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Use of *Bacillus thuringiensis* in Pest Management of the Tomato Ecosystem in Trinidad

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Major pests of tomatoes in Trinidad include: the pin worm, *Keiferia lycopersicella:* the army worm, *Spodoptera eridania*; the fruit worm, *Heliothis virescens*; leaf miners, *Liromyza spp.*; fruit piercing bugs, *Nezera viridula*, and *Phthia picta*; the mole cricket, *Scapteriscus vicinus*. Commercial producers have resorted to excessive application of chemical pesticides with consequent increase in leaf miner infestations, serious outbreaks of mites and developing resistances in mole cricket populations. Too frequent use of pesticides is also a deterrent to implimentation of classical biological control. Utilization of the relatively specific bacterial insecticide, *Bacillus thuringiensis*, seems encouraging as a pest control strategy for the tomato ecosystem.

Despite the fact that tomato is currently the most widely cultivated vegetable crop in Trinidad, large quantities of the processed fruit are still being imported into the country. The demand for both fresh and processed fruit is quite encouraging, but the farming community is faced with the problems of irrigation, labour, storage, transport and marketing as well as pest and disease outbreaks. All of these have been deterrents to the establishment of a viable tomato industry. The market is geared for production of fresh table varieties so that an attractive looking fruit with high consumer appeal is always desirable. Thus, fruit which has been blemished by pest attack is unmarketable. This paper presents an overview of the problem of pest infestation during 1981 to 1984 and suggests possible strategies for integrated management utilizing *Bacillus thuringiensis* Berliner.

Pest Composition and Degree of Damage in the Tomato Ecosystem

In Trinidad, the tomato plant is associated with a number of insect and mite pests of which the lepidopterans, *Spodoptera eridania, Heliothis virescens, Keiferia lycopersicella*, and the fruit-piercing bugs, *Nezara viridula* and *Phthia picta* are the most serious. Other associated species include *Spodoptera sunia* and *furgiperda, Agrotis repleta, Manduca quinquemaculata, Trichoplusia ni, Arvelius albopunctatus, Scapteriscus vicinus, Liriomyza sativae*, various Chrysomelid beetles, membracids and mites. This is quite a range of pest species. Nonetheless, data collected at Piarco in 1982 suggests that approximately 6% of fruits may be lost through direct feeding by the entire pest complex, most species being responsible for less than 1% fruit damage. In 1981, much higher losses were observed in the Piarco area, infestation being caused by both the army worm *Spodoptera eridania* and the fruit worm *Heliothis virescens*, in a situation in which the pin worm *Keiferia lycopersicella* was almost nonexistent. Such high infestation levels of *Heliothis* had not otherwise been obeserved in either commercial farms or experimental plots during the period 1980 to 1984. Heavy pinworm infestations on commercial farms had been reported during the mid-1970's, but outbreaks seem sporadic and documentation of data which confirms such high infestation levels is wanting. Data collected during 1982 to 1984 have demonstrated low pin worm fruit infestation levels.

Preliminary defoliation studies conducted under greenhouse conditions at Centreno (1983) suggest that yields may not be significantly affected by defoliation if all plant requirements are optimally supplied. Up to 50% defoliation produced no significant yield reductions. Similar observations have been made in the U.K. (Stacey, 1983). Perhaps this is due to the fact that the tomato plant produces a tremendous amount of foliage so that the uninfested leaves may be capable of manufacturing sufficient food for fruit production, or as Stacey suggests, there may even be some degree of over-compensation. The negative effects on yield which occur under conditions of disease are far more drastic, perhaps because in addition to reducing chlorophyllic leaf tissue, diseases such as *Pseudomonas solanacearum* cause collapse of xylem bundles with consequent interruption of food supply to the inflorescenses.

In the southern desert valleys of California, *Heliothis* and *Spodoptera* damage occurred in 21% and 8.5% of fruits in untreated fields for 1979 and 1980 respectively (Steenwyk, 1983). This is considerably higher than any recorded observations for Trinidad. Of the more serious pests, *H. virescens* is the only true fruit feeder. In 1981, approximately 6,800 Calypso fruits /wk/ha were fruitworm infested. In addition, many stems and calyces were tunnelled, causing flower loss. At that level of infestation, both green and orange phases were present. During 1982-1984's sampling, such tunnelling was amost nonexistent and the green phase of the worm was absent. Calypso fruit infestation/wk/ha was 656, 4,350, and 1,875 for 1982, 1983 and 1984 dry season trials respectively. *B. thuringiensis* (16,000 IUP per mg) in the form of Dipel at 0.55 kg AI per ha, reduced infestation levels in the aggregate of five varieties of tomato fruits by 54.5% and 57.6% respectively in dry and wet season trials of 1982. At an application rate of 1.1kg AI/ha using a high volume sprayer, reductions were 76.2% and 78.8% respecrively for dry season trials of 1983 and 1984. Weekly applications of *B. thuringiensis* in the form of Dipel at 0.56 kg AI/ha, reduced injury from 7.1% to 1.6% in Southern California when a boom sprayer was used (Oatman et al., 1983).

Infestation levels seem slightly higher during the wet than dry season and peaked at about the same time as did fruit production. This may have been due to the fact that oviposition is related to flower production (Zalom et al., 1983). *Polistes canadensis* is an extremely efficient predator of this pest and low population levels observed at Corn/Soyal Piarco from 1982 to

1984, may have been as a result of construction of shelters at the project site in close proximity to experimental plots. The shelters housed numerous nests and the wasps were always present within experimental plots. During the 1981 trials, there were no such shelters and extremely high levels of fruitworm infestation occurred. This relationship is to be further investigated.

Spodoptera eridania is basically a defoliator but in high density situations attacks fruit, making them totally unmarketable. The black form predominates under such conditions and often appears lodged within cavities in the fruit. As much as 4.9% fruits were destroyed by this pest in untreated plots during the dry season of 1982. Plots treated with *B. thuringiensis* (16,000 IUP per mg) in the form of Dipel (0.55kg AI/ha), demonstrated 39% less fruit damage. The same treatment reduced infestation levels by 59% during the wet season of that year and when application rates had been increased to 1.1 kg AI/ha in the dry season trials of 1983 and 1984, fruit infestation levels were reduced by 68% and 94% respectively. Like *Heliothis, Spodoptera* is also preyed upon by *P. canadensis* and early instars are trapped in silk spun by a variety of spiders. Parasites of *Spodoptera* include a number of hymenopterans.

Keiferia lycopersicella has been observed to infest as many as 99% fruits in Southern California (Elmore, 1937). This seems somewhat astronomic when compared to fruit infestation levels in Trinidad, which in untreated plots were 0.62, 1.89 and 0.81% for the dry seasons of 1982, 1983 and 1984 respectively (Table 3). A wet season trial of 1982 revealed a fruit infestation level as low as 0.22%. The pin worm is a pest of great economic importance in many tomato growing regions of the world and as a result of farmers' complaints has been the focus of research in Trinidad for some time. Experiments conducted at St. Augustine (Karwatu, 1978), Chaguaramas (Katwatu, 1979), Macoya (Barrow et al., 1979), Piarco, Aranguez and Santa Cruz (Jones, 1981), all revealed low infestation levels of this pest, damage being confined mainly to the leaves. Though subsequent investigations revealed higher levels of infestation, observations were by no means alarming. Pest populations are definitely much higher under dry conditions, but even during the very dry spell of 1984 (4.35mm/wk) untreated plots revealed just 0.81% fruit damage (Table 3). Leaf damage is considerably higher in Trinidad than is fruit damage (Jones, 1983) but does not appear to affect yields significantly. Thus, pin worms may be of economic significance only when fruits are being penetrated. In 1984, fruit infestation was reduced by 79% when weekly sprays of *B. thuringiensis* were applied and the same treatment (1.1kg AI/ha) resulted in a 50% reduction of leaf damage. Natural enemies of the pin worm in Trinidad include *Euderus sp., Bracon sp., Microchelonus sp.* (Barrow et al., 1979), *Chelonus sp., Apanteles sp., Agathis sp.*, (Des Vignes, 1974), an unidentified fungus, *Polistes canadensis* (Jones, 1981) and *Odynerus sp.* (Jones, 1984). This rich natural enemy population tends to suggest that in Trinidad, the pin worm ought not to be a serious pest in a well managed tomato ecosystem.

During the dry season of 1982, the army worm *Agrotis repleta* almost totally hindered establishment of vegetable crops, including tomato, in the Moruga/Penal area where it seems to have developed resistance to all traditional soil pesticides. As many as 12 caterpillars/sq ft land surface were counted at peak infestation. This pest has not been observed to cause serious damage to tomatoes in other areas of Trinidad during the last five years despite its wide distribution. Population densities at Moruga/Penal have been considerably reduced in 1983 and 1984.

Manduca quinquemaculata is the most voraciously feeding caterpillar in the system, one larva demonstrating a feeding capacity of one large fruit or an entire two week-old plant in less than 24 h. Fortunately, population levels are quite low year round, though slightly higher in the wet season. *Manduca* is mainly a defoliator, but unlike other defoliating caterpillars and beetles, it habitually consumes stems. Should this pest acquire major status, its effects on yield would be far more drastic than those of any other pest. Prophylactic measures should include preservation of the wasp *Microptilis sp.* which parasitizes the larva. White egrets and brown doves are suspect predators of larval stages.

Fruit-piercing bugs *Nezara viridula* and *Phthia picta* cause fruits to ripen prematurely with corky blotches. Fruits are again of poor quality for the fresh market. In 1983 and 1984, 1.17% and 0.05% fruits in combined treated and untreated plots were damaged by such bugs against which Dipel application is ineffective. The eggs of *Nezara* are parasitized by a wasp *Trisolcus bassalis.*

A number of Chrysomelid beetles including *Epitrix spp., Ceratoma spp.* and *Diabrotica spp.* feed on tomato leaves from the seedling stage. They scrape away layers of leaf tissue creating tiny shot holes, but loss of chlorophyllic tissue is negligible and these insects present no serious threat to tomatoes in Trinidad.

Leaf miners, *Liriomyza sativae*, infest tomato leaves by burrowing through mesophyllic tissue. Population density fluctuates considerably, but is usually higher under dry conditions. Presence of the pest did not necessarily affect tomato yields in California (Johnson et al., 1980) and does not appear to do so in Trinidad either. In commercial areas, particularly in Aranguez, leaf miner populations have been rising since 1982. It has not been established whether this is due to pesticide induction as in the case of methomyl in California, but that probability cannot be ruled out (Johnson et al, 1980). Leaf miners have been observed to be parasitized in Trinidad by yet unidentified wasps.

The mole cricket *S. vicinus* is a seedling pest and has been observed to do serious damage in experimental plots at Piarco under conditions of poor weed control within the surrounding area (1982). Less than 1% seedling damage occurred when good weed control had been practised in 1983 and 1984. In commercial areas, crickets appear to be a serious seedling pest because of poor field sanitation and developing resistance to such insecticides as Malathion, Methamidophos, Aldrin, Chlordane, Cartap Dimethoate, Carbaryl, Decamethrin, and Carbofuran.

Spider and russet mites have become serious problems in some commercial and home gardens since 1983. They now persist throughout dry and wet seasons. Feeding on the under sides of leaves, young stems, flowers and fruits, they give rise to chlorosis, crimping, flower and fruit shed, wilting, russeting and other pathological symptoms with resultant low yields. In addition, fruits may be deformed and bronzed, and thus unattractive for the fresh market. Prior to 1983, mites were not reported to be a serious pest of tomatoes and occurrence seemed to be quite sporadic and limited to the dry season, the first showers of rain being sufficient to significantly reduce population levels. Documentation on russet mites as pests of tomatoes in Trinidad is unavailable. Outbreaks have occurred in controlled environment systems and in open fields since the advent of pyrethroid insecticides and the Speedling method of producing seedlings, but mites have not yet been observed in experimental plots.

Pest composition of the tomato ecosystem in Trinidad appears to be rather complex and observations suggest that pest outbreaks are induced through improper pest management practices. Difficulty in reducing mole cricket populations may be related to poor field sanitation and pesticide abuse, while pin worm outbreaks in commercial plots seem related to improper application of pesticides. In view of the number of potentially dangerous pests associated with the crop, it is imperative that the system be managed in a manner such that secondary pests are not induced to cause major damage. This necessitates that the natural enemy population be protected and facilitated in functioning optimally.

Management Strategies

Cultural Practices In controlled environment systems, mites seem to be the only pest of significance. They do damage that is as serious as that done by the entire pest complex in open fields. The hot, dry conditions which prevail in most controlled environ-

ment systems favour mite development. Experimental work on various cooling systems is being conducted by individual farmers for use as a pest control strategy and to increase flower set. Mites of the genus *Tetranychus* infest a wide range of ornamental plants. Many home gardeners cultivate tomatoes as a back yard crop in close proximity to such ornamentals, thus increasing the probability of mite outbreaks. Within recent times, there has been quite a trade in ornamentals, many of which are cultivated in glasshouses in which serious mite outbreaks have occurred. This is undoubtedly a sure means of dispersal. Because of their small size, mites are wind bourne and, thus, easily transported from home gardens to commercial farms. They also find their way into commercial farms via seedlings which have been produced by the Speedling method at greenhouses. When those seedlings are already heavily infested, the farmer initiates a pest problem upon transplanting. Much stricter control of plant distribution centers seems advisable and controlled environment systems which have been designed for tomato cultivation in cooler climates must be accordingly modified to suit local conditions. Most tomato farmers still farm in open fields where pest populations are variable, but not alarmingly high. Good field sanitation, crop rotation and provision of *Polistes* shelters are good control strategies.

Breeding and Selection Currently, the most widely cultivated tomato varieties are all imported into the island. The local plant does, however, appear to be most tolerant to disease and pest attack, and is generally early flowering and high yielding. A particular "Larcario" selection has produced very large fruits even under wet season conditions. Consumer preferences have been for large fruit with good keeping quality, but generally the local fruit is small, irregularly shaped and sometimes too ugly for fresh table use. Its high high seed content makes it unsuitable for processing. Some of the smaller fruits are very cherry-like, but the skins are soft and a great deal of cracking occurs. Thus, despite tolerance for disease and pests, the local tomato plant is not very popular. In experiments conducted at Piarco during the period 1981-1984, the more disease tolerant and earlier maturing varieties, local and Roma, consistently gave the highest yields in both wet and dry seasons. Both these varieties also produced the most leaves and harboured the most pests.

A sound selection and breeding program aimed at producing a tomato variety which has improved fruit quality while maintaining tolerance to pest and disease is highly recommended. Low tomato yields in tropical countries have been attributed to the fact that unadapted varieties are being cultivated (Villareal, 1979); yet seed breeding programs for tropical countries are existent only at the Asian Vegetable Research Centre and Southern Tomato Exchange Programme, U.S.A. Certainly, there is need for Trinidad and the wider Caribbean region to begin to address the problem of breeding insect and disease resistant tomato varieties which can be marketed.

Biological Control and Pesticide Application The tomato ecosystem contains a wide range of natural enemies including many hymenopterans and Aranidae, which perhaps accounts for consistently low level infestations. Serious pest outbreaks are sporadic and appear to be pesticide induced. The most recent group of insecticides, the synthetic pyrethroids, are most extensively applied to vegetable crops because of their relatively low mammalian toxicities, reduced persistence, and specificity to lepidopterans, one of the most significant groups of vegetable pests. Their abuse has, however, led to serious mite outbreaks, with resultant higher losses.

A management strategy utilizing *B. thuringiensis* is being proposed for the tomato ecosystem in Trinidad, since fruit infestation by lepidopterans in experimental plots was reduced by 68.7% for 1983, with a resultant yield increase of 32.66% (Tables 1 and 2). Further research is being directed at increasing the effectiveness of this pesticide through use of adjuvants, overhead irrigation and late evening applications. By reducing use of insecticides which are toxic to hymenopterans and Araneidae, it is hoped that the biological balance within the system would favour pest reduction with consequent increase in yield. Fruit-piercing bugs which caused 1.7% fruit damage in combined treated and untreated plots in 1983 are not affected by *B. thuringiensis* treatments and must be controlled by application of chemical insecticides. Since these bugs tend to infest close to the time of the first harvest, timely application may reduce the number of sprays required for control.

CONCLUSION

Lepidopterans are by far the most serious tomato pests in Trinidad, but infestation levels are not very high and insurance spraying often leads to more serious problems. Leaf damage does not appear to have very significant effects on yield, and caterpillar species which bring about fruit damage fluctuate considerably. In 1981, highest fruit damage was inflicted by *Heliothis* followed by *Spodoptera*, whereas in 1982, *Spodoptera* did greatest damage, followed by *Keiferia*. In 1983 and 1984, *Heliothis* and *Keiferia* fruit damage was almost equal, *Spodoptera* damage being quite low. *B. thuringiensis* has given some measure of control of all three lepidopterans and it is being further investigated for increased effectiveness. Mite outbreaks, which are fairly recent, have not yet occurred in experimental plots in which *B. thuringiensis* has been used continually. This pesticide is being considered as one of the major inputs into a pest management package for the tomato ecosystem.

TABLE 1. Percent fruit infested by Lepidopterous pests at Corn and Soya, Piarco, Trinidad, during the dry season of 1982-1984.

YEAR	UNTREATED	TREATED	% REDUCTION
1982	5.85	3.70	36.6
1983	4.95	1.50	69.7
1984	1.10	0.49	63.6

TABLE 2: Marketable yields (tonnes/ha) of tomatoes at Corn and Soya, Piarco, for 1983 and 1984.

YEAR	UNTREATED	TREATED
1983	27.61	39.92
1984	32.0	33.93

TABLE 3: Percent fruit infested by Lepidopterous pests at Corn and Soya, Piarco, 1983-1984.

	K. lycopersicella		S. eridania		H. virescens	
YEAR	Untreated	Treated	Untreated	Treated	Untreated	Treated
1983	1.89	0.69	1.15	0.36	1.84	0.44
1984	0.81	0.17	0.11	0.005	0.68	0.12

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