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THE AFRICAN ARMYWORM *SPODOPTERA EXEMPTA* AND PRELIMINARY RESULTS ON ITS CONTROL WITH ISOLATES *OF BACILLUS THURINGIENSIS*

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INTRODUCTION

The African army worm causes great losses to graminaceous crops such as com, sorghum, rice, millet, rye, oat, wheat, barley and forage grasses. The pest is mainly distributed in the eastern portion of Africa (Kenya, Tanzania, Uganda, Ethiopia, Sudan and down to South Africa), but it has also been reported in central and western parts of the continent. This pest is also present in south east Asia, as well as in Indonesia, New Zealand and Australia.

Biology

Unlike *S. littoralis*, which populates fields in relatively close locations and whose migration is relatively moderate, *S. exempta* has a distinct migratory pattern of distribution. The insect breeds in the center of East Africa around Mozambique — Zimbabwe and causes a progression of outbreaks northward from Tanzania to Ethoipia, and southward to South Africa. Generally, the poulation dynamics of *S. exempta* is described in three main phases. The first is characterized by a very low population density of larvae, which may be analogous to the "solitary" phase of the desert locust. The second includes a sudden appearance (and simultaneously sudden disappearance) of the analogous "gregarious" phase larvae. It is difficult to predict the locations of such outbreaks before great losses occur. In cases where effective control measures are not taken, a third migrant phase will infest more areas and cause additional damage.

Army worms in low densities survive and breed during the dry season in areas where grasses remain green, such as in the highland areas and especially, the coastal areas of Kenya, Tanzania, and possibly, Somalia where it is hot and there are periodic showers during the dry season. These low density populations form the source for the first outbreaks (primary outbreaks) when the rains arrive at the end of the dry season. The size of army worm populations may increase rapidly, particularly because of a high rate of survival of young larvae on new flashes of grasses. Female moths may lay 1000 eggs each. Populations may increase 1000 fold in 2 months (2 generations) even when 90% mortality occurs. Thus, there is great potential for rapid population increases in grasslands from one solitary larva in $1000m^2$ to 10 gregarious larvae in lm^2 after 2 generations.

The conditions that bring heavy outbreaks of the army worm are being intensively studied by the research group headed by Dr. Rose in DLCO EA Nairobi (Haggis, 1987; Pedgley et al., 1987; Rose et al., 1988). Within Eastern Africa, army worm populations are at their lowest numbers in October. Scant precipitation during the short wet season from October to December in Eastern Africa favor a subsequent population increase. The first outbreaks of the season often occur in Tanzania or Kenya during November, December, and January, frequently downwind from the coast by the hills and the high grounds where early seasonal rainfall occurs and moths are concentrated. Moths which emerge in large numbers from these outbreaks are carried downwind and contribute to the spread of

infestations causing further outbreaks (secondary outbreaks) in subsequent generations at roughly monthly intervals.

The moths fly downwind during the hours of darkness. This migration may last for several nights before they lay their eggs. Within an armyworm outbreak area, moths emerge from their pupae in large numbers over a period of up to 12 nights. The newly emerged moths fill the trees in an outbreak area with thousands of moths/tree. Some migrate on the same night, but most hide in shaded and moist places throughout the day. They will migrate on the next night. Because migration occurs at different times over a 12 night period, the moths are dispersed in time, thus not forming swarms as can be seen with migrating locusts.

During migration, the moths may reach heights of several hundred meters, where they meet strong winds and because they are weak fliers, the moths are carried off in a downwind direction. The distance that the moths travel depends on the speed of the wind, the length of time the moths fly in the wind on any night, the number of nights individual moths fly before stopping to mate and lay eggs, and the weather, especially the rainfall and wind conditions which may not allow the moths to travel further.

Because the moths disperse in space and time downwind, further outbreaks depend on concentration and the number of eggs layed in one place. Concentration is achieved mainly when moths are brought together in the air by wind convergences or eddies often associated with rain storms. Although a proportion of the moths migrating out from an outbreak emergence area may be reconcentrated, large numbers of moths will still be dispersed over a wide area causing low density populations of larvae which are not seen by the farmers because of their solitary form coloration. The moths resulting from these low densities may contribute to future outbreaks if they become concentrated.

Since armyworm moths are carried by the winds, the direction of spread of the outbreaks is influenced by the seasonal prevailing winds, since these are dominant for most nights that the moths are flying. The areas in which further outbreaks occur are usually in locations downwind from the emergence areas when rain is falling at the time the moths arrive. Since the long rains in East Africa gradually move northwards through Tanzania, Kenya, Ethiopia, Somalia, and even reaching the Yemen, the monthly generations of armyworm outbreaks tend to show a gradual northward movement. Thus, outbreaks may start in November in Kenya or Somalia, or more commonly, December in Tanzania and begin in the Yemen in June or July the following year, seven or eight generations later. Outbreaks are regularly reported in the different DLCO countries as follows: Tanzania — Dec. to May; Kenya — Nov. to June; Uganda — Feb. to May; Somalia — Nov. to Dec.; Ethiopia — April to Sept.; Sudan — April to July.

By understanding the seasonal migrations of the armyworm and the underlying causes and factors which lead up to outbreaks, it is possible to issue long- and short-term forecasts where armyworm outbreaks are likely to occur.

Natural enemies

All stages of the armyworm are subject to attack by many natural enemies ranging in size from microscopic viruses to birds: (1) Nuclear polyhedrosis virus (NPV) can cause epizootics when heavy larval populations exist in the fields with up to 90% of the larval population succumbing. However, the larvae are normally killed after considerable crop damage has already occurred; (2) Cytoplasmic virus (CPV) kills the prepupal or pupal stages usually under stress conditions such as poor food, low temperature and little sunlight; (3) The fungal pathogen *Nomuraea rileyi* attacks the larval stages but for effective control, high humidity and temperature are required. They seldom control an outbreak of the pest; (4) A great number of insects parsitize the armyworm. About 28 different species of flies (Diptera) attack armyworm larvae, and about 25 types of wasps (Hymenoptera) have been recorded to attack the different stages as parasitoids and parasites (endo- and ectoparasites). Ants may play an important role in the destruction of both the eggs and the larvae. Certain beetles

also consume the armyworm larvae; and (5) Among the vertebrates, the birds are the most obvious predators of the armyworm (White Storks, Abdim's Storks or Marabu Storks). Sometimes outbreaks of armyworms may be recognized by monitoring bird concentrations. Such concentrations may play an important role in the regulation or even control small outbreaks of armyworms. Some mammals such as baboons, shrews and other small animals also feed on the armyworm.

Natural enemies especially viruses may sometimes have a significant effect in controlling small, medium or even large armyworm outbreaks. However, as the moths are migratory and outbreaks are usually tens or even hundreds of kilometers apart biocontrol using natural enemies is difficult to achieve. When severe outbreaks occur and no effective control means are taken, great yield losses occur. The armyworm is one of the contributing factors to hunger in East African countries.

Control

The strategy of control is mainly directed at populations where primary outbreaks occur. By effectively controlling primary outbreaks, it may be possible to suppress the large upsurges of armyworm which ravage eastern Africa, thus considerably reducing both crop and pasture losses. The majority of primary outbreaks occur in central Tanzania (usually in December), although the eastern side of the Kenyan highlands (Meru, Embu, Kitui) and sometimes on the coast of Kenya, can be of major importance (usually in November). By recognizing the areas where primary outbreaks are most likely to occur, it is possible to monitor moth arrivals into these areas using pheromone traps to give an early warning on outbreaks and improve the efficiency of control measures.

The detrimental effects of chemical pesticides on the environment and health, especially natural enemies, are well documented. The purpose of the present work is to (1) search for new isolates which possess effective insecticidal activities against the larvae of the African armyworm, and (2) direct the main efforts towards control of primary outbreaks to suppress subsequent spread and outbreaks in order to prevent yield losses in cereal crops and pastures in east African countries.

MATERIALS AND METHODS

Larvae of the genus *Spodoptera* are generally less susceptible to the delta-endotoxin of *B. thuringiensis* than larvae of other lepidopteran pests (Sneh et al., 1981). The isolates of *Bacillus thuringiensis* used for screening were obtained from soil samples collected at various locations in Kenya and Israel. In addition, isolates of various H-serotypes obtained from culture collections were also used for screening. New isolates were obtained by using the selective procedure and medium described by Travers et al. (1987) and Martin et al. (1985). Each isolate was grown on the medium described by Dubois (1968) and Sneh et al. (1981). The larvae were reared on the artificial diet described by Bot (1967). Bioassays on leaves were carried out as previously described (Sneh et al., 1981), and on the artificial diet of Bot (1967) as described by Yawetz et al. (1983).

Field experiments were carried out in Lambwe valley, Kenya. Nine pheromone traps were placed in various farms in the valley and counts of moths trapped were recorded periodically during the month of March. Two days after peak moth trapping, a search of ovipositions sites identified the fields in which treatments would be performed on neonate larvae. Powdered preparations of the most efficient new isolates were prepared by Becker Microbial Products of Israel. Random plots of 3×3 m in 4 replicates in cinadon grass and maize fields were sprayed with prepared Bt suspensions, while non-treated plots were used as controls. The number of surviving larvae were recorded 2- and 4-days after spray application.

RESULTS AND DISCUSSION

Results from a number of bioassay experiments carried out by first screening of the isolates for their

insecticidal activities against second instar larvae of the African armyworm (*Spodoptera exempta*) are summarized in Table 1. A number of isolates were re-tested (3–4 times) in this series. The results indicate that a number of the isolates killed 100% of second instar larvae at a concentration of ca. 5 × 10^6 cfu/ml. The isolates which incited 100% mortality at this dilution were: Berliner 1715 (*B.t.* var. *thuringiensis*, serotype 1) HD–151 (subsp. *galleriae*, serotype 5a 5b). Isolates 7f. HD–593 (Ao7), HD–228 (IHA), HD–133 (*B.t.* subsp. *aizawai* 7). *B.t.* 3, *B.t.* 7, *B.t.* 15, *B.t.* 17, *B.t.* 18, *B.t.* 30, *B.t.* 40, *B.t.* 53, *B.t.* 54, *B.t.* 55, 6105, K26–21, K26–8, MF4B–2, MR1–37 K30–3 have not been serotypically identified.

Table 2 summarizing comparison of the insecticidal activities (LC_{50} values) of several *B.t.* isolates tested against the Egyptian cotton leafworm (carried out at Tel Aviv University, Israel) and the African armyworm (tested at ICIPE, Mbita point, Kenya). Generally, the LC_{50} values for the *B.t.*

TABLE 1

Insecticidal activity of *Bacillus thuringiensis* isolates on second instar larvae of the African armyworm (*Spodoptera exempta*). Culture broths containing spores and crystals were diluted 45 fold in the diet (about 5 × 10^6 cfu/ml)

		Isolate number		Mortality (%)		
Serotype	100	81–98	61–80	41–60	26–40	5–25
ND	Bt 3	Bt 55	Bt 4	M 2	Bt 28	Bt 1
ND	Bt 7	Bt 56	Bt 16	M 14	–	Bt 6
ND	Bt 15	B 6105	Bt 20	M 16	–	Bt 8
ND	Bt 17	–	Bt 25	S 52–1	–	Bt 27
ND	Bt 18	–	Bt 29	–	–	Bt 35
ND	Bt 40	–	Bt 49	–	–	Bt 39
ND	Bt 53	–	G1 13–1	–	–	Bt 35
ND	Bt 54	–	Ko 4	–	–	Bt 45
ND	Bt 57	–	Koe	–	–	Bt 52
ND	K 30=3	–	–	–	–	G1 13–2
ND	–	–	–	–	–	M 9
ND	–	–	–	–	–	M 13
ND	–	–	–	–	–	S 31–3
ND	–	–	–	–	–	S 42–2
ND	–	–	–	–	–	S 32–1
ND	–	–	–	–	–	S 39–1
ND	–	–	–	–	–	S 39–2
1	HD 120	–	–	HD 2	–	HD 23
1	–	HD 695	–	–	–	–
3a 3b	HD 4	HD 263	HD 73	–	–	–
3a 3b	–	NRD–12	–	–	–	–
5a 5b	HD 151	HD 155	HD 220	–	–	–
7	7f	Ao 18	–	–	–	HA 3
7	Ao7	–	–	–	–	–
7	HD 133	–	–	–	–	–
7	IHA	–	–	–	–	–
10	–	HD 498	–	–	–	–
10	–	HD 601	–	–	–	–
17	–	–	–	–	–	B 17
18	–	–	–	–	–	B 18

ND = Serotype not yet determined.

TABLE 2
Comparative insecticidal activities of *Bacillus thuringiensis* isolates on second instar larvae of the African armyworm

Strain No.	Serotype	Insecticidal activity (LC_{50} cfu/ml)	
		S. exempta	*S. littoralis*
7f	7	2.5×10^4	1.0×10^7
MF4B–2	ND	4.2×10^4	1.5×10^6
K26–8	ND	4.2×10^4	1.7×10^6
MR1–37	ND	7.8×10^4	2.6×10^6
B.t.–57	ND	9.1×10^4	8.2×10^6
K26–21	ND	1.0×10^5	1.3×10^6
B.t.–24	6	2.1×10^5	6.3×10^6
HD–133	7	4.3×10^5	1.2×10^7
6105	ND	7.7×10^5	9.2×10^6
HD–73	3a 3b	1.0×10^6	–
HD–593 (Ao7)	7	1.3×10^6	4.5×10^6
NRD12	3a 3b	1.2×10^7	2.3×10^7
B.t.–25	ND	4.8×10^7	9.6×10^7

ND = Serotype not yet determined.

isolates were considerably lower against *S. exempta* than isolates tested against *S. littoralis*. The insecticidal activity of some isolates was 30–40 fold higher for the armyworm than the Egyptian cotton leafworm. The most active isolates against the armyworm (in a descending order) were: MF4B–2, K26–8, MR1–37, *B.t.*–57, K26–21 and $B.t._{24}$, and against *S. littoralis*, K26–21 (was five fold more active than $B.t._{24}$), MF4B–2, K26–8, MR1–37 and $B.t._{24}$.

Similar experiments were carried out with 4th instar larvae. However, due to high mortality in the controls in many experiments, these results were not of much value. The high mortality was probably caused by viral infections. Results of an experiment in which all of the control larvae survived are summarized in Table 3. These results indicate that 100% mortality to the 4th instar larvae (which are more tolerant than second instar larvae to the delta-endotoxin of *Bacillus thuringiensis*) were the following: 7f, *B.t.* 15, *B.t.* 54, M 16, and HD–695.

Powdered preparations of three isolates were manufactured by Becker Microbial Products Israel (BMPI). The insecticidal activities of the three isolates were tested on 4th–5th instar armyworm larvae on corn leaves. The results which are summarized in Table 4 indicate that notable activity was obtained with the isolates *B.t.* 24 (*entomocidus*) and IH–A (*aizawai*), but not with HD–263 (*Kurstaki*). The concentrations of *B.t.* 24 and IH–A, usually applied as a powder in the field against *Spodoptera littoralis* (1%), resulted in 100% mortality. Therefore, HD–263 (which is highly effective against other lepidopteran larvae), was not used in field experiments against the armyworm.

One of the preliminary field experiments was carried out on 15 × 15 m plots of a cinadon grass (which reduced the effect of migration of large larvae from the untreated control plots) with larval populations, consisting of 3rd–4th instars. Generally, there was a steady decrease in the survival of larval populations in both treated and untreated plots, while the decrease in the *B.t.* treated plots was significantly greater (Table 5). Seventy percent control of the armyworm was achieved after 48 h. In the treated plots, many dead and moribund larvae, and little movement of the surviving ones were observed on the ground. In the untreated control plots, large and very active larvae were observed on the ground. Only late instar (5th–6th) larvae were observed alive in the area, presumably because

TABLE 3
Insecticidal activity of several isolates of *Bacillus thuringiensis* on 4th–5th instar larvae of *Spodoptera exempta*[a]

Isolate No.	Serotype[b]	Mortality (%)
B.t. 15	ND	100
B.t. 54	ND	100
M16	ND	100
HD–695	1	100
7f	7	100
B.t. 35	ND	80
HD-498	10	80
Control	–	0

[a]Pellets of the washed isolates were diluted to give a 1:45 dilution of the original culture medium (ca. 5×10^6 cfu/ml diet) 40 larvae/isolate
[b]ND = not determined

TABLE 4
Insecticidal activity of powdered preparations of *Bacillus thuringiensis* against 4th–5th instar larvae of *S. exempta* on corn leaves

Isolate	Subspecies	LC_{50} (μg/ml)[a]
B.t. 24	*entomocidus*	16.8
IH–A	*aizawai*	27.3
HD 263	*kurstaki*	990.0

[a]Calculated according to 50,000 IU/mg.

TABLE 5
Effect of application of *Bacillus thuringiensis* var *aizawai* (IH–A) powder preparation (2% w/v) on cinadon grass in the field against larval populations of *Spodoptera exempta*

Time after treatment (days)	Non-treated control		*B.t. aizawai*		
	Number of larvae[a]	% of initial count	Number of larvae[a]	% of initial count	% of control[b]
0	200	100.0	167	100.0	83.5
1	177	88.5	59	35.3	39.9
2	130	65.0	32	19.2	29.5
3	81	40.5	34	20.3	50.1
4	43	21.5	16	9.6	44.7

[a]Numbers of surviving larvae were counted in 25 squares of 20 × 20 cm each in 15 × 15 m plots.
[b]Percentage was calculated as % of initial count of treated vs. non-treated control.

a greater dose or longer feeding time are required to kill large larvae. The grass also appeared to be much more healthy than in the control plot, with much new leaf growth evident.

After the third day of *B.t.* application, a sharper decline in larval count was observed in the control as compared to the treated plots. This decline may be the result of partial migration of larvae from the untreated to the treated plots, and the entry of the mature larvae into the soil to undergo pupation. Larvae that ingested sub-lethal concentrations of the delta-endotoxin, developed slower and pupated only after a delayed period of time. The non-treated control plots were completely destroyed, while the treated plots remained green and growth continued.

Usually, in an armyworm outbreak area, the larvae are noticed in the field when they reach 4th–5th instar. At this late stage, they have already caused a great deal of damage to the crops and they are more tolerant to insecticides. We have recently been able to locate the egg depositions in the fields using a network of pheromone traps placed in several farms in Makende Valley. When a suspension of a powdered preparation of a new isolate, MF4B–2 was applied to an infested cinadon grass field for control of neonate larvae, 95% armyworm control (compared to a non-treated control) was obtained with only 0.2% suspension, 1/10th of the usual concentration used. Another new isolate, K26–21 controlled 94% of the 2nd–3rd instar larvae in a maize field sprayed with only 0.4% suspension (3 × 3m plots in 4 replicates for each treated and non-treated control.

These results paved the way for plans to apply powdered preparations made from the most effective isolates on larger scale experiments (1–3 acres).

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