivia. Judging from the history of this pest in other countries in the region, it was considered to be a great threat to cotton production in Bolivia. In fact, Bolivian cotton area decreased from 50,000 hectares in 1997/98 to about 8,000 hectares in 2007/08. The boll weevil existed in Mexico prior to 1843 and is considered to have been responsible for the abandonment of cotton production in the state of Coahuila, Mexico, in 1848.

Both male and female weevils are capable of traveling long distances. In the U.S. marked weevils have been detected as far as 280 kilometers from their point of release. The capability to undertake such long flights shows that even if the boll weevil is eliminated from one area it can readily come back. In Brazil, the boll weevil is responsible for shifting cotton production from the north to the central south region. The boll weevil spread to many countries in South America and quickly attained the status of the most serious pest on cotton. The boll weevil still remains the most destructive cotton pest in the Americas. The only good thing is that the boll weevil has not spread to other continents and it is still a pest of the Americas only.

Life Cycle of the Boll Weevil

Cotton is the major host crop for the boll weevil in the USA. But, in Mexico and the countries in Central America, the boll weevil feeds on many native plant species related to cotton. The boll weevil is a pest of tropical and sub-tropical climates and cannot survive under severe winter conditions. However, the boll weevil can escape low winter temperatures by going into a state of reproductive diapause, and this is how the boll weevil has survived in the USA. If climatic conditions permit, as is the case in northern Argentina, the boll weevil never goes into diapause. The absence of a diapause phase has both advantages and disadvantages to growing. In the presence of alternate host crops/plants during the off-cotton season, the boll weevil can survive and continue multiplying to reach a higher population to attack cotton. In the USA, the boll weevil goes into diapause and, on the average, 5-6 generations are produced every year. A greater number of generations mean faster development of resistance to insecticides. So, it is not good for cotton when the boll weevil does not go into diapause and is capable of producing a greater number of generations every year.

On the other hand, the absence of diapause can be used as a control strategy to kill the greatest number of boll weevils before they appear on the cotton plant. This strategy is being followed by the ICAC in one of the projects currently being implemented in Argentina with funding by the Common Fund for Commodities. The State Government of the province of Formosa, with technical assistance from the Instituto Nacional de Tecnología Agropecuaria, set up pheromone traps to catch as many boll weevils as possible. The technique works well because when the preferred host crop, is not available, greater numbers of boll weevils are attracted to pheromone traps. Preliminary reports from the project indicate that the approach has had a significant impact on yield in the project area. Not only is the population that would otherwise appear on cotton reduced, but insecticide use is also reduced thanks to lower boll weevil pressure.

The two factors that are critical in the life cycle and multiplication of the boll weevil are temperature and food. As mentioned above, the boll weevil is a tropical/sub-tropical pest, and extremely low or high temperatures slow its multiplication process, while feeding on cotton anthers stimulates the multiplication process. So, the multiplication rate varies greatly among regions within countries and among countries. The data from the state of Mississippi, in the U.S., show that a female boll weevil can lay about 150 eggs in her life cycle. Eggs are deposited singly inside the flower buds/squares. Female weevils usually lay one egg per oviposition site per square, but multiple ovipositions have been reported on bolls. The eggs hatch in 3-5 days, and if they produce viable larvae, the bud/square will be shed. In those cases where for any number of reasons, the larva does not emerge from the egg, there is a likelihood that the flower bud or square will develop into a boll, although it may not be a fully-grown boll. Eggs are safe inside the flower bud, and on the average about 75 larvae may be produced by a single weevil in her life.

Soon after hatching, the larvae start feeding on immature anthers. Within 2-3 days after the larvae started feeding on the flower buds, the brackets start flaring away from the bud base. Affected buds are shed in the next 2-3 days, which is 5-6 days after the successful hatching. In these 5-6 days, the larvae go through three instars, which means that the larva molts or sheds its skin three times during its development. The larvae spend the rest of their lives inside the flower bud/square. The boll weevil prefers floral buds, but when the larvae are feeding on the bolls, the bolls may continue to grow and remain on the plant. The larva completes its life cycle in 7-14 days.

The larva develops into a pupa inside the flower bud or boll. The pupa lives only 3-5 days and becomes an adult weevil. The adult weevil is able to chew through the outer layer of the flower bud or boll and emerge as an adult weevil. The newly emerged boll weevil still has a soft skin, which hardens within the next 24 hours or so. The color of the skin also changes from reddish to dark gray. The adult boll weevil feeds on pollen grains in open flowers and starts the mating process. Egg laying begins in the next 3-5 days and the life cycle is completed in about three weeks in the USA.

Critical Considerations for Boll Weevil Control

Currently, the boll weevil is the most important pest in Argentina, Brazil, Colombia, Paraguay and parts of the USA. There is no biotech cotton resistant to the boll weevil, and the potential new biotech products, expected to be approved for commercial production in the next few years, show that a biotech gene resistant to the boll weevil is not available yet. Until science develops a biotech cotton resistant to the boll weevil, farmers will have to rely on other control measures.

The experience in all countries affected by the boll weevil shows that biological controls have not been very successful. There are many native predators and parasites of the boll weevil in the USA, including *Solenopsis invicta*, *Bracon mellitor*, *Bracon compressitarsus* and *Catolaccus grandis*. *Solenopsis invicta,* commonly called red fire ant, was considered to be the key boll weevil predator until 1990. The inaction level, i.e., no insecticide application, was established at 0.4 ants per plant. As long as the ant population was above the level of 0.4 per plant, there was no need for insecticide treatment against the boll weevil. However, artificial rearing remained a problem and the red fire ant never became a major control measure. The parasite *Bracon mellitor* was not found to be consistent in its performance, some times it provided good control and some times it did not. *Bracon compressitarsus* was tried, but wintering was a problem. Sometimes the parasites/predators were polyphagous and did not vigorously search for boll weevils. *Catolaccus grandis* has the ability to lay eggs close to boll weevil eggs, and its specificity to boll weevil larvae showed great promise for its use on a commercial scale. Artificial rearing of *C. grandis* was problematic too, but the two other factors that limited wide spread utilization of the wasp were unwanted preservations of floral buds on the ground by burying them in the soil during the cultivation process and extensive use of insecticides against other pests. Insect resistant and herbicide tolerant biotech cottons have reduced both these problems, but the U.S. approach is not to control the boll weevil but eliminate it. This is the reason that the US has not reverted to biological control even after planting over 90% of its cotton area to biotech varieties. The strategy might work in other countries, and Argentina, Brazil and Colombia have also commercialized biotech cotton.

The pheromone-trap approach has proven to be very successful. The pheromone attracts both sexes of the adult boll weevil. The boll weevil has an antenna with which it detects the pheromone, identifying it as a food source. The sex pheromone can also be used to attract female weevils for mating. The attraction of the pheromone is proportional to the smell it releases, but some data show that boll weevils are attracted from as far as 150 meters. Pheromone traps have been used extensively in the U.S. for monitoring the boll weevil population. The 'Attract and Kill Tube' produced by a private company based in Texas has been used commercially in many countries, including Argentina, Bolivia, Brazil, Colombia and Paraguay. When used as a monitoring device, however, it is not the odor alone that makes a pheromone trap effective. The "day-glow green" color of the trap body is also visually attractive to boll weevils and induces them to alight on the trap body from where they ultimately move up into the trap cone and cylinder. These traps are still used in the U.S. but mainly as a monitoring device. Trapped boll weevils are killed, however, thereby helping to minimize the population. The traps in any form constitute an important component of an integrated boll weevil control strategy.

Thus far, chemical control has been the mainstay of the boll weevil control strategy outside the US. The larvae of the weevils feed inside the fruiting structures of cotton and are protected from sprays, while the adult boll weevil has a very hard skin. The adult weevils have an elongated snout that can penetrate hard bolls. The experience in many countries has shown that insecticide control has failed to eliminate the boll weevil. Reliance on continuous use of insecticides has multiplied the need to use insecticides. Genetic resistance of the weevil to insecticides is the greatest impediment to long-term economical control of the pest. It has been confirmed in the United States, Mexico and Central America that boll weevils in the region are increasingly becoming resistant to chlorinate hydrocarbons, organophosphates and pyrethroids.

The U.S. Approach: Elimination not Control

The U.S. approach has not been to control the boll weevil for the short run, but to eliminate it completely. The approach is based on two fundamental principles.

- In the USA, the boll weevil goes into hibernation to diapause during winter. Thus, the boll weevil escapes the sever winter cold as well as the scarcity of food stemming from the non-existence of adequate alternate host plants after cotton has been picked. The U.S. strategy is to let only a minimum number of individuals go into diapause. The rationale is that reducing the number of weevils going into diapause proportionately reduces the emergence of boll weevils after over-wintering. The objective is achieved by spraying insecticide after cotton has been picked, thereby denying the boll weevil population that would presumably go into diapause, access to the food required to accumulate enough fat to successfully over winter. Chemical defoliation, insecticide application, rapid harvest and destruction of cotton stalks are combined to kill the greatest number of boll weevils directly and starve the ones that escape the chemicals to keep them from going into diapause.
- The second component of the strategy is to kill as many boll weevils as possible after they appear on cotton but before they start laying eggs. Researchers have discovered that it is most effective to spray when cotton reaches the 'pin-head' square stage. All cotton fields in an active boll weevil eradication program area must be sprayed with an insecticide during the pinhead square stage so that only the smallest possible population survives to multiply.

The strategy has worked very well. Continuous area-wide use of the strategy has successfully eliminated the boll weevil from the greater part of the cotton belt in the USA.

Boll Weevil Eradication Program in the US

The reproduction-diapause phenomenon in the boll weevil became prominent as a control option in the late 1950s. The National Cotton Council passed a resolution in 1958 wherein they declared the boll weevil as the number one enemy of cotton production. This was the turning point in the approach to the control and elimination of boll weevil from the U.S. cotton belt. A technological package to eliminate the boll weevil was formulated, refined and implemented in the form of a three-year Pilot Boll Weevil Eradication Experiment from 1971 to 1973. The objective of the program was to determine the technical and operational feasibility of eliminating the boll weevil. The three-year experiment showed that the technology had the potential but required further improvement. Later, Boll Weevil Eradication Trials were conducted in North Carolina and Virginia from 1978 to 1980 to ascertain that elimination was technically and practically possible. The program remained very successful, and the boll weevil was eradicated from the evaluation area, which was in isolation from the other cotton areas.

The boll weevil eradication trials in North Carolina and Virginia were completed in 1980, and the successful results provided an incentive to launch a beltwide eradication program (Bradley, 1996). A containment program was conducted in 1981 and 1982 in the buffer zone to prevent re-infestation of the eradicated area. Later, a series of actions were set in motion, but the most important was the decision of farmers to share the cost of the beltwide eradication program. The eradication cost was estimated as US$247 per hectare (US$100/acre), and farmers agreed to pay 70% of the cost, with the remaining 30% to be paid by the U.S. Department of Agriculture. The first eradication program started on July 1, 1983 and continued through 1985. The program covered all commercial cotton in the target area, which was expanded to cover the remainder of North Carolina and all of South Carolina. The program started in the western cotton growing states (western Arizona, southern California and northwestern New Mexico) in 1985 and continued to 1986. It was subsequently expanded in 1986 and 1987 and proved its success wherever it was implemented (Brazzel, *et al*., 1996).

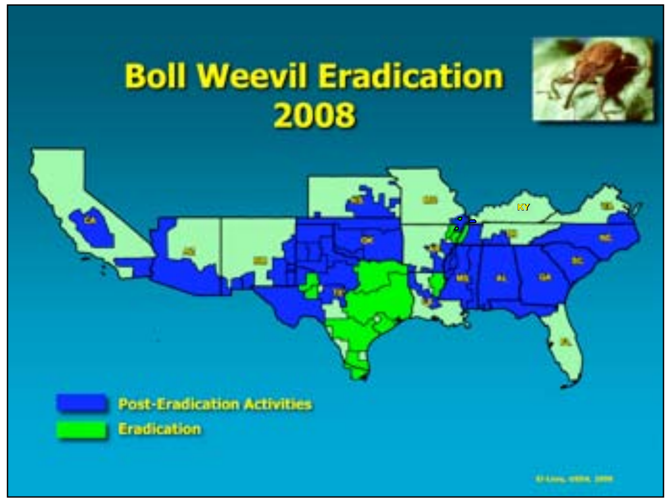
The Current Situation

Since its initiation, the boll weevil eradication program has covered cotton areas in Alabama, Arizona, Arkansas, California, Florida, Georgia, Kansas, Louisiana, Mississippi, Missouri, New Mexico, Oklahoma, South Carolina, Tennessee, Texas, and parts of northern Mexico near the U.S. border. According to the Animal and Plant Health Inspection Service (APHIS) of the USDA, the boll weevil has been eradicated from more than 87% of the cotton area in the US. The program has been completed in Alabama, Arizona, California, Florida, Georgia, Kansas, New Mexico, North Carolina, South Carolina, Virginia and large portions of the other States where the program is still active but eradication is not completed. Once the boll weevil is eliminated from an area, it is necessary to monitor boll weevil occurrence. APHIS estimates that the post-eradication costs of the overall eradication program will be between US$12 and US$25 per hectare in the beginning, but will then stabilize at US$7.5/ha.

The program is currently running in Arkansas, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, and Texas. The organizations that are responsible for statewide operations are Arizona Cotton Pest Research and Protection Council, Arkansas Boll Weevil Eradication Foundation, Georgia Boll Weevil Eradication Foundation, Louisiana Boll Weevil Eradication Commission, Oklahoma Boll Weevil Eradication Organization, Texas Boll Weevil Eradication Foundation, The Southeastern Boll Weevil Eradication (In Alabama, Florida, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia), South Central New Mexico Cotton Boll Weevil (New Mexico) and Pecos Valley Cotton Boll Weevil Control Committee (New Mexico).

The three components of the current program continue to be: diapause treatment, effective insecticide control in the beginning of the cotton season, and boll weevil trap monitoring. Once it gets under way, an eradication program usually runs for about five years, but in some cases the program is still active even after 10 years of operation. Some estimates suggest that by 2009 the boll weevil eradication program may be completed and all U.S. cotton areas may move into the post-eradication stage. The cost may vary by state, but on the average it will cost growers about US$60-70/ha/year. The departments of agriculture of the individual states provide regulatory support, and USDA's extension service helps in disseminating program information and providing other valuable information regarding crop production.

Malathion is the primary insecticide used against the boll weevil in the eradication program. As many as seven applications of malathion may be needed during the initial stages of a boll weevil eradication program. Malathion is applied only on infested fields, preferably by aircraft, and in ultra low volume concentrations at a rate of 25-40 ounces/ha; higher doses are used with ground application.



At the moment, Texas has the largest area under the boll weevil eradication program. Boll weevil eradication was started in Texas in 1994, and according to Allen *et al*. (2008), the Texas Boll Weevil Eradication Foundation implemented the eradication program on 2,291,085 hectares in Texas and eastern New Mexico in 2007/08. All cotton zones in Texas have been included in the eradication program since 2005, and the boll weevil has been eliminated from most of the western parts of the state. El-Lissy *et al*. (1997) break down the eradication methodology into three important components, cultural, mechanical and chemical. He considers uniform planting and harvesting of cotton in the program area to be a critical factor in creating a host-free environment for the boll weevil during the winter.

In the early stages, when the eradication program is first introduced into a boll weevil infested area, the number of boll weevil catches in the traps is high, but catches start to go down during the second year. Higher catches in traps indicate higher boll weevil populations on the cotton in the field, which means that insecticide use will be extensive. Allen *et al*. (2006) reported that in some areas malathion had to be sprayed as many as 8-9 times in the first year. The number of malathion applications came down to less than one every 3-4 years, which is indicative of the success of the program. In 2007/08, in most parts of Texas, malathion applications have been less than one per season and number of boll weevil catches were down to only a few individuals per 100 traps per season (Allen *et al*., 2006). The program is still being maintained in order to attain complete elimination. The data show that cotton production in Texas increased from 1.1 million tons in 1993/94 to 1.8 million tons in 2007/08. Other factors, such as changes in the types of varieties grown, favorable weather, biotech cotton, etc., have also contributed, but the reduction of crop damage due to boll weevil infestation has played a role in reducing losses due to pests and in increasing yields.

Conclusion

Many countries in South America can learn from the U.S. experience and pursue the approach of eliminating the boll weevil completely rather than controlling it through chemical applications. The eradication approach is simple and has already proved its worth through the many programs implemented in the U.S. at various stages over the last 25 years.

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Future of Cotton in Nonwovens

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Introduction

Because of many uniquely desirable attributes, cotton has been a very popular textile fiber for thousands of years and will continue to be so for the generations to come. Even with the advent of chemical (non-cellulosic and cellulosic) manufactured fibers, cotton production and utilization have continued rising, although cotton's shared fiber use has declines with the increasing world population and the people's improving life styles, cotton use mill continue higher. Cotton production in 2007/08 was 26.3 million tons, compared to ~ 13 million tons in 1980/81. The U.S. alone produced about 5.2 million tons of cotton in 2004/05, although U.S. production declined to only 4.2 million tons in 2007/08, mainly because of reduction in the area planted to cotton.

Locations of cotton textile manufacturing have shifted considerably over the decades during the World War II, mainly because global economics and competitiveness. Just a few decades ago, the U.S. was one of the largest, if not the largest, cotton producers, users and consumers in the world. Today, the traditional U.S. textile manufacturing industry, comprised of spinning, weaving, knitting, and fabric finishing, has shrunk to less than half of what it was about a decade ago. Hundreds of the U.S. textile mills have closed or moved abroad and thousands of mill jobs have been lost. The same scenario of steep declines in the traditional textile industry had also occurred in Western Europe, Japan and Canada. Although booming U.S. exports of cotton to Asia and other developing countries are keeping U.S. cotton production in relatively good economic health, dwindling traditional textile manufacturing in the U.S. remains a major concern for the domestic cotton industry. The U.S still is by far the largest per capita consumer of textiles at the retail level, but it is no longer one of the biggest players in the field of cotton textile manufacturing. The recent increases in land use for non-cotton crops may further adversely alter the metrics of the U.S cotton industry.

This article briefly explores a new strategy from the cotton industry, the feasibility of high-volume utilization of cotton in the nonwovens sector. The Agricultural Research Service of the United States Department of Agriculture (ARS-USDA) is investing in research & development of cotton-based nonwoven textile products and processes. After the devastation caused by Hurricane Katrina in 2005, a new nonwovens research laboratory with state-of-the-art technologies and equipment was established at the Southern Regional Research Center, New Orleans, Louisiana, to develop new and improved, function-specific nonwoven substrates and end-use products containing mostly cotton. New research concepts and approaches are currently being pursued in this new nonwovens research program. Undoubtedly, there are some challenges in the predominant use of cotton in nonwovens, but there are some good opportunities as well, which cotton producers, researchers, promoters and users alike need to explore. Cotton offers several positive attributes, such as absorbency of

A Glimpse at the Recent, Past and Projected Statistics of the Estimated Annual Sale and Quantities for the North-American and Global Markets for Nonwoven

Year	North American		Global		Disposables	Durables
	Sales ($)	Quantity	Sales ($)	Quantity		
2004	N/A	N/A	16 Billion	4.43 million tons [ref. 4]	N/A	N/A
2005	5 Billion	28 Billion sq. m.	N/A	N/A	83% of total	17% of the total
2009	N/A	N/A	25 Billion	6.31 million tons [ref. 2]	N/A	N/A
2010	6.1 Billion	N/A	26 Billion	N/A	N/A	N/A

Sources of the data: Smith, Johnson and Associates, Cotton Opportunities in Nonwovens, March 2008, INDA, Raleigh, NC, and others.

liquids, dyeability, dissipation of moisture resulting in wear comfort, static-freedom, sustainability, biodegradability, and the like. Unlike the petroleum-derived non-cellulose fibers such as polypropylene, polyethylene and polyester that presently are most commonly used in nonwoven products and applications, cotton is an environmentally benign agricultural commodity, which provides favorable "life cycle" and hence global impact. Considering that shipping charges are rising, domestic production, utilization and consumption of cotton may make more sense for domestic uses of the fiber. The manufacturing of nonwovens is highly capital intensive and less labor intensive, which offer another incentive/tool for additional markets for the industries of developed countries to be globally competitive and hence profitable. Cotton either directly or indirectly can be embedded in many nonwoven products and processes, including the needle-punching and hydro-entangling nonwovens systems, for numerous applications.

Current Consumption of Cotton in Nonwovens

Although cotton fiber certainly has many good attributes (such as high absorbency; an excellent substrate for chemical/functional modifications; wear-comfort; soft and supple hand; static-freedom; natural; renewability/sustainability; environmental biodegradability, etc.), cotton has only a small percentage of the rapidly growing nonwovens sector of the textile industry. Today's nonwovens overwhelmingly (~98%) utilize manufactured fibers, such as polypropylene, polyethylene, polyester, nylon, rayon, pulp, etc., that can be efficiently used for producing (generally non-reusable) products for many end-use applications and markets, such as disposable sanitary products; hygienic and cosmetic products; industrial and household wipes; surgical gowns and masks; medical end-use products; bed-sheeting; air and fluid filters; roofing materials; automotive interior components; military camouflage, tents, combat gear and other work outfits; geo and landscaping; reinforced composites and laminates; and even some semi-durable or durable (reusable) apparel/garments. The use of good quality virgin cotton is negligible in today's huge and yet growing nonwovens industry. This is partly due to economics and partly because of technical reasons. Fiber orientation and/or "entanglements" in cotton nonwoven fabrics are little understood. Cotton nonwoven structures, compared to the traditional fabrics, lack the strength, stability, down-stream processability, and certain other characteristics that may be essential for the intended end-use applications. Cotton nonwoven fabrics, compared to woven or knitted fabrics, may also lack the integrity, durability, uniformity, and drape in some end-uses, such as apparel, where cotton historically has been enormously popular. Further, for certain cotton nonwoven products and for certain medical, cosmetic and hygienic end-uses, U.S. (machine-picked and ginned) raw cotton must be thoroughly cleaned of its foreign matter content and then scoured and bleached in the fiber state. Although a hydro-entangled nonwoven cotton fabric structure may be sufficiently strong and stable to be bleached in fabric form, it may be difficult and perhaps costly to efficiently hydroentangle greige (untreated) cotton, whose foreign matter content is known to cause filtration problems when water is recycled. Furthermore, the natural waxes and other fine foreign particles in greige cotton may get firmly trapped/embedded in a hydroentangled nonwoven fabric, which, in turn, could cause certain difficulties in the downstream processes and/or end-use. All of the technical factors stated above, coupled with the current cost for bleached fiber, ultimately make cotton fiber uncompetitive in today's nonwovens markets. The following articles summarize why cotton thus far has not appreciably participated in the nonwovens boom and what could make cotton compelling for certain nonwoven products and applications:

Factors Responsible for Little of Cotton Use in Today's Nonwovens

- A very large majority of current end-use markets for nonwovens are "non-apparel" and "disposable or non-reusable." Mainly because of costs, these markets historically have not used cotton and, therefore, cotton's unique properties have not been adequately investigated, appreciated and utilized.
- Nonwovens, mainly due to their fiber orientation and bonding, inherently are relatively weaker, non-uniform, more combustible, and less stable compared to equivalent, traditional textiles. Hence, cotton nonwoven

Mechanical Properties of Cotton and Some other Fibers

Fiber	Tenacity (gm/den)	Breaking Elongation (5)	Elastic Recovery (%)	Toughness	Resistance to Abrasion
Cotton	3.9 to 4.9	3 to 7	45	0.15	Good
Polyester	9.5 (HT)	9 to 13 (HT)	35 -93		Good
Nylon	9.5 (HT)	16 to 28	99 -100	1.0 (HT)	Excellent
Olefin (PP)	up to 8.0		95 -100		Excellent
Polyethylene (gel-spun)	35	3		3.5	Excellent

structures may be difficult to handle during wet finishing, such as scouring, bleaching, dyeing, and/or during any special chemical treatment. This, in certain cases, may necessitate the use of a raw stock of bleached cotton, which is costly and cumbersome in down-stream processes. Certain modern nonwovens technologies, such as hydroentangling, demand a raw stock largely free of foreign matter and contaminants, which can disrupt and clog the system or increase the cost of water supply and/or its filtration. Thus, the use of costly bleached cotton in this scenario also becomes an economic issue.

- Cotton generally needs substantial preparatory processing for cleaning and homogenization that are essential for attaining the desired uniformity and consistency of the nonwoven end-product. From crop to crop, the quality, price and supply of cotton may be unpredictable for an efficient manufacturing operation.
- Single-fiber mechanical characteristics of cotton, such as tensile strength, modulus, dirt- and mildew- resistance, flame resistance, etc., generally are not the same as those of comparable manufactured fibers, such as polypropylene, polyethylene and polyester that are widely used today in the industrial and technical nonwovens that are durable. The table above shows a comparison of some mechanical properties of cotton with other fibers that presently are most commonly used.
- Generally, nonwovens are inherently stiffer than traditional textiles and, hence, may not drape as well, particularly in the case of apparel and household textiles where cotton is the best-suited fiber.
- Classical cotton textiles efficiently utilize the stress-strain relationship of constituent fibers and yarns, whereas cotton nonwovens inherently lack that relationship because their constituent fibers are mechanically or chemically bonded and randomly bundled together, resulting in a plastic-like rigidity. The constituent fibers in a nonwoven structure exhibit little flexibility, slippage and yield, which are essential for apparel.
- Huge capital investments and extremely high rates of production of modern, ultra-high-speed nonwoven manufacturing technologies necessitate continuous, uninterrupted mass-scale production of standardized nonwoven roll goods, products, or substrates day in and day out, in order to achieve a reasonable return on investment. However, the existing system of small-lot and diverse-style production of traditional cotton textile fabrics/apparel to satisfy a hugely-diverse human population currently does not permit enough high-volume, utilization of cotton in nonwovens, especially for clothing applications. However, this argument against use of cotton in nonwovens could change with proper research and development of cotton nonwovens for certain other mass markets, such as disposable, reusable, semi-durable, or even durable wipes, cosmetic pads, antistatic medical gowns and other products, sheeting, hospitality linens, drills, denims, towels and toweling, upholstery, automotive components, furnishing fabrics and undergarments.

Nonwovens Manufacturing Technologies

Although there have been many technologies and their derivatives in the past few decades to manufacture not-so-sophisticated nonwoven fabrics, the following paragraphs briefly describe the various modern technologies and methods that are most commonly deployed today to produce functional woven-like, nonwoven fabrics for numerous applications, such as personal care, medical, hygiene, household, industrial, automotive, filtration, and the like, predominantly using manufactured fibers, such as polypropylene, polyethylene, polyester and rayon and sparsely using natural fibers, such as cotton, jute, pulp, wool, etc.:

Web Formation Methods

Spun-bonding

This is the most commonly used method for producing a web from thermoplastic polymer chips that are melted and extruded on line into synthetic fibers, such as polyethylene, polypropylene and polyester. The extruded fibers are placed together to form a wide web-like sheet that is allowed to cool, thereby allowing inter-strand binding. The web or sheet may be rolled and shipped to converters or may be further processed on line to modify its aesthetics and/or functional performance for the intended end product for a specific application. Spun-bonding offers greater productivity by an order of magnitude compared with traditional weaving and knitting. For example, a typical spun bonding process may efficiently produce a continuous fabric-like structure up to 200 yards per minute, compared to only a yard or so in a weaving process.

Meltblown

In this method, an extruded fibrous sheet of a molten polymer is subjected to a continuous jet of hot air, before the sheet is allowed to cool and bond, which splits the extruded filaments into very fine fibers. This method of producing roll goods (webs) for subsequent nonwoven products is also highly productive.

Carded Webs

This method is utilized for staples fibers, whether natural, synthetic or blends. Fibers are carded using conventional machines to form a web, which then can be cross-lapped to attain the desired thickness and mass. It is a relatively slow and more expensive method to convert fibers into a continuous web of specified integrity.

Dry- and Wet- Laid

In the dry-laid technique, staple fibers, along with certain resins or thermally fusible fibers, are pneumatically "gathered" and laid to form a web of required density. This method does not involve carding. In the wet-laid technique, fibers of relatively short length, such as pulp, are passed through water or some other medium, which provides the required inter-and-intra-fiber adhesion and cohesiveness to form a continuous web of desired integrity for further down-stream processes.

Bonding Technologies (Bonding of webs into strong nonwoven structures/fabrics)

Needle-punching

A needle-punch is a machine that provides a mechanical bonding of a web's constituent fibers. Many barbed needles of proper specifications perform the mechanical bonding action. Although this nonwovens technology is not as efficient as other mechanical or chemical bonding technologies, it still is at least 20 times faster than traditional weaving and needle –punching is at least 5 times faster than knitting.

Hydroentangling

This probably is the most common technology for mechanical bonding of cohesive fibers and webs. This method further reinforces and strengthens structural integrity and improves functional performance of a nonwoven substrate. High-pressure water jets are used to provide the necessary energy to impart the required mechanical bonding of constituent fibers of underlying substrate. Sometimes, *spun lacing*, which was first developed and named by DuPont several decades ago, is also the terminology used for hydroentangling technology. It is very fast and productive and offers many online operations to attain different designs, finishes, and other attributes.

Chemical/Resin/Thermal Bonding

These bonding techniques are generally applied for producing certain nonwoven composites for numerous end-use applications, including industrial, awnings, building materials, furnishings, automotive components, and the like.

Stitch-through Technology

Although an old technology, it is still used for mass production of nonwovens for bedding, military, blankets, mattress components, etc. Warp knitting and sewing techniques are employed to reinforce a needle-punched or some other nonwoven substrate that by itself may not be strong enough for the intended application.

Finishing and Conversions of Nonwovens

The technologies for finishing nonwovens vary depending on their end-use applications. However, unlike traditional woven and knitted fabrics, the nonwovens generally are not piece-good bleached, dyed, and processed on a stenter. Dyes are generally added into the fiber extrusion process. For bleached cotton nonwovens, cotton in fiber state is generally bleached, which is costly. However, nonwovens are chemically and mechanically modified in many ways to obtain product-specific attributes. For example, nonwovens generally are more flammable than woven fabrics. Hence, flame retardance (FR) or resistance of nonwovens is achieved with a heavier dose of certain specific FR formulations. Similarly, nonwoven fabrics for certain wipe applications may require antimicrobial treatments. Abrasion resistance of cotton nonwovens may need to be beefed up for increased for applications.

Testing of Nonwovens

As in any other commercial product, testing nonwoven products for conformity and quality is essential to preserve the manufacturers' as well as the customers' interest. It is a human tendency to cut corners if there are no controls in place. Testing of nonwovens is done according to international standards framed by mutual involvement of various universities, nonwovens associations, and the manufacturers of nonwoven goods. Most of the required tests for nonwovens are similar (or slightly modified) to those that are in place for traditional textiles.

Potential Uses of Cotton in Nonwovens

The following are some good technical reasons that many enhance the use of cotton in nonwovens.

- Cotton is a naturally sustainable substance. It is also biodegradable, easily disposable, and hence ecologically friendly. Thus, extra efforts can be made to replace petroleum-based fibers with cotton, where affordability and functional performance of new products are justified. In this regard, Wal-Mart – the largest retailer in the world - is playing a significant role in the effort for more use of cotton in consumer and other goods by endorsing the "Vision on Sustainability and Environment".

- Cotton nonwoven products, if functionally and commercially acceptable, can be produced at speeds that may be an order of magnitude greater than those of the traditional weaving process, which could offset high manufacturing costs for cotton textiles. The processes of making nonwovens are relatively much less labor-intensive and environment-sensitive than traditional spinning and weaving.
- Because of its unique characteristics of high absorbency, static-freedom, ease of blending with other fibers, and excellent substrate for functional chemical derivitization, cotton could be the fiber of choice for many existing nonwoven applications, such as institutional sheets; upholstery; household furnishings; wipes; towels or toweling; medical, personal-care, cosmetic and sanitary products; and composites for certain industrial and technical applications. Cotton may also be ideally suitable for many potential new applications, such as nonwoven apparel.
- Because of varying soil and environmental conditions, cotton quality varies considerably from crop to crop. Almost every year, a certain portion of cotton production worldwide suffers damage of one kind or another that renders the cotton unsuitable for efficient utilization in traditional textile processing. This cotton of inferior quality is significantly discounted in price. Sometimes, it is even unsellable in cotton markets. It is possible that substantially discounted cottons may be efficiently used in nonwovens to produce useful products of economic significance. Furthermore, it is imaginable that certain high-yielding cotton cultivars may process and perform as good as (or, even better than) the classical cottons in certain nonwoven technologies and for certain end-use products and applications. So, the USDA intends to explore all uses to promote the value-added, mass utilization of this naturally sustainable fiber in nonwovens.
- Escalating costs of fuel/energy and, consequently, shipping will curb transportation (imports and exports) of heavy goods and commodities, which should encourage and brighten once again the indigenous production and utilization of cotton in the U.S.

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