United States
Department of
Agriculture

Animal and Plant Health
Inspection Service

Plant Protection and
Quarantine

May 17, 2013

Mortality of Pink Bollworm, *Pectionophora gossypiella* (Saunders), and Boll Weevil, *Anthonomus grandis* Boheman, Through Gin Processing With Particular Reference to High-Compression Baled Cotton (*Gossypium* spp.).

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Executive Summary

This document was prepared by the Plant Epidemiology and Risk Analysis Laboratory of the Center for Plant Health Science and Technology, USDA, APHIS, PPQ in response to a request to address the feasibility of amending treatment regulations that require the mandatory methyl bromide fumigation of baled cotton for *Pectinophora gossypiella* (Saunders) (Pink Bollworm), and *Anthonomis grandis* Boheman (Boll Weevil) moving from infested to non-infested areas in the United States, and for foreign imports of cotton from countries infested by these pests.

In its passage with the seed cotton through seed-cotton conditioning and cleaning to the gin stand, adults, larvae, or pupae of *P. gossypiella* or *A. grandis* encounter severe mechanical and environmental conditions, including agitation and pressing by multiple spiked cylinders against grid-rod sections, wiping onto saw-toothed cylinders by stationary brushes, being repeatedly thrown against stationary rods by centrifugal forces 25-50 times the force of gravity, striking the walls of conveyance piping at speeds up to100 km/h, and exposure to temperatures as high as176ºC. Subsequent passage of the ginned fiber through the gin stand and through one stage of saw lint cleaning further expose any possible surviving *P. gossypiella* or *A. grandis* to additional similar severe mechanical conditions. In addition, quarantine regulations designed to prevent the artificial spread of *P. gossypiella*, and *A. grandis* in cotton lint require that all cotton bales shipped from infested to un-infested areas must be either fumigated with methyl bromide or compressed to a minimum density of 22 lb /ft3.

An analysis of the scientific evidence shows that the risks associated with the domestic movement or importation of cotton lint and linters from areas where *P. gossypiella* or *A. grandis* are found can be mitigated by ginning processes that include at least two stages of seed cotton cleaning and at least one stage of lint cleaning and compression to a minimum density of 352 kg m-3 (22 lb ft^3)
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1. Introduction and Initiating Event

This document was prepared by the Plant Epidemiology and Risk Analysis Laboratory of the Center for Plant Health Science and Technology, USDA, APHIS, PPQ in response to a request to amend the treatment regulations and eliminate the mandatory methyl bromide fumigation of baled cotton for domestic movement from *Pectinophora gossypiella* (Saunders) (Pink Bollworm), or *Anthonomis grandis* Boheman (Boll Weevil) infested to non-infested areas and for foreign imports of cotton from countries infested by these pests. The treatment requirements for imported cotton are found in 7 CFR § 319.8 (Foreign Quarantine Notices, Subpart-Foreign Cotton and Covers Quarantine).

2. Biology of *Pectionophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae)

Pectinophora gossypiella (Saunders) causes severe damage to cotton. The species originated in southern Asia, probably India (Marlatt, 1918) or Africa (Busck, 1917), and was introduced into Mexico in 1911 from infested cotton seed from Egypt (Noble, 1969). Infestations in the United States first occurred, and were eradicated, in Texas in 1917 (Spears, 1968). Re-infestations in Texas in 1936 eventually spread into Louisiana, New Mexico, Arizona, Arkansas, California, and Nevada (Henneberry and Naranjo, 1998).

Female *P. gossypiella* oviposit 100-200 eggs singly or in small clutches (Henneberry and Naranjo, 1998) on any part of the plant, and the first larval infestations occur in the squares (Henneberry and Clayton, 1989). The larvae develop through four instars in 12-18 days. Last instar larvae exit the blooms, pupate in and on the soil, and adult emergence occurs 4-7 days later. Subsequent generations develop primarily within the maturing fruit (Henneberry and Naranjo, 1998). In the southwestern United States, four to six generations may occur during the cotton-growing season (Noble, 1969). Larval feeding reduces lint quality and seed quantity (Noble, 1969).

3. Biology of *Anthonomus grandis* Boheman (Coleoptera: Curculionidae)

Anthonomus grandis Boheman, a native of Mexico and Central America, is invasive in the United States. Adults overwinter under leaf litter, in woods, in weeds and along fence rows near cotton fields (Cross, 1983; Smith and Harris, 1994). In the spring, these adults return to the fields, and feed primarily on terminals of cotton seedlings (Cross, 1983). When the squares are available, adults feed on them, and oviposition occurs when the squares are one-third to one-half grown, this usually occurs in the lower one-third of the square (Anon., 1996). Adult females make a small cavity in each square and oviposit a single egg. Later in the season, adults attack and reproduce in the bolls (Cross, 1983). Larvae feed for 7- 14 days in the squares (which turn yellow, flare, and usually abscise, and drop from the plant 3- 5 days after eclosion from the egg) or bolls (Bohmfalk *et al*., 2002, Cross, 1983), pupation occurs in the squares or bolls, and has a 3½ -8½ day duration. The entire life cycle can take as little as 16 - 18 days under ideal conditions, and five (Cross, 1983) to seven (Bohmfalk *et al*., 2002; Smith and Harris, 1994) generations may be produced each season.

4. Cotton Quarantine and Treatment - The Current Regulations

7 CFR § 319.8 (Foreign Quarantine Notices—Foreign Cotton and Covers) and 7 CFR § 305.5 (Treatment Requirements) govern the movement, and treatment of raw cotton bales into the United States. 7 CFR § 319.8 prohibits the unrestricted importation into the United States from

all foreign countries and localities of (1) any parts or products of plants of the genus *Gossypium*, including seed cotton; cottonseed; cotton lint, linters, and other forms of cotton fiber (not including yarn, thread, and cloth); cottonseed hulls, cake, meal, and other cottonseed products, except oil; cotton waste, including gin waste and thread waste; and any other unmanufactured parts of cotton plants; and (2) second-hand burlap and other fabrics, shredded or otherwise, which have been used or are of the kinds ordinarily used for containing cotton, grains (including grain products), field seeds, agricultural roots, rhizomes, tubers, or other underground crops, due to the pink bollworm [*Pectinophora gossypiella* (Saund.)], the golden nematode of potatoes (*Heterodera rostochiensis* Wr.), the flag smut disease (*Urocystis tritici* Koern.), and other injurious plant diseases and insect pests.

The current treatment requirements for raw cotton (bales) being imported into the United States are found in 7 CFR § 319.8-8, which differentiates between raw cotton lint (bales) and uncompressed raw cotton lint. Raw cotton (seed cotton or field cotton) is prohibited entry into the United States. On the other hand, "Ginned and Baled Cotton" (cotton lint and linters) is allowed into the United States with a methyl bromide vacuum fumigation treatment. In locations where no vacuum chambers are available, commercial cotton bale shipments can be treated by tarpaulin fumigation with methyl bromide.

7 CFR§ 319.8-8 states that the entry of lint, linters, and waste that are compressed to high density (approximately 28 or more pounds/ft^3) will be authorized subject to vacuum fumigation by approved methods at any port where approved fumigation facilities are available. Importations of these materials at a northern port where there are no approved fumigation facilities may be authorized for transportation to another northern port where facilities are available for the required vacuum fumigation. Additionally, the entry of these materials will be authorized without vacuum fumigation at any northern port subject to movement to an approved mill or plant where the owner or operator has an agreement with PPQ. Lint, linters, and waste compressed to high density arriving at a port in the State of California where there are no approved fumigation facilities may be entered for immediate transportation via an all-water route if available, or by overland transportation in van-type trucks or box cars after approved surface treatment to any port in California or any northern port where approved fumigation facilities are available, or to an approved mill or plant for utilization.

The entry of uncompressed (baled or packaged to a density less than approximately 20 lb/ft^3) or compressed lint, linters, and waste are authorized, subject to a methyl bromide vacuum fumigation by approved methods, through any northern port, through any port in the State of California, and through any port on the Mexican Border, where approved fumigation facilities are available. Importations of these materials arriving at a northern port where there are no approved fumigation facilities may be entered for immediate transportation to another northern port where such facilities are available, for the required vacuum fumigation. Uncompressed lint, linters, and waste arriving at a port in the State of California where there are no approved fumigation facilities may be entered for immediate transportation by an all-water route to any port in California or any northern port where approved fumigation facilities are available, or to a northern port for movement to an approved mill or plant for utilization.

5. Risk Mitigation

5.1 Seed- Cotton Cleaning System

In the U.S., raw seed cotton is subjected to drying, cleaning, and extracting before the lint is removed from the seed (Fig. 1). Seed cotton dryers reduce lint cotton moisture content to 5-8 percent in order to facilitate cleaning and fiber/seed separation. A high-pressure fan conveys seed cotton through the drying system to the first seed-cotton cleaner, which opens up large masses of the seed cotton and removes contaminants, such as particles of leaf, sand, and dirt. In the second cleaner, large pieces, such as sticks, stems, and burs are also removed. After seed-cotton cleaning, the seed cotton then enters the gin stand (Fig. 1) to separate the fiber from the seed (EPA, 2012).

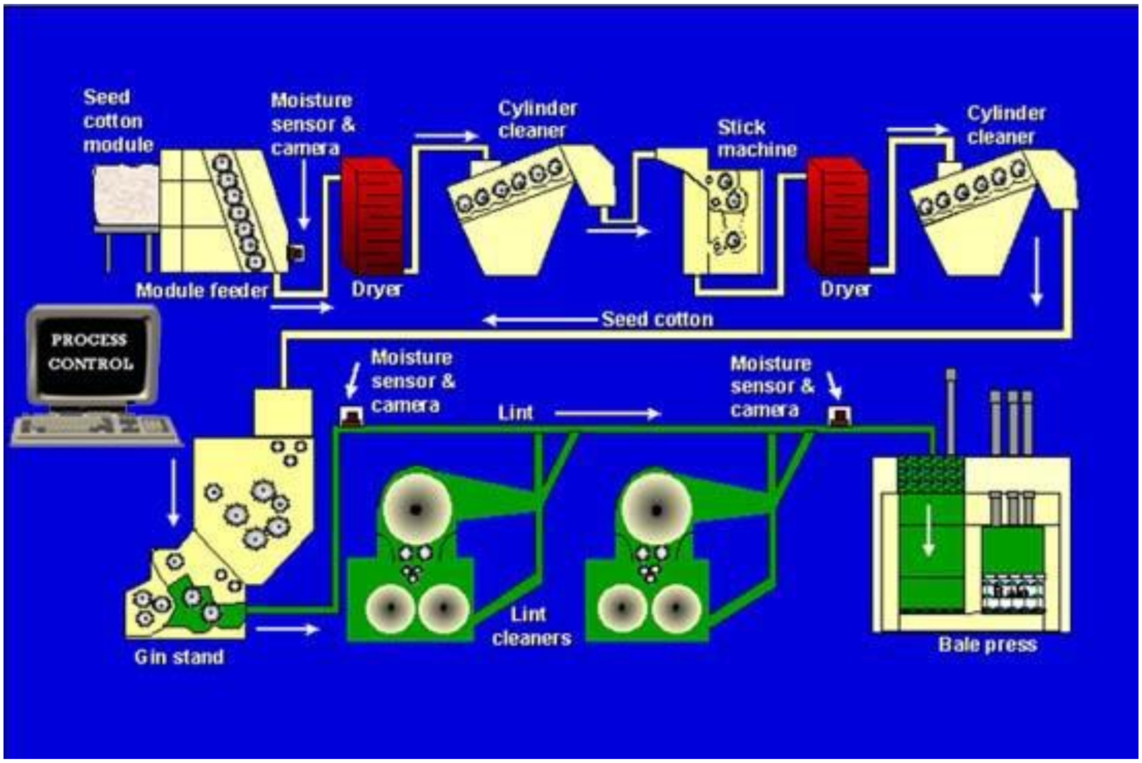

Fig. 1. Generalized cotton gin process (ARS., 2012).

5.2 The Ginning and Lint Cleaning Process

The function of the gin stand is to separate cotton fiber (lint) from seed after the seed-cotton cleaning process has removed most of the foreign matter and excess moisture that would reduce the value of the ginned lint (Anthony, 1994). In a two-step ginning and cleaning process, gin stands (either saw-type or roller-type) remove the lint (long fibers that are used as textile raw materials) from the seed. Then the ginned lint is further cleaned by passing it through lint cleaning machinery appropriate to the variety and ginning process. Cotton varieties with shorter staple or fiber length belong to the species *Gossypium hirsutum* L., and are commonly known as upland cottons. Worldwide, *G. hirsutum* is the most commonly produced and traded cotton lint (Estur and Gergely, 2010). These cottons are normally ginned with saw gin stands. This process involves the use of circular saws that grip the fibers and pull them through narrow slots. After the saw gin stand the fiber is then processed through at least one saw-type lint cleaner. The saw lint cleaner has a rotating saw cylinder that grabs the ginned fiber and beats it over a series of stationary grid bars to remove remaining trash by centrifugal force and aggressive beating action.

Extra long fiber length cottons (Pima, Egyptian, America-Egyptian, Sea Island cottons, *G. hirsutum* L.) accounted for 3% of world cotton production in 2007-2008 (Estur and Gergely, 2010), and are usually ginned on a roller gin stand to preserve fiber quality (saw gins break and shorten their longer fibers). However, approximately 20% of upland cotton, worldwide, was roller-ginned in 2007-2008 (Table 1). A roller gin uses a laminated cotton and rubber wrapped roller to grab the fiber and pull it under a stationary bar that rides on the roller surface with significant force. Passing the fiber under the bar effectively separates the fiber from the seed. After roller ginning, the ginned lint is then processed through a flow-through air lint cleaner and one or two cylinder cleaners or a mill-type lint cleaner and a flow-through air lint cleaner that removes most of the remaining trash in the ginned lint (Whitelock *et al*., 2007).”. The cleaned lint for both saw- or roller-gins is then sent to a press where it is compressed into steel-banded high-density bales that weigh between 450 and 500 pounds, and a standard density of 28 lb/ft^3 (Anon, 2008). These bales are then sampled and immediately wrapped for protection, and loaded onto trucks for shipment to storage yards, textile mills, and export (Anon, 2012). The U.S. cotton industry has adopted approximate dimensions for a bale at 55 inches tall, 28 inches wide, and 21 inches thick with 28 lb/ft^3 standard packing density that is commonly called a universal density (UD) bale (Anon, 2012).

Table 1 - Roller Ginning of Upland Cotton, 2007-08[1]

Country	Upland Production (thousand tons lint)	Roller Ginned	
		(thousand t)	(%)
Kenya	10	10	100
Bangladesh	9	9	100
Uganda	12	11	92
Turkey	675	575	85
India	5,275	4,150	79
Myanmar	65	50	77
Tanzania	145	75	52
Sudan	14	5	36
Zambia	40	10	25
Zimbabwe	125	20	16
USA[2]	4,000	40	1
Afghanistan, Indonesia, Iran, Laos, Madagascar, Nepal, Nigeria, Sri Lanka, Thailand	14,880	45	0.30
Total	25,250	5,000	20

[1]After Estur and Gergely, 2010.
[2]15% of Acala production in California and Arizona is roller ginned.

5.2a The Ginning Process – *Pectinophora gossypiella* Mortality

Research has shown that ginning with the simplest saw-gin killed 84% of *P. gossypiella* in seed taken at the gin stand. With additional machinery, the mortality increased to more than 99% (Noble, 1969). However, the large number of live larvae found in gin trash, despite the high kill in seed, confirmed the need for treating this material (Noble, 1969). In contrast, *P. gossypiella* mortality in seed cotton ginned with a roller gin is lower than that from a saw gin. When infested cotton passed through the gin stand alone, bypassing all other equipment, the larval mortality was 6% for a roller gin compared with 32% for a saw gin operated at 570 rpm and 77% at 865 rpm (Noble, 1969). However, later research has shown that the proper use and design of gin trash handling fans will eliminate live *P. gossypiella* in gin trash (Hughs and Staten, 1995).

Graham *et al*. (1968) ginned short- and long-staple seed cottons (240- and170-lb replicates, respectively) on conventional reciprocating knife and high-capacity rotary knife roller gins with and without lint cleaners. They split the samples into lots. They examined 45 pounds of lint by hand, and separately caged 290 pounds from short-staple cotton ginned in the conventional gin; 277 pounds of short-staple cotton ginned in the high-capacity gin; 402 pounds of long-staple cotton ginned in the conventional gin; and 363 pounds of long-staple cotton ginned in the high-capacity gin. They found no live larvae in the hand-examined samples. In the caged samples, they recovered two adult moths from the conventional gin with lint cleaner, one adult from the conventional gin without lint cleaner, four adults from the high-capacity gin with lint cleaner, and one adult from the high-capacity gin without lint cleaner.

Hughs and Staten (1995) used two fan sizes and air-intake velocities in *P. gossypiella* mortality tests: a fan with an 81.3 cm diameter fan wheel, and a fan with a 107.3 cm diameter fan wheel, and air-inlet velocities of 1,585 and 2,804 m/min. Each test lot consisted of 22.7 kg of trash into which an average of 138 infested green bolls were mixed; the rate of infestation was estimated at 1.4 *P. gossypiella* per boll, or about 193 live *P. gossypiella* per lot. They found that the 107.3cm fan wheel, operating at tip speeds between 3,742 and 4,845 m/min, was 100% effective in killing *P. gossypiella* larvae. They also reported that fan tip speeds above 3,962 m/min appeared to be the most effective method in killing larvae, even when shielded inside whole green bolls, and that fan-inlet air velocity is not critical, although it should be kept at 1,585 m/min or above.

5.2b The Ginning Process – *Anthonomus grandis* Mortality

Sappington *et al*. (2004a) found *A. grandis* could not survive passage through the minimal machinery sequence typically used to clean picker-harvested cotton, even when the dryers were unheated. Concomitantly, they found no evidence of *A. grandis* survival when passed through two incline cleaners, which constitute only a portion of the seed-cotton cleaning process. In addition, heated dryers proved to be another source of mortality, especially when two were run at moderately high temperatures of 66ºC. At higher mix-point temperatures, 149ºC for one tower and only 85ºC for two towers, there was no survival. They concluded that few, if any *A. grandis* can survive the pre-cleaning process to approach the gin stand in the seed cotton. However, they did recover live adults in the green boll/rock trap in both the seed-cotton cleaning and the incline cylinder cleaner. Because of this, they suggested that it is important that at-risk gins destroy the trash collected in the rock trap or collect it in an escape-proof container. Another potential avenue of escape is with the gin trash, which is shunted out of the cleaning system at several points in the process.

In a subsequent study, Sappington *et al*. (2004b) found that *A. grandis* adults not killed by the seed-cotton cleaning machinery were shunted alive into the trash fraction (the fraction which passes through a centrifugal trash fan before exiting the gin). However, these weevils were fatally injured and did not survive 24 h post-ginning. They also reported that when green bolls infested with both adult and larvae were fed through the fan, that several adults survived 24 h, and that there was no evidence that fan-tip speed affected either initial survival of weevils, or the number of unbroken, infested boll locks. Therefore, it was not possible to designate a minimum fan-tip speed that would ensure 100% kill. However, a device attached to the gin that partially crushes or cracks the bolls open before entering a trash fan would increase mortality.

In another study Sappington *et al*. (2004c) quantified the survival potential of *A. grandis* passing through the gin stand and segregating into the cottonseed, mote, or lint fractions; and examined adult survival when passed with ginned lint through a lint cleaner. They demonstrated that there is little chance of *A. grandis* being segregated alive into the cottonseed or surviving in the lint to approach the bale press. They concluded that quarantine or fumigation of cottonseed and cotton bales is unwarranted in guarding against introduction of *A. grandis*.

Hughs *et al*. (2006) reported that no *A. grandis* survived processing through a 93-saw Continental saw-gin stand and one saw-type lint cleaner. In addition, most adults survived pressing densities up to 20 $lb/ft^3$for at least1 min, but were immediately killed at compressions of 22 lb/ft^3 and higher in the bale press. They also found that there were also no survivors after six days at the industry target density and weight of U.S. UD bale density of 28 lb/ft^3. They concluded that it was extremely unlikely that live *A. grandis* could survive both gin processing and bale compression. As an added factor, they noted that at the time of strapping, a 480 lb UD bale is momentarily compressed to a density greater than 30 lb/ft^3 in order to apply the ties (after tying, the bale is released to the nominal restraint density of 28 lb/ft^3). Thus, these extra compressive forces will further decrease the risk of survival. They also stated that there is a risk of *A. grandis* surviving in underweight U.S. bales even if tied in a UD press or in bale packages such as flat or modified flat whose normal densities are approximately 24 lb/ft^3. This underweight type of bale package, although not produced in the US, is produced overseas. Thus, to counter the concern about introducing *A. grandis* into non-infested areas, a restriction on underweight UD bales or any bale design with standard densities less than 20 - 22 lb/ft^3 would be a possible and important control factor.

6. Conclusion

In the passage with the seed cotton to the gin stand, organisms such as *P. gossypiella*, and *A. grandis* encounter inimical environmental conditions, *e.g*., agitation and pressing by multiple spiked cylinders against grid-rod sections, wiping onto saw-toothed cylinders by stationary brushes, repeated catapulting against stationary rods by centrifugal forces of up to 50 times the force of gravity, striking the walls of conveyance piping at speeds of up to100 km/h, and exposure to temperatures as high as176ºC (Baker *et al*. 1994a,b) (Fig. 1). Quarantine regulations designed to prevent the artificial spread of *P. gossypiella* and other cotton pests associated with cotton lint also require that all cotton bales shipped from infested to un-infested areas are either fumigated with methyl bromide or compressed to a minimum density of 22 lb/ft^3. Therefore, based upon published studies of *P. gossypiella* and *A. grandis* survival through the ginning process it should be concluded that the fumigation of uniform, densely-packed baled cotton is unwarranted. A ginning process that include at least two stages of seed cotton cleaning and at least one stage of lint cleaning and compression to a minimum density of 352 kg m^3 (22 lb ft^3) is sufficient to meet the quarantine security requirements of the United States for domestic movement and imports of cotton lint and linters. In addition, any pest emerging inside a UD bale is going to shortly die in the bale, and will not be able to get out unless right on the surface – which is extremely unlikely (S. E. Hughs, pers. com).

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7. Acknowledgements

Appreciation is given to Ed Hughs for his thoughts, and review of this document, and to Scott Redlin[a] and Thomas Culliney[a] for their reviews and comments.

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