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Potency of *Bacillus thuringiensis* Strains and Formulations Against Gypsy Moth and Spruce Budworm Larvae: 1980-86

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Abstract

Between 1980 and 1986, 260 strains of *Bacillus thuringiensis* (Bt) representing 26 serovars and 20 registered and 50 experimental preparations of Bt produced by the manufacturers, were evaluated against the gypsy moth (GM); some of these were also evaluated against the spruce budworm (SBW). None of the 18 strains within serovar H14 were toxic to GM. Against both GM and SBW there was a broad spectrum of activity ranging from non-potent to very potent for strains within serovars H3a3b, H4a4c, H7, and H8a8b. By 1986, both the potency and efficacy of formulated and experimental products relative to the international standard, increased by over 200%. Regression analysis of these preparations showed that the regression coefficients (slopes) of a manufacturer's products were surprisingly consistent, but differed significantly between manufacturer, and different products with similar LD_{50} values had substantially different LD_{95} estimates. Finally, strains and preparations that were most potent against GM were not necessarily the same ones most potent against SBW.

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Pesticide Precautionary Statement.--This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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Introduction

The development of *Bacillus thuringiensis* (Bt) as an effective biological insecticide against gypsy moth (GM) and spruce budworm (SBW) has been investigated by the Northeastern Forest Experiment Station, Center for Biological Control of Northeastern Forest Insects and Diseases, for over 25 years. In an initial review of early field studies, Lewis and Connola (1966) concluded that strain selection along with application timing and formulation composition were critical for developing and optimizing Bt as a microbial insecticide usable against forest insect pests. Recently, the need for improvement in application technology, particularly in canopy penetration and drop deposition, also has been recognized as critical for maximizing Bt effectiveness.[1]

The evaluation of new formulations and new strains of Bt (includes any isolate having its own NRRL-HD number) has been a continuing part of our program to develop and improve the use of microbial insecticides in the control of forest insect pests. Periodic reports on the entomocidal activity of numerous strains of Bt have been published (Rogoff and others 1969, Yamvrias and Angus 1970, Morris and Moore 1983, Trottier and others 1988). The first comprehensive survey on the insecticidal activity of 18 strains of Bt against the GM was reported by Dubois and Squires (1971), and included representative strains from Serovar 1 (*subsp. thuringiensis*) through Serovar 8 (*subsp. morrisoni*). Shortly thereafter, "The International Cooperators Program on the Spectrum of Activity of *Bacillus thuringiensis*" was organized by H. T. Dulmage (United States Department of Agriculture (USDA) Agricultural Research Service (ARS), Weslaco, Texas). This group of more than a dozen scientists from the international community, collected every strain of Bt available from worldwide sources. These strains were numbered (HD-#) and classified into their respective serovar (de Barjac 1981). Primary powders of these strains were prepared and distributed to cooperating scientists for the determination of their spectrum of insecticidal activity against a variety of insect pests. A description of this international cooperators program and a summary of the evaluation of 319 strains from Serovar 1 (*subsp. thuringiensis*) through Serovar 11 (*subsp. toumanoffi*) has been published by Dulmage and others (1981). A detailed report on the insecticidal activity of these individual strains against GM is in press (Dubois, in press). This collection of Bt strains became known as the USDA Collection of *Bacillus thuringiensis* strains and its repository was the USDA, ARS Laboratory at Brownsville, Texas. Today there are approximately 1,000 strains in this collection representing over 31 serovars and the collection has been transferred to the repository at the Northern Regional Research Laboratory, Northern Utilization Branch, ARS, USDA, (1815 North University Avenue, Peoria, IL.. 61604). The curator of this Bt culture collection is Dr. Laurence K. Nakamura, and the present strain designation is NRRL-HD-#, an acronym from the Northern Regional Research Laboratory, plus HD and the unique isolate number. From 1980 through 1986, numerous new Bt strains were added to the NRRL-HD collection. Fresh primary powders of older strains as well as of new ones (prepared by H. T. Dulmage) have been evaluated recently against GM and SBW, and the results of most of these bioassays were briefly summarized by Dubois(1985). Detailed results of this study are presented here which, with the previous reports, provide a detailed and extensive information base on the spectrum of activity of Bt strains against the GM and to a lesser extent, against the SBW. To date, strains NRRL-HD-1 through NRRL-HD-929 have been evaluated against the GM and some of these were evaluated against the SBW as well. Eighty-one strains (NRRL-HD-930 through NRRL-HD-1013) remain to be evaluated against the GM. Through the courtesy of Dr. Nakamura, the remaining strains are available and will be evaluated; the results will be published as a supplement to this report. The information derived from these bioassays is expected to be of value to the bioinsecticide industry, academia, and other laboratories involved in a variety of fundamental and applied studies on Bt.

In addition to the evaluation of the primary powders of the NRRL-HD Bt strain collection, this report in-

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

cludes the evaluation of experimental and registered formulations of Bt provided by cooperating manufacturers from 1980 through 1986. The information is intended to show the progress made by the manufacturers of Bt in fermentation and formulation technology, during the past few years. Further inquiries concerning the formulations must be addressed to the appropriate manufacturer. The manufacturers and their addresses are:

Abbott Laboratories
North Chicago, IL, 60064

Sandoz, Inc.*
Crop Protection
P.O. Box 220
Wasco, CA 93280

Biochem Products, Inc.
P.O. Box 264
Montchanin, Delaware, 19710.

*Formulations produced by Zoecon Co., Inc., are also included under the name of Sandoz, Inc.

General Procedure

Strain and formulation preparation. All primary powders of the strains in the NRRL-HD collection presented here were prepared by H.T. Dulmage (USDA ARS, Weslaco, Texas) by fermentation in the B-4C medium and were harvested by acetone precipitation as described by Dulmage (1982). (Note: USDA Forest Service Laboratory preparations in Tables 17 and 18 were prepared by Dubois (1968)). All formulations provided by the cooperating manufacturers were used "as is".

Bioassays. The primary powders of all the NRRL-HD Bt strains were bioassayed by diet incorporation. For GM, 6 doses (in ug/ml of diet) were incorporated into the commercially prepared antibiotic-free diet of ODell and Rollinson (1966) (Bioserv, Inc., Frenchtown, New Jersey) and fed to second instar GM for 5 days. Details of the bioassay procedure have been published by Dubois (1986). For SBW (obtained from the Forest Pest Management Institute, Canadian Forestry Service, Sault Ste. Marie, Ontario), 6 doses (in ug/ml of diet) were also used and fourth instar larvae were exposed to the same test diet for 8 days. Incubation conditions of 22°C with a 16:8 light:dark photoperiod and 45% RH were used for both insect pests. Each time a new batch of larvae was used, the international standard, HD-1-S-1980 with a determined potency of 16,000 international units per milligram (IU/mg), was bioassayed also in parallel with the primary powders (HD-1-S-1971 with a defined potency of 18,000 IU/mg was used in 1980). The slope, LD_{50}, and associated 95% confidence intervals (CI) of each bioassay was estimated by either Berkson's minimum logit X^2 procedure (Berkson, 1953) using the LOCSAN program devised by Paschke and others (1968), by probit (Finney 1971), or by the eye-fitted curve procedure of Litchfield Jr.,and Wilcoxon (1949). The same procedures were used for all experimental and registered formulations received from industry; their doses were based on the labelled potency (in IU/ml or IU/mg) provided by the manufacturers, or in ug/ml of diet.

Because of the variation that occurs between and within batches of larvae (particulary with the SBW), a direct comparison between Bt strains or formulations based on the LD_{50} cannot be made. Rather, the relative toxicity of each preparation is measured by the Potency Ratio (PR). The PR is calculated by dividing the LD_{50} of the standard by the LD_{50} of the test strain that was bioassayed at the same time with the same batch of larvae. If a particular bioassay for the standard was discarded for any reason, the PR was calculated using the mean LD_{50} of the standard bioassays of that particular year (that is, the same GM or SBW generation), and the PR is noted by an asterisk (*). Bioassays with unusually wide CI (that is, generally with a range greater than 3.5-fold) were discarded. Based on the distribution of the PR, the different NRRL-HD strains were separated into six categories; 1. All strains that failed to effect any significant mortality at up to 100 ug of primary powder per ml of diet; 2. Strains with a PR of less than 0.75; 3. Strains with a PR between 0.75 and 1.24; 4. Strains with a PR between 1.25 and 2.00; 5. Strains with a PR between 2.01 and 3.00; 6. Strains with a PR greater than 3.00. For most strains, the PR is the mean PR of several bioassays; some strain preparations were bioassayed up to 12 times. Commercial and experimental formulations were grouped by year.

Results and Discussion

Bt strain evaluation. Successive generations of the New Jersey strain of GM have been reared and maintained on artificial diet at the Center for Biologi-

cal Control of Northeastern Forest Insects and Diseases for over two decades and generations F_{24}(1980) through F_{30}(1986) were used in the bioassays reported here. The mean slope and LD_{50} of the bioassays with the Bt standards (Table 1) have been very consistent and did not differ significantly from each other (HD-1-S-1971 vs. HD-1-S-1980) or in successive generations except for 1981 (F_{25}). We have no explanation for the results obtained with F_{25}; however genetic alterations or acquired resistance to Bt in the New Jersey GM strain can almost certainly be ruled out. The higher LD_{50} values were also observed in the bioassays with the other strains and experimental formulations resulting in PR values consistent with those obtained from other generations of GM that were used. This observation strongly supports the use of PR to evaluate the potency of different Bt strains compared to the use of LD_{50} values only. Also the Bt standard appeared to be reasonably stable when stored at 4°C between 1980-1986 (additional supplies of HD-1-S-1980 are stored at -70°C until needed).

The distribution of Bt strains within a particular serovar group, into several PR categories is generally narrow (Table 2) and does not extend beyond two successive categories. Bt strains of Serovar H14 are generally insecticidal to mosquitoes and black flies; however, not one of the 18 Bt strains of this group was insecticidal to GM. Exceptions to this general observation were Serovars H3a3b, H4a4c, H7, and H8a8b where these groups all have broad activity spectra, including representative Bt strains that were not toxic at 100 ug/ml of diet (Category 1, Table 3) to some strains that had a PR greater than 5.00 (Categories 2 through 6, Tables 4 through 8). Within the Serovar H3a3b, the broad spectrum of activity may be partially explained by the fact that strains with a K-73 type crystal are generally weak or non-potent and strains with a K-1 type crystal are generally moderately to very potent against GM (Dubois, in press, Dulmage and others 1981). Also, qualitative and quantitative differences in the protein components of the P1(165kDa) and P2(35kDa) crystals can influence the potency and activity spectrum of individual strains (for a review of delta-endotoxins of Bt strains and associated genes see Aronson and others, 1986). For other than non-potent strains, slopes of individual strains within a serovar can vary from 2.0 to greater than 5.0 regardless of the PR except for those of Serovar H4a4b *subsp. dendrolimus*, which are consistently less than 3.0 (Table 4). The NRRL-HD-1 strain of Bt has been used almost exclusively in the production of lepidopteran-toxic formulations, however strain NRRL-HD-854 (H7) has a steeper slope and is significantly more potent against GM than any other strain evaluated to date (the results of the evaluation of the primary powder preparation of the NRD-12 strain (NRRL-HD-945) used for the production of SAN 415 and Javelin, will be reported at a later date).

Fewer Bt strains were evaluated against SBW than against GM, partly because strains that were not potent against GM were eliminated from further consideration and because strain-screening activities against SBW were limited to the CANUSA program. The average slopes and LD_{50} values of bioassays with the standard, HD-1-S-1980, did not differ significantly from generation to generation (Table 9), however within-generation variability is extensive, not only in the bioassays with the standard, but also in the bioassays of the different strains and formulations. Temporary feeding inhibition followed by recovery and reingestion of Bt probably contribute to this variation (Retnakaran and others 1983). The LD_{50} values of the standard were not significantly different from those estimated for the GM; however, the slopes are considerably flatter. As such, the estimated LD_{95} dose would be significantly higher for SBW than for GM. Strains that were not potent against GM were not evaluated against SBW at this time; however every Bt strain evaluated against SBW did have some insecticidal activity. There are definite differences between GM and SBW in their susceptibility to different Bt strains. With SBW, the spectrum of activity of Bt strains within a serovar is distributed into several PR categories (Table 10). Strains of serovars H3a3b and H4a4c are represented in every PR category from a PR less than 0.75 to a PR greater than 3.00. Also, regardless of the PR category, none of the slopes was greater than 3.9 and most were 3.0 or less. (Categories 2 through 6, Tables 11 through 15). The most potent strain evaluated against SBW was NRRL-HD-545 (PR 5.0, Table 15) which is a Serovar H3a3b strain. Against GM, this strain had a PR of only 1.39 (Category 4, Table 6). These differences are also observed with strains of other serovars; NRRL-HD-293, a serovar H4a4c, for example, has a PR of 4.53 against SBW (Category 6, Table 15), but its PR against GM is only 0.91 (Category 3, Table 5). Generally, the PR of individual Bt strains will differ between GM and SBW. However, strains that are insecticidal against GM are also insecticidal against SBW.

Experimental and registered Bt formulations. Initial efforts (1960-70) to improve on the operational use of Bt against GM, focused primarily on the development of better formulations. Poor suspendability of Bt powders in oil-based carriers and clogging of spray nozzles were two problems that severely compromised the efficacy of Bt treatments. By 1971, the NRRL-HD-1 strain was used almost exclusively in Bt formulations, and past physical problems associated with application were resolved with the introduction of liquid flowable Bt concentrates. By 1980, the potency of Bt formulations had increased from an initial 4 Billion International Units (BIU) /gallon to 16 BIU/gallon and in the following 6 years, continued improvement in fermentation and formulation technology resulted in another fourfold increase in potency to 64 BIU/gallon (Table 16). Of greater significance has been the steady increase in the PR versus the GM. Bt formulations are standardized against the cabbage looper (*Trichoplusia ni*) and theoretically, the PR against that insect should always remain at 1.00. Against GM however, the PR increased from less than 1.00 in 1981 to more than 2.00 by 1986, showing an increase in efficacy against GM by over 200%.

There is little difference in the apparent efficacy of the registered formulations against GM when they are compared at the LD_{50} (or their respective PR). However, comparisons between formulations at that single point on a regression line can be misleading, particularly when the regression lines are not parallel. The regression coefficients (that is, slopes) also must be taken into consideration when comparing Bt formulations. Bt is used operationally at doses exceeding LD_{100}. When we use the regression coefficients to estimate the LD_{95}, differences between products can be considerable. Against GM, the regression coefficient of the international standard, HD-1-S-1980, is usually above 4.50 (Table 1). However, regression coefficients of commercial formulations produced by Abbott Labs are usually 3.00 or less, and those of formulations produced by Sandoz and Biochem Products are usually above 3.00 and frequently are similar to that of the standard.

A standardized preparation of Dipel, with a lower LD_{50} dose-concentration (and a higher PR), may seem more effective than a standardized Thuricide preparation. However, when their respective regression coefficients are taken into consideration, the dose-concentration estimates for the LD_{95} would indicate otherwise (for example, the LD_{95} estimates for the 1984 preparations of Dipel 8L and Thuricide 32LV are 421 and 344 IU/ml respectively, Table 16). Or if one compares the 1986 preparation of Javelin (NRD-12) with Dipel 8L (NRRL-HD-1) where the LD_{50} and PR are very similar (Table 16), their LD_{95} of 75 and 136 IU/ml, respectively, are substantially different.

Presently it is unclear what causes the regression coefficient of some Bt preparations to be consistently low. It may be characteristic of the strains used. It may result from increased feeding inhibition as doses are increased, due either to the incompatibility of formulant carrier with the feeding behavior of GM or to some unidentified metabolite(s) produced as a byproduct of the fermentation. The relative concentration of spores to delta-endotoxin as a whole or some of its specific protein components, may also influence the regression coefficient estimate. Noteworthy are the bioassay results of the 1984 standardized experimental formulations prepared with the NRD-12 (NRRL-HD-945) strain of Bt by the major producers of Bt (Table 17). They are: a) SAN 415 32LV produced by Sandoz, Inc., b) ABG 6163 produced by Abbott Labs and c) Bactospeine HD-945 produced by Biochem Products. ABG 6163 had the highest PR, the lowest LD_{50} and lowest regression coefficient; SAN 415 had a slightly lower PR, similar LD_{50} and a higher regression coefficient; and finally, Bactospeine-HD-945 had the lowest PR, the highest LD_{50}, and the highest regression coefficient. Undoubtedly, different nutrients and fermentation procedures used to produce the Bt, as well as the formulants used to produce the final product, will significantly influence GM's response to different formulations produced with the same strain of Bt.

Finally, the use of genetic engineering to improve the efficacy of Bt along with advances in fermentation technology, provide new opportunities to increase both efficacy and toxin yield. These improvements will make the use of Bt cost-competitive with chemical insecticides. Indeed, in 1983 Abbott Labs produced three very potent experimental powder preparations (Table 17). Although the PR of the NRRL-HD-1 and NRD-12 were impressive, HP-1201 is even at present, the most potent preparation ever evaluated against GM. It had a PR of approximately 22, and even with a lower regression coefficient than other preparations, its estimated LD_{95} would

still be lower than either of the other two preparations tested against GM.

The impressive high potency of HP-1201 observed in GM could not be duplicated in SBW (Table 18). Indeed, against this noctuid, the other two preparations (that is NRRL-HD-1 and NRD-12 spray dry powders) were significantly more potent. It should not be surprising that SBW responds differently to standardized and unformulated Bt preparations. This uniqueness in susceptibility and activity spectrum compared with GM was observed in the bioassay against the primary powders as well. Also, variability within bioassays is more extensive than in the bioassays with GM.

Conclusions

The NRRL-HD-1 strain is still the most widely used strain of Bt for the production of lepidopteran-toxic Bt formulations. However, with both the GM and the SBW, other strains are significantly more potent and their commercial potential should be evaluated. Modern techniques in biochemistry and molecular biology have identified specific genes that code for and when cloned in *Escherichia coli*, produce insecticidal lepidopteran toxic delta-endotoxin proteins. However these studies fail to explain differences in susceptibility between insect species to a particular Bt strain. These differences, in part, may be explained by the specific gut proteolytic mechanism that digests the 130kd protein to its 55kd protease-resistant protein fraction, and by the unique receptor sites that may be found in different insect species (Haider and Ellar 1987a, 1987b).

Differences at other points than the LD_{50} or the PR, should also be considered when evaluating different Bt formulations to be used in operational programs, particularly if their regression coefficients differ significantly. Use of the regression coefficient to estimate efficacy at or near the LD_{95} level of effectiveness should be used to differentiate formulations that otherwise may appear similar in their efficacy, but investigators must be aware of the wide confidence intervals that exist at the extremes of a regression line. Other factors, outside the scope of this publication, should also be considered when selecting a formulated product for operational use (such as stability, ease of handling, residual activity, deposit efficiency, and cost). Finally, sufficient evidence has been presented here to discourage generalization of Bt effectiveness either as primary powders or formulated products against insect groups. Each Bt preparation should be evaluated against each intended target pest. Results of all the bioassays are summarized in the following tables.

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Appendix.--Index of Table Titles

Bioassays against the Gypsy Moth:

Table 1.--Mean slope, LD_{50} (in ug/ml of diet), and associated 95% confidence intervals (CI) of all bioassays conducted with HD-1-S-1971 (18,000 IU/mg) in 1980 and the yearly (1981-86) F-generation means of the bioassays conducted with HD-1-S-1980 (16,000 IU/mg) against second instar GM, 1980 through 1986.

Table 2.--Summary of the bioassays against second instar GM of the different NRRL-HD *B. thuringiensis* strains by their serovar, subspecies, and potency ratio (PR) category ranges.

Table 3.--Category 1. Individual NRRL-HD strains of *B. thuringiensis* not insecticidal to second instar GM at 100 ug/ml of diet.

Table 4.--Category 2. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strain of *B. thuringiensis* bioassayed against second instar GM with a potency ratio of 0.75 or less.

Table 5.--Category 3. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against second instar GM with a potency ratio between 0.75 and 1.24.

Table 6.--Category 4. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against second instar GM with a potency ratio between 1.25 and 2.00.

Table 7.--Category 5. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against second instar GM with a potency ratio between 2.01 and 3.00.

Table 8.--Category 6. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against second instar GM with a potency ratio greater than 3.00.

Bioassays against the Spruce Budworm:

Table 9.--Mean slope, LD_{50} (in ug/ml of diet), and their associated 95% confidence intervals of all bioassays conducted with HD-1-S-1980 (16,000 IU/mg) against fourth instar SBW from 1981 through 1984.

Table 10.--Summary of the bioassays against fourth instar SBW of the different NRRL-HD *B. thuringiensis* strains by their serovar, subspecies, and potency ratio category ranges.

Table 11.--Category 2. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against fourth instar SBW with a potency ratio of 0.75 or less.

Table 12.--Category 3. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against fourth instar SBW with a potency ratio between 0.75 and 1.24.

Table 13.--Category 4. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against fourth instar SBW with a potency ratio between 1.25 and 2.00.

Table 14.--Category 5. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against fourth instar SBW with a potency ratio between 2.01 and 3.00.

Table 15.--Category 6. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of *B. thuringiensis* bioassayed against fourth instar SBW with a potency ratio greater than 3.00.

Evaluation of commercial formulations and experimental preparations.

Table 16.--Evaluation of commercially available formulations of Bt against GM, 1981 through 1986.

Table 17.--Evaluation of experimental formulations of Bt against GM, 1981 through 1986.

Table 18.--Evaluation of commercially available and experimental formulations of Bt against SBW, 1981 through 1986.

Table 1.--Mean slope, LD_{50} (in ug/ml of diet), and associated 95% confidence intervals (CI) of all bioassays conducted with HD-1-S-1971 (18,000 IU/mg) in 1980 and the yearly (1981-86) F-generation means of the bioassays conducted with HD-1-S-1980 (16,000 IU/mg) against second instar GM, 1980 through 1986.

YEAR	TOTAL #	SLOPE (95% CI)	MEAN LD_{50} (95% CI)
1980*(F-24)	31	4.50 (3.28-5.73)	6.05 (4.97- 8.10)
1981 (F-25)	22	4.30 (2.99-5.62)	9.32 (7.33-13.43)
1982 (F-26)	29	4.88 (3.62-6.12)	5.01 (4.27- 5.95)
1983 (F-27)	30	4.92 (3.53-6.31)	6.81 (5.55- 9.57)
1984 (F-28)	23	4.93 (3.61-6.25)	5.07 (4.06- 8.92)
1985 (F-29)	17	4.88 (3.61-6.14)	5.77 (4.84- 6.96)
1986 (F-30)	29	4.95 (3.64-6.25)	4.95 (4.18- 5.91)

*HD-1-S-1971

Table 2.--Summary of the bioassays against second instar GM of the different NRRL-HD B. thuringiensis strains by their serovar, subspecies, and potency ratio (PR) category ranges.

SEROVAR	SUBSPECIES	Potency Range						
		0 [a] (1) [b]	<0.75 (2)	0.75-1.24 (3)	1.25-2.00 (4)	2.01-3.00 (5)	>3.00 (6)	TOTAL
1	thuringiensis	6	26	4	5			41
2	finitimus	3	1					4
3a	alesti	3	2					5
3a3b	kurstaki	6	9	9	9	6	3	42
4a4b	sotto	1						1
4a4b	dendrolimus	6	4					10
4a4c	kenyae	4	5	2			2	13
5a5b	galleriae	4	12	1			1	18
5a5c	canadensis	5						5
6	subtoxicus				1			1
6	entomocidus		3		1			4
7	aizawai	2	15	5	3		1	26
8a8b	morrisoni	9	8	1		1		19
8a8c	ostriniae	1						1
8a8d	nigeriae							
9	tolworthi		4	2		1		7
10	darmstadiensis	12	1					13
11a11b	toumanoffi		2					2
11a11c	kyushuensis	2						2
12	thompsoni	1		1				2
13	pakistani	2						2
14	israelensis	18						18
15	indiana	2						2
16	dakota	2						2
17	tohokuensis							
18	kumanotoensis							
19	tochigiensis							
20	colmeri	1						1
20	yunnanensis							
20a20c	pondicheriensis							
22	shodogiensis							
	wuhanensis	3	2					5
	not identified	10	2		1		1	14
	TOTALS	103	96	25	20	8	8	260

[a] 0 = no significant mortality at 100 ug of primary powder per milligram of diet.
[b] Numbers in parentheses indicate the appropriate category for the PR range.

Table 3.--Category 1. Individual NRRL-HD strains of *B. thuringiensis* not insecticidal to second instar GM at 100 ug/ml of diet.

HD #	SEROVAR	HD #	SEROVAR	HD #	SEROVAR
27	1, thuringiensis	30	5a5c, canadensis	500	14, israelensis
28	1, thuringiensis	552	5a5c, canadensis	522	14, israelensis
54	1, thuringiensis	553	5a5c, canadensis	563	14, israelensis
364	1, thuringiensis	554	5a5c, canadensis	567	14, israelensis
362	1, thuringiensis	592	5a5c, canadensis	653	14, israelensis
770	1, thuringiensis			654	14, israelensis
		111	7, aizawai	655	14, israelensis
526	2, finitimus	596	7, aizawai	656	14, israelensis
527	2, finitimus			657	14, israelensis
529	2, finitimus	325	8a8b, morrisoni	658	14, israelensis
		515	8a8b, morrisoni	659	14, israelensis
04	3a, alesti	531	8a8b, morrisoni	792	14, israelensis
72	3a, alesti	534	8a8b, morrisoni	796	14, israelensis
79	3a, alesti	559	8a8b, morrisoni	798	14, israelensis
		597	8a8b, morrisoni	800	14, israelensis
331	3a3b, kurstaki	600	8a8b, morrisoni	916	14, israelensis
336	3a3b, kurstaki	611	8a8b, morrisoni	918	14, israelensis
344	3a3b, kurstaki	652	8a8b, morrisoni	920	14, israelensis
347	3a3b, kurstaki				
546	3a3b, kurstaki	536	8a8c, ostriniae	519	15, indiana
929	3a3b, kurstaki			521	15, indiana
		146	10, darmstadiensis		
48	4a4b, dendrolimus	147	10, darmstadiensis	511	16, dakota
548	4a4b, dendrolimus	199	10, darmstadiensis	512	16, dakota
557	4a4b, dendrolimus	498	10, darmstadiensis		
568	4a4b, dendrolimus	499	10, darmstadiensis	847	20, colmeri
584	4a4b, dendrolimus	539	10, darmstadiensis		
585	4a4b, dendrolimus	601	10, darmstadiensis	525	wuhanensis
		602	10, darmstadiensis	572	wuhanensis
453	4a4b, sotto	603	10, darmstadiensis	573	wuhanensis
		604	10, darmstadiensis		
550	4a4c, kenyae	609	10, darmstadiensis	326	not identified
560	4a4c, kenyae	612	10, darmstadiensis	327	not identified
578	4a4c, kenyae			329	not identified
591	4a4c, kenyae	541	11a11c, kyushuensis	330	not identified
		571	11a11c, kyushuensis	333	not identified
184	5a5b, galleriae			334	not identified
224	5a5b, galleriae	543	12, thompsoni	351	not identified
650	5a5b, galleriae			357	not identified
651	5a5b, galleriae	395	13, pakistani	569	not identified
		462	13, pakistani	570	not identified

Table 4.--Category 2. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against second instar GM with a potency ratio of 0.75 or less.

HD #	SLOPE (95% CI)	LD 50 (95% CI) (IN UG/ML)	PR	SEROVAR
020	5.40 (4.08-6.72)	18.78 (15.71- 22.25)	0.32	1, thuringiensis
022	4.01 (2.23-5.79)	26.77 (20.47- 34.43)	0.31	1, thuringiensis
026	5.40 (3.35-7.45)	26.43 (21.71- 35.45)	0.04	1, thuringiensis
039	4.14 (2.78-5.50)	11.30 (8.87- 16.30)	0.46	1, thuringiensis
054	4.08 (2.98-5.18)	9.99 (7.41- 12.95)	0.61	1, thuringiensis
059	3.80 (2.73-4.88)	11.24 (8.39- 14.83)	0.48	1, thuringiensis
095	2.01 (0.85-3.17)	24.20 (13.00-181.80)	0.25	1, thuringiensis
096	4.21 (2.88-5.54)	14.05 (10.30- 17.59)	0.46	1, thuringiensis
103	4.10 (2.73-5.46)	12.08 (9.44- 17.61)	*0.59	1, thuringiensis
225	3.83 (2.38-5.27)	28.76 (18.32-188.30)	0.29	1, thuringiensis
264	4.20 (2.81-5.58)	14.93 (11.77- 18.53)	0.36	1, thuringiensis
271	2.13 (1.12-3.13)	65.48 (45.95-119.60)	0.09	1, thuringiensis
281	6.29 (4.22-8.36)	19.65 (15.60- 23.47)	0.43	1, thuringiensis
308	6.13 (4.46-7.80)	22.03 (18.71- 25.88)	0.25	1, thuringiensis
309	4.13 (2.80-5.46)	19.98 (15.76- 27.03)	0.28	1, thuringiensis
350	4.11 (3.00-5.21)	10.59 (8.41- 13.62)	0.53	1, thuringiensis
364	2.47 (1.56-3.37)	152.10 (94.79-359.70)	0.04	1, thuringiensis
556	4.47 (3.31-5.64)	10.86 (8.78- 13.27)	0.54	1, thuringiensis
561	3.15 (2.44-3.86)	21.53 (16.66- 28.31)	0.18	1, thuringiensis
574	3.80 (2.47-5.13)	17.13 (13.53- 20.98)	0.33	1, thuringiensis
583	4.38 (3.02-5.75)	17.75 (14.51- 21.58)	0.25	1, thuringiensis
696	4.21 (2.81-5.62)	12.21 (7.38- 16.93)	0.26	1, thuringiensis
699	3.64 (2.48-4.80)	33.36 (26.04- 42.73)	0.10	1, thuringiensis
701	5.57 (3.79-7.34)	10.39 (8.58- 12.61)	0.45	1, thuringiensis
704	2.67 (1.76-3.57)	19.08 (10.33- 87.75)	0.35	1, thuringiensis
708	4.27 (2.76-5.77)	40.97 (27.74-167.50)	0.13	1, thuringiensis
335	3.49 (2.39-4.59)	13.09 (9.57- 21.19)	0.42	2, finitimus
083	3.53 (2.20-4.42)	36.72 (27.91- 59.28)	0.16	3a, alesti
084	3.58 (2.38-4.81)	87.88 (62.11-173.20)	0.07	3a, alesti
073	5.11 (3.31-6.90)	22.08 (17.27- 26.82)	0.38	3a3b, kurstaki
191	7.31 (5.00-9.61)	8.59 (7.41- 10.25)	0.61	3a3b, kurstaki
338	3.95 (2.96-4.94)	9.67 (7.26- 12.25)	0.47	3a3b, kurstaki
342	4.12 (3.01-5.24)	9.17 (7.21- 11.53)	0.61	3a3b, kurstaki
345	3.59 (2.49-4.69)	10.81 (8.39- 15.00)	0.52	3a3b, kurstaki
348	3.83 (2.85-4.81)	7.07 (5.47- 9.31)	0.66	3a3b, kurstaki
349	2.97 (2.07-3.88)	91.33 (65.75-147.30)	0.06	3a3b, kurstaki

Continued

Table 4.--Continued

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
352	3.80 (2.87- 4.73)	7.95 (6.05- 10.14)	0.55	3a3b, kurstaki
923	8.25 (5.74-10.77)	8.74 (7.69- 10.14)	0.74	3a3b, kurstaki
034	2.10 (1.11- 3.08)	24.50 (15.99- 36.30)	0.21	4a4b, dendrolimus
547	2.25 (1.35- 3.15)	95.72 (63.70-202.90)	0.07	4a4b, dendrolimus
575	2.66 (1.73- 3.59)	79.78 (56.98-136.60)	0.05	4a4b, dendrolimus
586	2.85 (2.16- 3.54)	28.29 (20.83- 40.96)	0.22	4a4b, dendrolimus
278	4.58 (2.43- 6.73)	12.00 (6.61- 15.76)	0.40	4a4c, kenyae
291	3.75 (2.99- 4.50)	13.92 (10.46- 18.34)	0.33	4a4c, kenyae
328	2.57 (1.78- 3.36)	61.54 (44.73- 94.80)	0.07	4a4c, kenyae
549	3.65 (2.91- 4.40)	11.09 (8.69- 14.11)	0.36	4a4c, kenyae
555	5.34 (4.12- 6.56)	26.09 (21.57- 31.89)	0.24	4a4c, kenyae
029	3.67 (2.55- 4.79)	76.90 (57.74-122.00)	0.07	5a5b, galleriae
129	5.44 (3.38- 7.51)	24.25 (19.72- 29.06)	0.20	5a5b, galleriae
150	2.76 (2.09- 3.42)	37.54 (27.89- 53.65)	0.19	5a5b, galleriae
234	4.80 (3.21- 6.40)	24.60 (19.98- 32.89)	0.18	5a5b, galleriae
236	8.08 (5.68-10.49)	9.06 (7.91- 10.60)	0.57	5a5b, galleriae
240	3.53 (2.30- 4.76)	61.33 (48.29- 83.09)	*0.08	5a5b, galleriae
305	3.57 (2.36- 4.78)	90.51 (67.58-140.90)	0.09	5a5b, galleriae
322	2.78 (1.95- 3.60)	54.90 (41.92- 77.11)	0.09	5a5b, galleriae
359	3.60 (2.68- 4.52)	24.20 (19.39- 30.61)	0.20	5a5b, galleriae
360	3.63 (2.43- 4.82)	22.05 (14.53- 69.60)	0.27	5a5b, galleriae
361	4.55 (3.49- 5.61)	14.74 (11.67- 18.21)	0.33	5a5b, galleriae
558	3.07 (2.37- 3.76)	27.18 (20.68- 36.71)	0.15	5a5b, galleriae
110	8.25 (5.75-10.75)	26.06 (22.53- 29.89)	0.04	6, entomocidus
320	3.53 (2.20- 4.86)	17.71 (12.52- 35.21)	0.25	6, entomocidus
635	4.66 (3.23- 6.08)	47.82 (39.61- 60.80)	0.12	6, entomocidus
122	4.32 (3.01- 5.62)	37.35 (30.31- 46.46)	0.11	7, aizawai
128	3.33 (2.46- 4.21)	7.71 (6.03- 10.51)	0.71	7, aizawai
248	4.01 (2.56- 5.36)	20.26 (10.04-967.30)	0.49	7, aizawai
283	2.08 (1.20- 2.96)	24.50 (13.56- 90.36)	0.28	7, aizawai
593	2.96 (1.51- 4.41)	29.71 (18.38-253.30)	0.30	7, aizawai
595	4.61 (2.76- 6.44)	24.83 (18.42- 52.43)	0.36	7, aizawai
596	2.02 (1.14- 2.89)	193.80 (114.60-618.40)	0.10	7, aizawai
780	5.33 (3.72- 6.94)	10.92 (9.30- 12.43)	0.46	7, aizawai
848	3.40 (2.31- 4.50)	15.44 (10.25- 29.79)	0.31	7, aizawai
849	2.35 (1.28- 3.40)	29.15 (11.66-358.40)	0.48	7, aizawai
851	1.96 (1.01- 2.92)	8.94 (2.87- 14.67)	0.57	7, aizawai
858	5.05 (3.62- 6.47)	35.26 (29.07- 42.61)	0.14	7, aizawai
860	2.65 (1.59- 3.70)	9.03 (5.26- 16.16)	0.71	7, aizawai
863	3.23 (2.21- 4.25)	8.29 (5.52- 11.55)	0.59	7, aizawai
864	3.83 (2.93- 4.74)	34.78 (27.90- 43.92)	0.13	7, aizawai

Continued

Table 4.--Continued

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
012	4.06 (2.38- 5.74)	36.02 (28.54- 48.36)	0.03	8a8b, morrisoni
324	3.87 (2.84- 4.89)	37.35 (30.12- 47.46)	0.13	8a8b, morrisoni
530	2.56 (1.44- 3.68)	13.97 (9.38- 30.84)	0.43	8a8b, morrisoni
535	3.99 (2.86- 5.11)	21.37 (16.14- 30.56)	0.23	8a8b, morrisoni
579	2.81 (1.50- 4.11)	21.37 (13.06- 88.46)	0.26	8a8b, morrisoni
580	3.68 (2.42- 4.94)	11.63 (8.82- 17.85)	*0.62	8a8b, morrisoni
598	3.17 (1.92- 4.42)	72.93 (39.77-962.50)	0.18	8a8b, morrisoni
599	3.86 (2.59- 5.14)	81.98 (64.45-115.80)	0.04	8a8b, morrisoni
013	5.23 (3.76- 6.70)	17.91 (14.88- 21.24)	0.22	9, tolworthi
124	4.49 (3.10-11.75)	17.91 (12.44- 81.80)	0.27	9, tolworthi
125	4.23 (2.72- 5.74)	20.03 (15.62- 29.12)	0.61	9, tolworthi
537	2.91 (2.06- 3.77)	9.67 (6.72- 18.11)	0.50	9, tolworthi
200	2.74 (2.09- 3.40)	38.39 (28.45- 55.10)	0.12	10, darmstadiensis
201	4.11 (3.15- 5.06)	40.86 (32.99- 51.70)	0.10	11a11b, toumanoffi
540	2.75 (1.71- 3.78)	53.95 (40.92- 77.02)	0.08	11a11b, toumanoffi
572	3.46 (2.05- 4.87)	36.44 (26.45- 53.70)	0.13	wuhanensis
573	4.59 (3.25- 5.94)	55.30 (45.16- 69.50)	0.07	wuhanensis
275	3.66 (2.58- 4.73)	8.31 (5.80- 11.23)	0.61	not identified
346	3.62 (2.58- 4.66)	65.25 (48.43- 99.60)	0.08	not identified

*Mean LD_{50} of the standard was used.

Table 5.--Category 3. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against second instar GM with a potency ratio between 0.75 and 1.24.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
053	4.01 (2.71-5.32)	5.22 (3.47- 6.91)	0.97	1, thuringiensis
260	5.35 (3.94-6.75)	4.60 (3.84- 5.47)	1.17	1, thuringiensis
290	3.51 (2.59-4.44)	9.69 (6.75-19.15)	1.03	1, thuringiensis
319	4.71 (3.55-5.88)	5.58 (4.15- 7.05)	0.89	1, thuringiensis
089	4.12 (2.51-5.73)	25.10 (18.10-48.27)	0.81	3a3b, kurstaki
241	3.63 (2.58-4.69)	7.19 (5.40-11.40)	0.86	3a3b, kurstaki
304	5.23 (3.87-6.58)	4.14 (3.43- 4.94)	1.07	3a3b, kurstaki
306	5.95 (4.46-7.44)	4.97 (4.23- 5.85)	1.23	3a3b, kurstaki
332	3.08 (2.04-4.12)	7.32 (5.24-10.76)	1.00	3a3b, kurstaki
340	4.65 (3.46-5.84)	6.50 (4.97- 8.20)	0.81	3a3b, kurstaki
343	3.76 (2.85-4.67)	4.96 (3.57- 6.46)	0.93	3a3b, kurstaki
544	3.80 (2.88-4.72)	3.52 (2.59- 4.58)	1.17	3a3b, kurstaki
564	2.51 (1.58-3.44)	9.39 (5.04-58.75)	1.12	3a3b, kurstaki
136	4.96 (3.49-6.43)	8.21 (6.75-10.54)	0.82	4a4c, kenyae
293	3.64 (2.50-4.78)	9.18 (6.96-14.58)	0.91	4a4c, kenyae
008	3.89 (2.53-5.25)	13.73 (10.38-21.63)	0.78	5a5b, galleriae
137	4.85 (3.67-6.02)	7.29 (5.95 -8.94)	0.78	7, aizawai
249	5.57 (3.63-7.52)	5.76 (4.09- 7.21)	1.10	7, aizawai
606	4.76 (2.57-6.94)	7.92 (6.16- 9.35)	1.09	7, aizawai
850	2.81 (1.56-4.07)	5.48 (1.75- 9.18)	0.93	7, aizawai
853	2.63 (1.56-3.71)	5.99 (3.59- 9.93)	1.21	7, aizawai
621	4.80 (3.36-6.23)	5.10 (4.18- 6.24)	1.22	8a8b, morrisoni
301	4.14 (2.25-6.03)	10.07 (7.35-12.49)	0.83	9, tolworthi
538	4.56 (3.44-5.68)	11.53 (8.27-12.19)	0.99	9, tolworthi
542	4.17 (3.05-5.30)	4.63 (3.80- 6.22)	1.07	12, thompsoni

Table 6.--Category 4. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against second instar GM with a potency ratio between 1.25 and 2.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
120	4.05 (3.12-4.98)	3.76 (2.79- 4.84)	1.55	1, thuringiensis
581	4.06 (2.88-5.23)	4.30 (3.49- 5.29)	1.60	1, thuringiensis
698	4.13 (3.06-5.20)	3.31 (2.66- 4.42)	1.86	1, thuringiensis
703	5.60 (4.04-7.16)	2.97 (2.54- 3.50)	1.58	1, thuringiensis
707	4.34 (2.93-5.78)	4.35 (2.82-17.38)	1.81	1, thuringiensis
164	5.36 (4.07-6.65)	3.08 (2.55- 3.60)	1.41	3a3b, kurstaki
203	4.93 (3.53-6.35)	5.39 (4.45- 6.87)	1.26	3a3b, kurstaki
231	4.90 (3.44-6.37)	3.86 (3.14- 4.75)	1.85	3a3b, kurstaki
243	4.47 (3.11-5.82)	6.18 (5.10- 7.47)	1.43	3a3b, kurstaki
255	6.54 (4.76-8.33)	3.77 (3.26- 4.42)	1.55	3a3b, kurstaki
270	4.00 (2.80-5.20)	5.98 (4.85- 8.11)	1.55	3a3b, kurstaki
339	4.50 (3.39-5.61)	3.17 (2.64- 3.91)	1.84	3a3b, kurstaki
341	4.83 (3.71-5.95)	2.87 (2.43- 3.37)	1.68	3a3b, kurstaki
545	5.85 (4.24-7.45)	3.31 (2.89- 3.79)	1.39	3a3b, kurstaki
010	2.20 (1.17-3.23)	27.30 (19.10-42.52)	1.28	6, subtoxicus
198	3.50 (1.57-5.43)	5.21 (1.74- 7.65)	1.61	6, entomocidus
052	4.28 (3.09-5.46)	3.66 (2.71- 5.18)	1.56	7, aizawai
133	4.45 (3.50-5.40)	3.56 (2.94- 4.32)	1.53	7, aizawai
855	5.32 (3.84-6.80)	2.65 (2.29- 3.11)	1.88	7, aizawai
363	4.60 (3.48-5.73)	2.93 (2.24- 3.75)	1.76	not identified

Table 7.--Category 5. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against second instar GM with a potency ratio between 2.01 and 3.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
087	4.50 (3.41-5.61)	3.58 (3.03-4.23)	2.22	3a3b, kurstaki
244	3.89 (2.98-4.79)	2.40 (1.51-3.46)	2.38	3a3b, kurstaki
251	5.35 (3.82-6.89)	3.28 (2.70-3.92)	*2.18	3a3b, kurstaki
258	5.50 (3.90-7.10)	2.21 (1.89-2.75)	2.61	3a3b, kurstaki
263	4.68 (3.09-6.26)	3.85 (2.64-6.52)	2.00	3a3b, kurstaki
337	4.83 (3.70-5.97)	1.81 (1.52-2.16)	2.70	3a3b, kurstaki
532	4.93 (3.78-6.08)	1.84 (1.51-2.17)	2.44	8a8b, morrisoni
285	5.37 (4.04-6.70)	2.30 (1.87-2.75)	2.28	9, tolworthi

*Mean LD_{50} of the standard was used.

Table 8.--Category 6. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against second instar GM with a potency ratio greater than 3.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
001	4.91 (3.63-6.19)	1.35 (1.12-1.65)	3.49	3a3b, kurstaki
262	5.12 (3.69-6.55)	1.98 (1.30-2.51)	3.29	3a3b, kurstaki
562	4.60 (3.50-5.69)	2.04 (1.66-2.51)	3.57	3a3b, kurstaki
551	4.48 (3.11-5.85)	1.29 (1.06-1.59)	3.75	4a4c, kenyae
588	4.82 (3.08-6.56)	1.60 (1.34-2.10)	3.95	4a4c, kenyae
287	5.01 (3.66-6.36)	1.56 (1.21-1.91)	3.51	5a5b, galleriae
854	5.24 (3.77-6.71)	0.98 (0.83-1.14)	5.18	7, aizawai
582	3.23 (2.07-4.39)	1.84 (1.36-2.41)	3.37	not identified

Table 9.--Mean slope, LD_{50} (in ug/ml of diet), and their associated 95% confidence intervals of all bioassays conducted with HD-1-S-1980 (16,000 IU/mg) against fourth instar SBW from 1981 through 1984.

YEAR	TOTAL #	SLOPE (95% CI)	MEAN LD_{50} (95% CI)
1981	6	3.09 (1.62-4.56)	4.84 (2.88- 6.87)
1982	18	3.16 (1.46-4.86)	4.17 (2.59- 8.22)
1983	15	3.06 (1.54-4.58)	7.21 (4.72-17.65)
1984	15	2.92 (1.27-4.56)	5.33 (3.25-12.09)

Table 10.--Summary of the bioassays against fourth instar SBW of the different NRRL-HD B. thuringiensis strains by their serovar, subspecies, and potency ratio category ranges.

SEROVAR	SUBSPECIES	Potency Range					
		<0.75 (2)[a]	0.75-1.24 (3)	1.25-2.00 (4)	2.01-3.00 (5)	>3.00 (6)	TOTAL
1	thuringiensis	2	1	1		1	5
2	finitimus						
3a	alesti		1				1
3a3b	kurstaki	1	6	1	3	1	12
4a4b	sotto						
4a4b	dendrolimus						
4a4c	kenyae	2		1	1	1	5
5a5b	galleriae						
5a5c	canadensis						
6	subtoxicus						
6	entomocidus						
7	aizawai	3		1	3		7
8a8b	morrisoni						
8a8c	ostriniae						
8a8d	nigeriae						
9	tolworthi	1	1				2
10	darmstadiensis						
11a11b	toumanoffi						
11a11c	kyushuensis						
12	thompsoni						
13	pakistani						
14	israelensis						
15	indiana						
16	dakota						
17	tohokuensis						
18	kumanotoensis						
19	tochigiensis						
20	colmeri						
20	yunnanensis						
20a20c	pondicheriensis						
22	shodogiensis						
	wuhanensis						
	not identified		1				1
	TOTALS	9	10	4	7	3	33

[a]Number in parentheses indicates the appropriate category number for the PR range.

Table 11.--Category 2. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against fourth instar SBW with a potency ratio 0.75 or less.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
350	1.89 (1.06-2.72)	5.70 (2.74- 9.87)	0.41	1, thuringiensis
561	2.67 (1.36-3.99)	13.27 (7.81-20.46)	*0.31	1, thuringiensis
338	2.14 (1.29-3.00)	3.39 (1.52 -5.72)	0.69	3a3b, kurstaki
136	1.97 (0.83-3.10)	3.59 (0.72- 6.55)	0.57	4a4c, kenyae
278	2.37 (1.19-3.54)	12.92 (7.83-22.10)	*0.37	4a4c, kenyae
248	2.14 (1.30-2.97)	7.83 (4.50-12.78)	0.65	7, aizawai
858	3.32 (1.63-5.00)	65.06 (44.45-89.09)	*0.08	7, aizawai
864	3.85 (1.85-5.85)	18.67 (5.70-28.66)	*0.16	7, aizawai
537	2.20 (0.73-3.67)	6.41 (3.76-20.29)	0.29	9, tolworthi

*Mean LD_{50} of the standard was used.

Table 12.--Category 3. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against fourth instar SBW with a potency ratio between 0.75 and 1.24

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
703	1.73 (0.56-2.91)	11.01 (6.31-52.24)	*0.87	1, thuringiensis
083	2.15 (0.95-3.36)	2.94 (1.38- 4.70)	1.22	3a, alesti
087	2.18 (1.71-2.66)	21.71 (12.75-38.91)	*0.86	3a3b, kurstaki
262	1.84 (0.98-2.70)	13.80 (4.45-28.43)	0.80	3a3b, kurstaki
263	1.43 (0.45-2.40)	9.21 (4.19-44.86)	*1.04	3a3b, kurstaki
332	2.03 (0.59-3.48)	4.00 (0.19- 7.95)	*1.21	3a3b, kurstaki
339	2.55 (1.21-3.90)	8.09 (4.49-13.37)	*0.89	3a3b, kurstaki
352	2.20 (0.77-3.63)	4.87 (0.64- 8.82)	*0.99	3a3b, kurstaki
538	2.28 (0.79-3.76)	2.35 (0.62- 3.91)	0.79	9, tolworthi
582	1.83 (0.67-3.00)	8.92 (5.17-25.71)	*1.07	not identified

*Mean LD_{50} of the standard was used.

Table 13.--Category 4. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against fourth instar SBW with a potency ratio between 1.25 and 2.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
581	2.50 (0.99-4.01)	7.00 (4.41-18.45)	*1.36	1, thuringiensis
337	2.58 (1.25-3.91)	5.35 (3.35- 9.73)	*1.35	3a3b, kurstaki
549	2.99 (1.38-4.61)	2.99 (1.52- 4.53)	*1.39	4a4c, kenyae
137	2.58 (1.26-3.91)	2.07 (0.89- 3.17)	1.73	7, aizawai

*Mean LD_{50} of the standard was used.

Table 14.--Category 5. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against fourth instar SBW with a potency ratio between 2.01 and 3.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
244	3.60 (1.79-5.40)	1.88 (1.18- 2.48)	2.71	3a3b, kurstaki
562	2.78 (1.33-4.24)	2.89 (1.77- 4.47)	*2.37	3a3b, kurstaki
923	2.33 (1.25-3.41)	2.63 (1.68- 4.46)	2.02	3a3b, kurstaki
551	1.98 (0.95-3.02)	2.68 (1.53- 5.70)	*2.56	4a4c, kenyae
249	1.76 (0.61-2.90)	2.10 (0.09- 4.74)	*2.30	7, aizawai
283	3.89 (2.25-5.52)	3.25 (2.22- 4.42)	*2.94	7, aizawai
855	1.89 (0.71-3.07)	6.06 (3.22-11.60)	2.14	7, aizawai

*Mean LD_{50} of the standard was used.

Table 15.--Category 6. Slope, LD_{50}, and their associated 95% confidence intervals for individual NRRL-HD strains of B. thuringiensis bioassayed against fourth instar SBW with a potency ratio greater than 3.00.

HD #	SLOPE (95% CI)	LD 50 (95% CI)	PR	SEROVAR
		(IN UG/ML)		
290	2.89 (1.36-4.43)	3.18 (1.93-5.33)	*3.00	1, thuringiensis
545	3.09 (1.95-4.22)	1.37 (0.87-1.99)	*5.01	3a3b, kurstaki
293	1.56 (0.58-2.54)	2.11 (0.27-4.64)	*4.53	4a4c, kenyae

*Mean LD_{50} of the standard was used.

Table 16.--Evaluation of commercially available formulations of BT against GM, 1981 through 1986

Manufacturer	Material	Slope (95% CI)	LD_{50} (95% CI)	PR
1981				
Biochem Products	Bugtime (Pdr)	3.03 (2.06-4.01)	24.65 (17.74- 39.26)ug/ml	0.72
1982				
No new commercial materials tested.				
1983				
Biochem Products	Bactospeine WPV	2.40 (1.07-3.74)	12.62 (8.87- 37.03)ug/ml	0.43
	Bactospeine	3.76 (2.51-5.02)	122.00 (100.50-163.90)IU/ml	0.63
	Bactospeine F.C.	4.60 (3.34-6.06)	124.37 (104.08-167.96)IU/ml	0.72
	Futura	4.79 (3.26-6.31)	127.30 (104.58-183.60)IU/ml	0.77
Sandoz, Inc.	Thuricide 32LV	3.71 (2.18-5.24)	173.77 (137.37-282.70)IU/ml	0.38
1984				
Abbott Labs	Dipel 6L	1.57 (1.04-3.09)	36.52 (18.78- 50.75)IU/ml	3.18
	Dipel 8L	2.29 (1.22-3.36)	81.02 (54.47-123.92)IU/ml	1.73
Sandoz, Inc.	Thuricide 32LV	4.36 (3.05-5.67)	144.71 (118.59-194.32)IU/ml	0.49
	Thuricide 48LV	4.97 (3.62-6.31)	126.02 (98.18-185.42)IU/ml	0.63
	Thuricide 64LV	5.08 (3.47-6.69)	154.77 (135.10-180.87)IU/ml	0.68
Biochem Products	Bactospeine	5.77 (5.09-7.44)	218.70 (185.03-294.57)IU/ml	0.52
1985				
Sandoz, Inc.	Thuricide 24B	4.20 (2.76-5.64)	86.25 (70.67-108.30)IU/ml	0.69
	Thuricide 32LV	3.95 (2.80-5.11)	115.86 (97.50-173.76)IU/ml	0.83
	Thuricide 48LV	4.39 (3.17-5.61)	70.94 (56.76- 92.34)IU/ml	1.03
	Javelin	4.40 (3.36-5.45)	48.31 (39.66- 58.87)IU/ml	2.20
	Thuricide WG	3.18 (1.88-4.48)	1.99 (1.13- 2.76)ug/ml	2.53
Abbott Labs	Dipel 8L	2.58 (1.59-3.57)	33.05 (21.03- 44.91)IU/ml	2.47
1986				
Sandoz, Inc.	Javelin	4.40 (2.83-5.98)	31.55 (18.12- 41.46)IU/ml	1.87
Abbott Labs	Dipel 8L	2.62 (1.43-3.80)	31.72 (18.17- 45.38)IU/ml	2.10

Table 17.--Evaluation of experimental formulations of Bt against GM, 1981 through 1986.

Manufacturer	Material	Slope (95% CI)	LD_{50} (95% CI)	PR
1981				
Abbott Labs	HD-1 4L	2.60 (1.85-3.35)	63.60 (43.00 - 95.70)IU/ml	1.96
	HD-243 4L	2.85 (2.10-3.60)	136.32 (102.85 -184.93)IU/ml	1.34
	HD-263 4L	2.76 (2.05-3.50)	91.81 (68.22 -125.85)IU/ml	1.75
	HD-1(pdr)	3.75 (2.75-4.76)	1.37 (0.98 - 1.79)ug/ml	5.18
	HD-243(pdr)	2.81 (1.96-3.66)	3.50 (2.74 - 4.34)ug/ml	1.83
	HD-263(pdr)	3.57 (2.63-4.51)	2.28 (1.76 - 2.79)ug/ml	2.78
1982				
Biochem Products	Bugtime	2.83 (2.05-3.60)	3.68 (2.83 - 4.55)ug/ml	1.14
Abbott Labs	HD-1(pdr)	2.35 (1.66-3.04)	0.51 (0.31 - 0.73)ug/ml	8.51
	HD-243(pdr)	1.95 (1.31-2.59)	2.14 (1.50 - 3.38)ug/ml	2.08
	HD-263(pdr)	2.62 (1.89-3.35)	0.95 (0.69 - 1.26)ug/ml	4.71
Sandoz, Inc.	HD-1(pdr)	5.40 (3.90-6.90)	1.04 (0.86 - 1.24)ug/ml	5.97
	HD-243(pdr)	4.79 (3.54-6.03)	2.69 (2.10 - 3.82)ug/ml	2.62
	HD-263(pdr)	2.88 (2.05-3.70)	3.03 (2.09 - 4.98)ug/ml	2.26
	HD-545(pdr)	4.37 (3.10-5.63)	4.31 (3.71 - 5.11)ug/ml	1.27
	HD-551(pdr)	4.30 (3.22-5.38)	2.94 (2.23 - 4.40)ug/ml	2.12
	NRD-8(pdr)	3.25 (2.34-4.16)	1.70 (1.25 - 2.53)ug/ml	4.21
	NRD-10(pdr)	5.06 (3.71-6.40)	1.15 (0.96 - 1.38)ug/ml	5.21
	NRD-12(pdr)	5.66 (4.21-7.11)	1.29 (1.06 - 1.58)ug/ml	4.69
USDA Lab[a]	HD-1(lab batch)	3.52 (2.70-4.33)	0.79 (0.60 - 1.01)ug/ml	5.69
	HD-243(lab batch)	4.06 (3.20-4.92)	0.88 (0.69 - 1.09)ug/ml	5.99
	HD-263(lab batch)	6.11 (4.87-7.35)	1.95 (1.63 - 2.30)ug/ml	2.49
	NRD-8(lab batch)	5.54 (4.19-6.91)	1.07 (0.87 - 1.27)ug/ml	5.64
	NRD-10(lab batch)	5.20 (3.96-6.44)	0.93 (0.74 - 1.13)ug/ml	6.07
	NRD-12(lab batch)	4.94 (3.55-6.31)	1.19 (0.85 - 1.52)ug/ml	5.22
Abbott Labs	HD-1 4L	2.21 (1.48-2.95)	35.55 (20.48 - 51.92)IU/ml	2.38
	HD-243 4L	2.20 (1.54-2.86)	62.91 (41.14 - 89.21)IU/ml	1.23
	HD-263 4L	2.49 (1.72-3.25)	45.91 (27.43 - 66.24)IU/ml	1.64
Sandoz, Inc.	Thuricide 16B	4.54 (3.46-5.61)	101.99 (76.62 -128.37)IU/ml	0.69
	Thuricide 24B	3.85 (2.83-4.86)	108.23 (79.76 -138.27)IU/ml	0.65
	Thuricide 32BX	3.88 (2.85-4.91)	99.67 (67.93 -132.45)IU/ml	0.76
	Thuricide XHP	4.49 (3.54-5.44)	100.50 (81.11 -122.00)IU/ml	0.68

Continued

Table 17.--Continued

Manufacturer	Material	Slope (95% CI)	LD_{50} (95% CI)	PR
1983				
Sandoz, Inc.	NRD-12 32LV	5.51 (4.05-6.98)	50.36 (41.16- 58.67)IU/ml	1.73
	HD-1-32LV	4.59 (3.38-5.80)	128.20 (109.80-148.50)IU/ml	0.51
	NRD-10-32LV	5.17 (3.87-6.48)	59.05 (44.68- 72.27)IU/ml	1.10
	NRD-12-32LV	5.91 (4.54-7.28)	69.77 (55.14- 83.69)IU/ml	0.93
	HD-1-48LV	5.35 (3.83-6.88)	179.45 (148.15-249.95)IU/ml	0.41
	NRD-10-48LV	5.70 (4.35-7.05)	55.79 (45.46- 65.46)IU/ml	1.38
	NRD-12-48LV	6.08 (4.65-7.51)	59.16 (48.48- 69.11)IU/ml	1.25
	NRD-8(pdr)	6.07 (4.18-7.97)	1.81 (1.54- 2.04)ug/ml	3.64
	NRD-10(pdr)	7.16 (5.13-12.1)	2.14 (1.87- 2.49)ug/ml	4.01
	NRD-12(pdr)	5.22 (3.44-7.06)	1.87 (1.54- 2.21)ug/ml	4.15
Abbott Labs	HD-1(spr.dry pdr)	5.04 (3.61-6.47)	1.00 (0.87- 1.17)ug/ml	6.74
	NRD-12 "	4.28 (2.85-5.71)	0.75 (0.61- 0.87)ug/ml	8.96
	HP-1201	2.82 (1.64-4.00)	0.30 (0.18- 0.40)ug/ml	21.83
1984				
Sandoz, Inc.	SAN 415-A	6.48 (4.72-8.24)	4.29 (3.79- 4.82)ug/ml	1.28
	SAN 415-B	7.18 (5.34-9.01)	5.24 (4.72- 5.87)ug/ml	1.08
	SAN 415-C	7.63 (5.74-9.52)	7.12 (6.52- 8.19)ug/ml	0.78
	SAN 415-D	6.47 (4.69-8.28)	16.82 (14.86- 19.86)ug/ml	0.36
	SAN 415 32LV	4.85 (3.64-6.07)	36.54 (29.52- 43.64)IU/ml	2.08
Abbott Labs	ABG 6163(NRD-12)	3.29 (2.30-4.17)	30.14 (22.72- 37.96)IU/ml	3.04
Biochem Products	BactospeineHD-945	6.89 (5.16-8.62)	99.61 (87.96-111.10)IU/ml	1.11
1985				
Sandoz, Inc.	SAN415 SC 32LV	4.43 (3.35-5.51)	41.24 (33.71- 50.70)IU/ml	2.04
	SAN415 SC 353	5.25 (4.10-6.45)	37.09 (30.22- 44.13)IU/ml	2.44
	SAN415 SC 355	5.03 (3.83-6.23)	47.32 (39.84- 54.91)IU/ml	1.96
Abbott Labs	ABG 6158	2.26 (1.35-3.17)	35.24 (22.64- 54.92)IU/ml	2.23
1986				
Sandoz, Inc.	SAN415 32LV	5.69 (4.03-7.34)	24.76 (19.53- 29.15)IU/ml	2.49
	SAN415 SC 363	5.82 (4.25-7.40)	57.51 (47.87- 66.00)IU/ml	1.00
Abbott Labs	ABG 6167	3.10 (1.64-4.54)	33.04 (24.20- 40.59)IU/ml	1.85
Biochem Prod.	FC 48BP	5.12 (3.65-6.60)	49.46 (43.19- 57.41)IU/ml	1.12
	EFC 64	2.87 (1.89-3.86)	73.30 (58.35- 92.40)IU/ml	0.81

[a]Prepared at the USDA Forest Service, Northeastern Forest Experiment Station, Center for Biological Control of Northeastern Forest Insects and Diseases (Dubois, 1968)

Table 18.--Evaluation of commercially available and experimental formulations of Bt against SBW, 1981 through 1986.

Manufacturer	Material	Slope (95% CI)	LD_{50} (95% CI)	PR
1981				
Abbott Labs	HD-243-4L	1.25 (0.62-1.89)	115.25 (38.17-250.53)IU/ml	2.19
1982				
USDA Lab [a]	NRD-8(lab batch)	2.43 (1.03-3.82)	0.48 (0.06- 1.00)ug/ml	16.47
	NRD-12(lab batch)	2.92 (1.57-4.26)	0.49 (0.34- 0.78)ug/ml	8.51
	HD-1 (lab batch)	2.27 (0.97-3.57)	0.16 (0.05- 0.26)ug/ml	26.06
	HD-243(lab batch)	2.20 (0.91-3.50)	1.43 (0.70- 2.51)ug/ml	2.92
	HD-263(lab batch)	2.10 (0.67-3.53)	3.19 (1.74- 14.83)ug/ml	1.31
Sandoz, Inc.	Thuricide XHP	2.12 (1.18-3.05)	37.04 (11.84- 65.43)IU/ml	2.63
1983				
Biochem Products	Bactospeine	5.53 (3.17-7.90)	160.30 (123.40-190.40)IU/ml	0.78
	Futura	3.31 (1.17-5.45)	106.85 (49.25-300.45)IU/ml	1.44
Sandoz, Inc.	HD-1(32)	1.94 (0.87-3.02)	159.60 (89.59-640.10)IU/ml	0.96
	NRD-12(32)	2.08 (1.02-3.15)	97.34 (61.19-212.30)IU/ml	1.59
	HD-1(48)	2.06 (0.62-3.49)	37.50 (8.18- 58.55)IU/ml	2.39
	NRD-12(48)	5.18 (3.44-6.92)	47.76 (35.83- 58.58)IU/ml	1.88
	NRD-8(pdr)	4.01 (1.76-6.26)	1.22 (0.91- 1.60)ug/ml	9.86
	NRD-12(pdr)	4.60 (2.10-7.09)	1.81 (1.47- 2.84)ug/ml	5.28
Abbott Labs	HD-1(pdr)	3.36 (1.36-5.36)	0.62 (0.24- 0.86)ug/ml	9.82
	NRD-12(pdr)	3.28 (1.21-5.35)	0.54 (0.15- 0.78)ug/ml	11.28
	HP-1201	2.88 (1.02-4.75)	1.39 (0.81- 2.15)ug/ml	3.91
1984				
Sandoz, Inc.	Thuricide 32LV	1.94 (0.85-3.01)	91.26 (54.08-239.00)IU/ml	1.26
	SAN 415	2.40 (0.97-3.84)	28.68 (6.50- 40.03)IU/ml	3.35
Abbott Labs	Dipel 4L	1.76 (0.69-2.84)	74.66 (42.11-226.00)IU/ml	1.57
	Dipel 6L	1.63 (0.51-2.76)	45.90 (17.01- 95.87)IU/ml	1.52
	ABG 6163	2.38 (1.32-3.45)	62.01 (39.35-103.49)IU/ml	1.48
Biochem Products	Bactospeine FC	1.80 (0.51-3.09)	38.91 (4.82- 68.86)IU/ml	1.65

[a] See footnote, Table 17.