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Historical Records of Application of Bio-control Agents and IPM to Combat Cotton Leafworm and Cotton Bollworms with Special Reference to the Hazard of Conventional Insecticides from 1900-2006

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INTRODUCTION

The cotton leafworm, *Spodoptera littoralis* (Boisd) is a key polyphagous pest in Egypt. Without a hibernation period, cotton leafworm (CLW) is active all year round, attacking cotton as well as more than 29 hosts from other crops and vegetables. The rate of CLW infestation can reach up to 50, 000 egg-masses/acre, causing severe damage to leaves, buds, flowers and bolls. The cotton leafworm has the ability to develop relatively quick resistance to most conventional insecticides. Several publications have confirmed that cited from Temerak [1]. Egypt lost 50% of the national yield of cotton due to the countrywide CLW resistance to Toxaphene in 1961 [2].

The cotton bollworms (CBW) namely pink bollworm (PBW), *Pectionphora gossypiella* and the spiny bollworm (SBW), *Erias insulana* are considered the direct responsible for the yield deterioration. Also cotton lost 35% of the yield due to the sub lethal doses from conventional insecticides and the sub doses from the disruption pheromone of PBW in 1998 to combat CLW/CBW [1].

Historical records of low field performance of products or of cotton leafworm (CLW) resistance during 1950-2002 are published [1].

No chemicals (1900-1950): Almost no chemical control was applied. Cotton production control was based on the pick up of eggmasses by school children. Hand picking CLW egg-masses is a reliable practice as well as a safe approach for control, particularly in the first generation of CLW on cotton in Egypt [3].

The local rich resources of predaceous arthropods and parasitoids in addition to predators from wild birds were very successful tools to manage the infestation and have a good yield of famous Egyptian lint. Local parasitoids were recorded in Egypt from 1912-1969 (Table 1). However, Egypt introduced some parasitoids as shown in Table 2.

Several predaceous arthropod species were seen on cotton, e.g., Coccinelids, Staphylinids, Anthocorids, Chrysopids, Reduviids, Carabidae, Formicids and true spiders specially during the eggmasses deposition.

Also, mechanical and culture control were played a significant role for management the infestation. This period was characterized by no pollution, no resistance problem, no cost and very good yield.

Temerak [4] indicated that around 180 different species of parasitoids attacking 218 different species of host insects in Egypt.

No rotation program of insecticides (1950-1978): During the 1950-1978, there was no CLW resistance management program. The Ministry of Agriculture sprayed the same product, e.g. trichlorfon, toxaphene, or carbaryl, 3-4 times via airplane in the same area within the same season. Several products showed high levels of resistance (field failure) and have since been cancelled from the official cotton-spraying program against cotton leafworm: DDT, toxaphene, lindane, endrin, carbaryl, trichlorfon, fentrotion, methyl parathion, leptophos, azinophos methyl, monocrotophos, tetrachlorvinphos, mephosfolan and phosfolan [2, 5].

Cross-resistance was common and was detected between toxaphene and endrin, monocrotophos and trichlorphon, methyl parathion and tetrachlorvinphos and carbaryl and methomyl [5].

Egypt lost 50% of the national cotton yield due to countrywide resistance of the CLW to toxaphene in 1961. Toxaphene was used in four successive sprays in the same season at very high rates of 4 L/acre in comparison

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Table 1: Records of local parasitoids of CLW and CBW in Egypt from 1912-1969

Parasitoid	Host insect	Reference
Bethylidae		
Parasierola sellaiaris Say	*Pectinophora gossypiella* Saund.	Willcocks 1916
Braconidae		
Apanteles platyedrae Wikn	*Peotinophora gossypiella* Saund.	Hafez 1969
Bracon brevicornis Wesmael	*Erias insulana* Boisd.	Willcocks 1913
Bracon brevicornis Wesmael	*Pectinophora gossypiella* Saund.	Dudgen & Lewis 1912
Bracon variegator	*Erias insulana* Boisd.	Willcocks 1913
Bracon variegator	*Pectinophora gossypiella* Saund	Willcocks 1913
Chelonus inanitus L.	*Spodoptera littoralis* Boisd.	Hafez *et al.* 1976
Chelonus sulcatus Nees	*Pectinophora gossypiella* Saund	Willcocks 1916
Chelonella sulcata Nees	*Pectinophora gossypiella* Saund	Willcocks 1916
Microplitis demolitor Wilk	*Spodoptera littoralis* Boisd	Kamal 1951b
Microplitis rufiventris Kokujev.	*Spodoptera littoralis* Boisd.	Hammad *et al.* 1965
Zele chlorophthalma Nees	*Spodoptera littoralis* Boisd.	Kamal 1951b
Zele nigricornis Walk	*Spodoptera littoralis* Boisd	Willcocks & Bahgat 1937
Chalcididae		
Chalcis brevicornis	*Erias insulana* Boisd.	Willcocks 1912
Eulophidae (incl. Elasmidae)		
Pleurotropis sp	*Pectinophora gossypiella* Saund	Kamal 1936
Ichneumonidae		
Barylypa humeralis Brauns	*Spodoptera littoralis* Boisd	Kamal 1951b
Eulimnerium xanthostoma Grav.	*Spodoptera littoralis* Boisd	Kamal 1951b
Limnerium interruptum	*Pectinophora gossypiella* Saund.	Willcocks 1916
Pimpla foborator Fabr.	*Pectinophora gossypiella* Saund	Willcocks 1916
Pteromalidae		
Conomorium eremita Foerster	*Spodoptera littoralis* Boisd	Kamal 1951b
Scelionidae		
Telenomus nawaii Ashm	*Spedoptera littoralis* Boisd.	Kamal 1951b
Telenomus spodopterae Dodd	*Spodoptera littoralis* Boisd	Kamal 1951b
Trichogrammatidae		
Trichogramma evanescens Westwood	*Erias insulana* L.	Willcocks & Bahgat 1937
Trichogramma evanescens Westwood	*Pectinophora gossypiella* Saund.	Kamal 1936
Trichogramma evanescens Westwood	*Spodoptera littoralis* Boisd.	Willcocks & Bahgat 1937
Tachinidae		
Exorista larvarum L.	*Spodoptera littoralis* Boisd	Willcocks & Bahgat 1937
Strobliomyia aegyptia Will	*Erias insulana* Boised	Willcocks & Bahgat 1937
Strobliomyia aegyptia Will	*Spodoptera littoralis* Boisd	Bishara 1934
Strobliomyia pagpalis Will	*Spodoptera littoralis* Boisd	Kamal 1951b

Cited from Temerak [4]

Table 2: List of introduced parasitoids to combat CLW and CBW in Egypt from 1909-1941

Parasitoid	Country	Year	Host insects	Degree of success
Braconidae				
Bracon kirkpatricki Wilk	Kenua	1928	*Pectinophora gossypiella Saund*	S
	Sudan	1931		S
B. lefroyi Dudgeon and gough	India	1909	*Erias insulana Boisd*	D
B. lefroyi Dudgeon and gough	India	1912	*Erias insulana Boisd*	D
B. lefroyi Dudgeon and gough	India	1934	*Erias insulana Boisd*	D
B. lefroyi Dudgeon and gough	India	1935	*Erias insulana Boisd*	S
B. lefroyi Dudgeon and gough	India	1934	*Pectinophora gossypiella Saund*	D
B. lefroyi Dudgeon and gough	India	1935	*Pectinophora gossypiella Saund*	S
B. mellitor Say	hawaii	1935	*Pectinophora gossypiella Saund*	D
B. mellitor Say	australia	1939-41	*Spodoptera littoralis boisd.*	D
Chelonus blackburni Cam.	USA	1937	*Pectinophora gossypiella Saund*	P
Scelionidae				
Telenomus nawaii Ashm.	Figi islands	1937	*Spodoptera littoralis boisd.*	P
T. spodoptera Dodd	Java	1939/41	*Spodoptera littoralis boisd.*	D
Tachinidae				
Actia nigritula Mail	Australia	1939	*Spodoptera littoralis boisd.*	D
		1941	*Spodoptera littoralis boisd.*	D
Trichogrammatidae				
Tricogramma minutum riley	england	1931	*Spodoptera littoralis boisd.*	P

S = Established, P = Partial establishment, D = Not liberated, died before liberation, or not established, CLW = Cotton leafworm CBW= Cotton bollworms
Cited from Temerak [4]

to 1.5 L/acre in 1956. An amount of 54, 000 metric tons of the active chemical was used during 1956-1961 [2, 5] indicated that the total numbers of collected egg-masses of CLW from an area of 2 million acres was close to 10,000 million. The total treated area for CLW was 2,764,007 acres according to Ministry of Agriculture (MOA) records.

Hand picking of eggmasses is not enough to control CLW due to its overlapping generations plus the inadequate beneficial insects.In addition, when cotton grows too big, this process becomes too difficult. Consequently, the Ministry of Agriculture (MOA) has had to spray the cotton crops every year despite hand picking.

In 1991/2: after application of Sevin, all phytophagous mites were significantly increased due to the mortality of predaceous mites (Phytosidae mites) and insects. In 1967/68; high mammalian toxicity was recorded for cotton labors after application of Cytrolane. In 1971/72; mammalian toxicity was recorded for cotton labors after airplane application of Cytrolane.

In 1971, 3000 of baflo chronic toxicity were appeared in Koutour, El-Gharbia Governorate due to the airplane application of Leptophos (Phosvil). In 1975/76; MOA imported Gusathion methyl which arrived Egypt as gusathion ethyl. The last showed severe toxicity to cotton labors. Also. the same was happened with Gelecron to kill CLW eggmasses.

Almost, wild birds, honey bees and beneficial arthropods were not seen in the agro-ecosystem.

Rotation program of conventional insecticides + IGRs (1979-1993): The first nationwide CLW/CBW resistance management program was adopted by Egypt in 1979 in cooperation with Dr. Sawicki to prevent or delay resistance to pyrethroids as well as other insecticides. Dr. Sawicki began communications with managers of the Ministry of Agriculture and visited Egypt in 1975 and 1983. A program based on alternate different class of chemicals (organophosphates (OP) + insect growth regulators (IGR), pyrethroids (PY) and carbamates (CAR) was initiated [6].

Dr. Sawicki's approach to reducing CLW resistance required that parathyroid's be applied only once per season and solely on cotton. During this period, the area treated for CLW larvae was minimal which achieved a good delay in resistance to most of the parathyroid's, in addition to a good crop yield despite of no considerable numbers of beneficial insects.

The CLW almost disappeared from a third of the total cotton area in the 5 governorates of south Egypt during 1989-1997 with very low infestation in the delta-north. This may be a result of two different modes of action of organophosphates and insect growth regulators in the first generation of CLW, accompanied by sterilization and reduction of both fertility & fecundity of CLW moths due to the insect growth regulators [7]. The Egyptian government still up to now applying Dr. Sawicki's approach.

In 1991, ground motors replaced airplanes for spraying cotton. This last change was due to the start of the Improved Ground Application Techniques Project (IGATP). Almost, wild birds, honey bees and beneficial arthropods were not seen in the agro ecosystem.

Rotation program with the addition of some alternatives (1993-95): In 1993, as step to encourage bio-control agents, MOA made exception for registration of Bio-pesticides, in which these products have to pass only two years testing instead of 3 years for conventional insecticides. Also, to pass the test of a Bio-product, the efficacy accepted level by MOA is only 50% whereas in OPs and PYs is 70 and 80%, respectively. In 1995, to pass the test for pheromone is only one year trials.

Beginning in 1993, several alternatives were used for CLW control: mineral oil, sulphur, B.t. products, irrigation with kerosene and CLW/PBW-pheromones. Conventional insecticides were used below the recommended doses, especially in 1994. The rotation program was not stressed as strongly during this period. Disruption pheromones for pink bollworm (PBW) were used in small areas initially, reaching 50% of the total cotton area by 1995. In addition, conventional insecticides were applied in cases where infestations reached 3% in the bolls and the CLW began to slowly rebuild its fecundity and fertility. This increase was due to the low use of conventional insecticides, including insect growth regulators for CLW or mixed population of CLW/CBW [1].

The addition of alternatives to the resistance management program resulted in a tremendous decrease in the cost of importation of conventional insecticides. In addition, cotton yields were still maintained at an acceptable level [1].

Alternatives period, including extensive use of PBW-pheromones (1995-98): By 1995, the rotation program had been discontinued. All cotton areas sprayed by disruption pheromone of pink bollworm. The resistance management program began to depend mostly on alternatives with the spray of conventional insecticides used only when infestation reached economic injury levels. Conventional insecticides were used below the recommended doses. In 1996, several conventional products were banned due to possible carcinogenesis (class B or C group carcinogens). Insect growth regulators were used alone without mixing with an organophosphate to conserve natural enemies. In 1997, all conventional insecticides for the control of CLW were cancelled in vegetables, orchards, date palm and the resistance control program depended primarily on alternatives. Disruption pheromone for PBW was used extensively in all cotton areas [1].

CLW continued to rebuild its fecundity and fertility slowly as a result of the low pressure of conventional insecticides in cotton and outside cotton on vegetables and grapes. CLW returned to south Egypt after a disappearance of at least 8 years. Very high infestation rates in the delta-north area of Egypt also began to be recorded as early as 1998. Also, phermones were used below recommended rates in which normal pheromone was dominant. By this time, spiny bollworm established in new areas and occupied almost all governorates due to the commercial pheromone application that had targeted pink bollworm. This pheromone application saved the clean cotton bolls for the spiny bollworm. Even CLW started to be CBW due the saved bolls by controlling Pink Bollworm. Cotton yield was significantly lower as 35% loss in 1998. All Predaceous beneficial arthropods were seen on cotton leaves[1].

Rotation program (1999-now): Almost all slow-acting alternatives were cancelled, specifically from cotton uses and a return to the normal rotation program (with the exception of Agrin). Agrin (*Bacillus thuringiensis* subsp *aegypti*) had been used to control CLW during the egg-mass hatching period. Insect growth regulators alone were kept for the first spray in the control of newly hatched CLW larvae. Organophosphates as well as conventional insecticides were prohibited from the spray on eggmasses and used later on CBW during boll formation to give a chance for propagation of natural enemies [1]. Also, Spintor (spinosad 24SC) was recommended recently against neonate CLW larvae and to be used in 2006.

Private Co. started to sell cards of the egg parasitoid, *Trichogramma* in cotton and outside cotton. MOA established two laboratories to rear the parasitoid *Trichogramma evanescens*, one in the delta and second in middle Egypt. Also, special laboratory to produce different phermones for differed insect pests. MOA, also established bio-control laboratories to produce bio-products for farmers at cheap prices e.g.,

- Bioranza (0.29%), it is a natural metabolite of the Deuteromycete, *Metarhizium anisopliae* Sorok and locally produced by Insect Pathogen Unit, Plant Protection Research Institute, MOA, Egypt).

- A natural product (0.25%) (without name yet), at the rate of 200 mL/100 L. It is a natural metabolite of the Deuteromycete, *Paecilomyces farcinus.* It is locally produced by Insect Pathogen Unit, Plant Protection Institute, MOA, Egypt).

- Agerin WP (*Bacillus thuringiensis* subsp *aegypti* (32000 Inter. Units). It is locally produced by MOA. It is recommended and on sale in Egypt

- Protecto (WP) 10%, a commercial product formulation contains $32x10^6$ IU/mg of *Bacillus thuringiensis* subsp *Kurstaki*

- Virotecto (WP) 4% a commercial product of granulosis virus (GV), containing $5x10^9$ viral particle (PIB)/mg

Also, laboratories for mass production of Chrysopa vulgaris larvae started in Cairo university. Furthermore, small laboratories start to sell phytosidae predaceous mites for organic farming. Organic farming start to increase slowly for purpose of exportation reaching 22,000 ha.

Mass release of *Trichogramma evanescens* in more than 10,000 acres of cotton to control CBW eggs in areas without conventional insecticides is applied every year. Local predaceous arthropods were seen in considerable numbers on cotton leaves e.g., Coccinelids, Staphilinids, Anthocorids, Chrysopids, Formicids and true spiders during the eggmasses deposition.

In 2005, the bio-insecticide spionsad was used for the first time 110,000 acres to replace carbamate (sevin) at the last spray based on Temerak [8] research recommendation.

Cotton yields improved dramatically and CLW and CBW were better controlled. Natural enemies started to be seen on cotton leaves in considerable numbers.

Outcome of previous programs: Egypt has suffered from cotton leafworm resistance for over 50 years.

Before rotation program, considerable tons of active ingredient of conventional insecticides were used for CLW control, especially in the non-rotation program period (e.g., DDT as 13,500/1952-1971; Carbaryl as 21,000/1961-1987; Lindane as 11,300/1952-1987 and Endrin 10,500/1961-1981 [1]. Egypt has suffered from the environmental toxicity to animals and human. Egypt has also suffered from the high considerable amount of money spent.

During the rotation period and after, amounts of conventional insecticides has been decreased [1]. Growth rate of using bio-control agents started in 1993 and reached high level after 1995 and up to now.

Ministry of Agriculture (MOA) future trend: The general trend of MOA experts is to alternate different class of safe chemicals with different mode of action to minimize number of spray and reserve the beneficial insects. Expect that all conventional old chemistry will be replaced as soon as they found new effective insecticides with new mode of actions plus safety on natural enemies. The Ministry of Agriculture will likely continue to encourage the use of alternatives and natural products, especially if they have rapid kill rates. Different insect growth regulator groups will continue to be used during the egg-mass hatching period to conserve the natural enemies and control CLW at the same time.

MOA has very limited resources of old effective conventional insecticides. MOA is looking forward to have safe new molecules with different mode of action. MOA is encouraging bio-control agents eg *Trichogramma* to be released in the area treated by bio-insecticides only eg spinosad. Application of spinosad in conjunction with the mass release of *Trichogramma* are an excellent example of a functional cotton integrated pest management (IPM) program.

Spinosad, the natural bio-insecticide offered a new mode of action and relatively safe on natural enemies. Temerak [9] indicated that this product is not easily affected by existing resistance mechanisms to conventional insecticides. He also added that field populations of CLW with high levels of resistance to conventional insecticides are more susceptible to this product. He expects that spinosad may have a great future in the integrated pest management (IPM) of CLW in Egypt.

Spinosad could play a significant role to combat conventionally resistant insects as a result of its novel mode of action [11]. Some individuals have even indicated that the low toxicity of Spionosad to natural enemies should allow it to be easily incorporated into most integrated pest management programs [11, 12]. Based on United States Environmental Protection Agency (USEPA) reports, this product won the Green Chemical Challenge Award from the White House in 1999.

Spraying Spinosad, can save considerable numbers of natural enemies according to Peterson *et al.* [12], who stated that similar beneficial arthropod populations were measured in the untreated and spinosad treated cotton plots in Florida USA. He added that after application of spinosad will not be a significant flare up of secondary pests such as whiteflies.

Future B.t. cotton and its effect on host/pray availability for natural enemies: Egypt started the Plant Incorporated Protection program eg B.t. cotton in cooperation with Monsanto Co. using 4 cotton varieties of *Gossypium barbadense*. Expect that these varieties may be launched in 2008 or after to combat CLW/CBW without spraying cotton insecticides and to be planted in the same areas of the non B.t. cotton. The last can decrease the cost of insecticides plus the environmental safety. However, establishment of B.t. cotton mostly will affect natural enemies due to the lack of host/pray availability in B.t. cotton areas [13].

CONCLUSION

The above is a good example how the conventional insecticides destroy the natural enemies, disturb the equilibrium position plus the resistance problems and the tremendous cost over years.

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