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CHEMICAL CONTROL OF THE COFFEE BERRY BORER *Hypothenemus hampei* Ferrari

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ABSTRACT

The paper reviews the history of chemical control of *H. hampei* around the world, including results of field trials and laboratory bioassays of various insecticides against the pest.

Brazil pioneered the use of modern organic insecticides against *H. hampei* in 1947 with the aerial and mechanical application of BHC dust. The technique was soon adapted by Africa where BHC dust was replaced by wettable powder. Since the late 1960s, endosulfan has completely replaced BHC.

Field trials with 73 formulations of 54 different insecticides including 10 organochlorines (OC), 26 organophosphorous compounds (OP), 9 carbamates, 4 synthetic pyrethroids (SP) and 3 mixtures have revealed that only OCs provide good control of the pest. Laboratory screening of 39 formulations of 25 insecticides demonstrated high susceptibility of the pest to several OCs, OPs and SPs.

The need for developing more presistant formulations of some OPs and SPs, and for integrating chemical spraying with other methods of pest control are emphasized.

INTRODUCTION

The coffee berry borer *Hypothenemus hampei* Ferrari (Scolytidae : Coleoptera) was first recorded from African coffee beans in 1867, but recognized as a pest of the crop in Central Africa during the first decade of this century (Lepelley, 1968). It has since spread to all the coffee growing regions of the world, reaching the Americas (Brazil) in 1922 (Filho, 1927), Asia and the Pacific (Java), in 1909 and Jamaica in about 1977 (Johanneson, 1983).

A major pest of coffee, it attacks only 12 of the 60 species of the genus Coffea on a preferential basis (Tichelar, 1961). Laboratory and field studies have revealed that *C. arabica* var. *caturra* and *typica* are significantly more attractive and nutritionally more suitable to the migrant beetle and its' offsprings, than var *geisha* (Boothe, 1987; Reid, 1987).

The damage is caused by the feeding stages of H. hampei, the migrant female adult and the F_1larvae. Strangely enough, the damage is usually restricted to only one of the two beans of a berry. The pest is thus capable of destroying just over 50% of the beans, even if the infestation of the berries is about 100%. Estimates of losses vary according to the method of assessment, level of infestation and quality of coffee. Brazil had reported a loss of over 100 million cruzeiros to its 1946 crop (Toledo, 1948), Guatemala lost only about 8% of her export earnings in 1970-1971 (Paz and Leon, 1972), and Jamaica had over 20% of export coffee, equivalent to US$1.9 million destroyed by the pest in 1980-1981 (Reid and Mansingh, 1985). Infestation of immature fruits may lead to about 6 to 18% of abscission (Kranz et al, 1978; Reid and Mansingh, 1985).

During the first half of the twentieth century, natural enemies and cultural practices were employed to control the pest. With the advent of modern organic insecticides in the 1940s, Brazil pioneered the use of chemicals against the berry borer, by applying BHC dust in selected plantations (Sauer, 1947; Sauer et al, 1947). The success of the trials led to the wide scale application of the chemical in Brazil (Seixas 1948). Since then, at least 73 different formulation of 54 insecticides have been tested in field experiments with varying results. Extensive laboratory screening of 39 formulations of 26 insecticides has provided excellent data for selecting insecticides for further field trials.

Various authors, such as Seixas (1948), Sauer (1947), Sauer et al (1947), Teledo et al (1948), Duval et al (1948), Gomes (1948), Duval (1949), LePage and Geannotti (1950), Monti (1954), Schimitz and Carsinel (1957), Evans (1965), Ingram (1965) and Bardner (1978) have reviewed the success of organochlorines, particularly BHC and endosulfan against the berry borer in their respective countries. However, an exhaustive review of the available data on the effectiveness of different insecticides has been long overdue. Recently, Rhodes (1987) has compiled the available literature on the topic, which is being reviewed critically in the present paper.

Field Evaluation of Insecticides

Although the results of field trials with 173 formulations of 54 different insecticides including 10 organochlorines (OC), 26 organophosphorous compounds (OP), 9 carbamates, 4 synthetic pyrethroids (SP) and 3 mixtures of insecticides are summerized in Table 1, their comparision is rendered difficult by the lack of information on the technique of application, time of application in relation to crop phenology, dosage of active ingredient, criteria and time of assessment of effectiveness, and environmental conditions during experimental period. However, certain general conclusions may be drawn from these data.

Table 1. Results of field trials of various insecticidal formulations for the control of c ffee berry borer <u>Hypathenumus hampei</u> Ferr

Formulatio s Common Name	Trade Name	Effectiveness	Reference
ORGANOCHLORINES			
Aldrin	Aldrin EC	Fair	6, 8, 35
	Aldrin D	Low	51
Benzene hexachloride	r-BHC D	High	2, 3, 5, 6, 7, 8, 10, 12, 17, 21, 30, 31, 33, 35, 37, 39, 44, 51, 52, 53
	Lindane EC	High	20, 21, 30, 31, 54
	Cafe sana EC	High	43, 45, 49
Chlordane	Chlordane EC	None	2, 7, 10, 12, 35
	Chlordane D	None	10, 12, 35
DDT	DDT EC	High	35, 50
	DDT D	High	35, 50
Dieldrin	Dieldrex EC	None	2, 3, 13
	Dieldrin EC	High	7, 10, 12
	Dieldrin D	Repellent	22, 30
	Dielderol EC	High	25, 32, 33
	Malex EC	High	2, 3, 12
Endosulfan	Thiodan EC & dust	High & repellent	2, 3, 5, 11, 12, 13, 14, 19, 20, 21, 22, 23, 26, 27, 30, 31, 34, 36, 38, 39, 41, 42, 46, 53, 54
Endrin	Endrin EC	Fair	13, 16, 33, 51
Heptachlor	Heptachlor D	High	7, 10
Isobenzene	Telodran EC	High	24
Toxaphene	Camphechlor EC	High	7, 19, 22, 28
ORGANOPHOSPHOROUS COMPOUNDS			
Azinophos methyl	Gusathion EC	High	5, 23
Carbophenothion	Trithion EC	Little & repellent	2, 21
Chlorfenvinphos	Chlorfenvinphos EC	Fair	28
	Birlane EC	High	5, 20, 21
Chlorpyrifos	Lorsban EC	Fair	17, 28
Dicrotophos	Bidrin EC	Moderate	5, 18, 23

Table 1 contd.

Formulations Common Name	Trade Name	Effectiveness	Reference
Dimethoate	Perfekthion EC	Low	3, 5, 52, 54
	Rogor EC	Low	3, 52
Disulfoton	Disyston G	Little	14, 22, 26, 54
Dowco 214	Dowco EC	Low	20
Ethion	Ethion EC	Low	5, 26, 27
Fenitrothion	Fenitrothion EC	Low	24, 26, 27, 30, 39
	Sumithion EC	Low	5, 39
Fenthion	Labaycid EC	Low	5, 12, 30, 31, 38
Fenthoate	Diodol EC	None	11
	Fenthoate EC	Fair	5
Heptenofos	Hostaquick EC	Low	20
Isoxathion	Karphos EC	Low	4, 20
Methomyl	Lannate EC	Moderate	20
Leptophos	Phosvel EC	Fair	5
Monocrotophos	Azodrin EC	Low	5
	Nuvacro SE	Low	5
Omethoate	Folimat	Fair	20, 22
Parathior	Parathion EC	High	35, 51
Parathior methyl	Meth. Par. EC	High	35, 51
Phazolone	Zolone EC	Moderate	20
Phorate	Phorate G	Little	29
Phosmet	Imadan EC	Little	2, 12
Phoxim Valexon EC	Valexon EC	Low	37
Trichlorfon	Dipterex SP	Low	5, 11, 20, 30
	Hoc2960 EC	Low	30, 32
Triazophos	Hostathion EC	Low	5, 20, 27
Vamidithion	Kilval EC	Low	5
CARBAMATES			
Aldicarb	Temik G	Little	14, 22, 36, 54
Bendiocarb	Ficam SP	Low	26, 27
Carbaryl	Sevin D	Moderate	3, 11, 13
	Dicarbam EC	Fair	3, 11
Carbofuran	Furadan SC	Fair	14, 22, 26, 54
Cartap	Cartap EC	Low	20
Isolan	Isolan EC	Moderate	37
Isoprocarb	Entrofolan WP	Low	31
Mercaban	Murfotox EC	Fair	5
Methomyl	Lannate WP	Fair	5
Mexacarbate	Zectran WP	Low	2, 12

Table 1 contd.

Formulations Common Name	Trade Name	Effectiveness (a)	Reference (b)
Propoxur	Unden WP	Low	5
Thiodicarb	Thiodicarb SC	Low	26, 27
SYNTHETIC PYRETHROIDS			
Cypermethrin	WL43467 EC	Low	1, 19, 20, 21, 22
Decamethrin	Decis EC	Little	1, 19, 20, 44
Fenvalerate	Sumicidin EC	Little	1, 4, 20, 21, 22
Permethrin	Permethrin EC	Little	1, 4, 20, 22
MIXTURES			
Carbaryl & Tniodan	Sevidan EC	Moderate	26, 27
Ethon & lindane	Etanox EC	Moderate	20
Malathion & fenitrothion	Ambithion EC	Low	20, 31

(a) Gradings of high, moderate, fair, low, little and none represent 75 - 95, 50 - 74, 30 - 49, 15 - 29, 5 - 10 and 0 - 4 percent mortality of *H. hampei*.

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49. Ruegg et al, (1977)
50. Sauer et al, (1947)
51. Schmitz & Cristinel, (1957)
52. Seixas, (1948)
53. Yoko Yama et al, (1977)
54. Zarate et al, (1977)

Firstly, only the organochlorines are effective against the berry borer, though some organophosphorous compounds may be used as alternatives. Carbamates, except carbaryl and synthetic pyrethroids are almost completely ineffective in controlling the pest.

Secondly, different formulations of an insecticide may vary in their effectiveness against H. hampei. For instance, r-BHC was found to be better than lindane, and dieldrin > dieldrol > dieldrex = malix (Almeida and Cavelanti, 1964; Amaral and Oliviera, 1974), perfekthion > rogor (Alvarenga and Paulini, 1975) and thiodan EC35 > tiovel (Reid, 1987).

Thirdly, EC, dust, WP and SP formulations of various insecticides were equally effective but systemic insecticides such as vamidithion (Alvarenga and Paulini, 1975) and granular disulfoton (Ferriera et al, 1977), phorate (Heinrich and Nato, 1967) and aldicarb (Zarate et al, 1977) were ineffective against the berry borer.

Among the OCs, BHC, DDT, dieldrin endosulfan, heptachlor, isobenzene and toxaphene were highly effective in reducing infestation by about 75 to 100%, aldrin and endrin provided only 30 to 49 protection, whereas chlordane was completely ineffective (Table 1). Recently Reid (1987) reported that single application of endosulfan at a rate of 200, 300, 500 and 650 g/ha reduced the infestation of test plots in Jamaican plantations by 68 to 88%.

Almost all the OPs, carbamates and SPs were ineffective against H. hampei, due to their short persistance. Only parathion and methyl parathion were toxic enough to the pest to provide 75 to 100% reduction in infestation. Dicrotophos (bidrin), methomyl (lannate) and phazolone were only moderately effective (Table 1). Carbaryl provided some protection, all the four SPs were completely ineffective whereas mixtures of carbaryl and thiodan and ethion and lindane reduced the infestation by 50 to 74%.

Frequency and Timing of Applications

Investigations on the minimum numbers of application of insecticides during one cropping season, for otaining maximum yield, were started in the mid-1960s and are still continuing in different countries (Boncato and Gadia, 1967; Ingram, 1968; Amante et al, 1971; de Lima et al, 1974; Mariconi et al, 1974; Reid, 1987). For Brazilian conditions, Amante et al (1971) recommended only one application of BHC. In Africa, Ingram (1968) found that one application of endosulfan at a rate of 0.2% was as effective as two application at 21 or 26 days interval. Almeida et al (1966 and Alvarenga and Paulini (1975) tried 1 to 5 frequencies of application at 10 to 50 day intervals, without any siginficant differences. Zarate et al (1977) obtained inconsistent results with different rates of endrin, BHC and dieldrex at first and second applications. Morallo-Rejesus et al (1981) reported highest yield from plots treated with two applications of endosulfan (0.75 kg/ha) or chlorpyrifos (0.5 kg/ha) at 6 week interval, provided the first spraying was done at the "mung bean" stage of the beans.

Reid (1987) reported that in Jamaican lowland plantations, a single application of 200, 300, 500 or 650 g/ha of endosulfan provided good control of H. hampei for at least 12 weeks. However, a second application at 4 or 8 week interval extended the protection for over 20 weeks, or the entire season. The relative index of effectiveness for the four doses ranged from 1.89 to 2.26 for single spray, 2.13 to 2.3 for two applications, 2.06 to 2.48 for three applications at 4 weeks interval, and 1.99 to 2.34 for two applications at 8 weeks interval. The effect of dose within different frequencies was not significantly different from each other, though were significantly ($P > 0.001$) better than the controls. Earlier, de Lima et al (1974) had reported better results with two or three spray cycles than one.

Timing of first application in relation to crop phenology was found to be critical in controlling the pest. Generally, the best results are obtained when young berries (7 mm long) with beans at "mung or chumbinho" stage are sprayed (Paz and Dardon, 1974; Zarate et al, 1977; Morallo-Rejesus et al, 1981).

Laboratory Bioassay

In their pioneering work on the laboratory screening of insecticides against H. hampei, Sauer et al (1947) demonstrated high susceptibility (98 to 100% mortality)of the beetle to 5% DDT or BHC dust. Later, Lepage and Gianotti (1950) and Schmitz and Crisinel (1957) assayed 5 OCs and found DDT, BHC, dieldrin and endrin to be almost equitoxic whereas chlordane was found to be completely ineffective.

Almost a quarter of a century later, Rhodes and Mansingh (1981; 1985) Mansingh and Rhodes (1983; 1985) and Rhodes (1987) provided data on the bioassay of 34 formulations of 24 insecticides for their efficacy and residual toxicity against different developmental stages of H. hampei, in green, ripe and dry berries. The 26 hours LC_{50} data, obtained by dipping the infested berries in emulsions of different concentrations of a formulation, are presented in Table 2.

Contrary to the field data, the inherent toxicity of the OCs, OPs, carbamates and SPs was found to be very high under laboratory conditions. In the green berries thiodan EC35 was the worst toxic formulation, followed closely by perfekthion > carbicron > decis > actellic > basudin. Lindane and dieldrin were far behind in the order of toxicity. Strangely enough, fenitrothion and chlorpyrifos were only about 0.005 and 0.001 times as toxic as thiodan EC35.

The relative toxicity of an insecticide to H. hampei may depend upon the location of the pest in the berry. The LC50 balues of all the formulations tested were far less when the borers were in pulp than in endosperm; the differences being about 254-, 197-, 183- and 158-fold for carbicron, thiodan EC35, perfekthion and decis respectively, and about 11- to 62-fold for other formulations (Table 2; Rhodes and Mansingh, 1981).

Residual Toxicity

The toxicity of several formulations increased with time, suggesting different rates of penetration in the berry. Oata obtained on treated berries which were then allowed to be infested with adult female beetles in glass vials, at regular intervals for 30 days after treatment, revealed that the 7 day LC50 values of the formulations were about 4- to 87-fold less in green berries and 5- to 96-fold less in red berries than the 26 hour LC50 values (Mansingh and Rhodes, 1985; Rhodes, 1987). Such major differences (-fold, figures parentheses) were noticed for lindane (87-) > chlordane (83-) chlorfenvinphos (69-) > tiovel (65-) > bidrin (46-) > basudin (42-) > folimat > malathion > nexagan > nexian (39- to 34-) > carbicron (27-) > actellic (25-) > thiodan EC35 (22-) > ciodrin (19-) > dimilin (17-) and others (listed in Table 2), less than 10-fold.

The penetration of the formulations was much slower in red ripe berries than in green ones, as is reflected by great differences in the 26 hours and 7 day LC50 values. The toxicities of methoxychlor, lindane, chlordane, kelthane, methomyl, azodrin, dursban, tiovel, aldicarb, gardona, bidrin and chlorpyrifos were increased by 96-, 94-, 92-, 88-, 83-, 77-, 75-, 72-, 68-, 68-, and 63-fold respectively; folimat and fenitrothion had registered an increase of 58-fold, while all others (Table 2) were 50- to 28-fold more effective, except thiodan EC35 and decis which showed only 21- and 4-fold difference respectively between the 26 hour and 7 day LC50 values.

The LT50 values (time for residual toxicity to inflict 50% mortality) calculated from data obtained for 30 days after treatment of the berries, suggest that lindane persisted the longest in the berries, followed by thiodan EC35 > perfekthion > thiodan EC3 > tiovel > demethoate > malathion > rogor > decis > belmark; respective LT50 values being 27.7, 18.8, 18.2, 17, 15, 14, 12.6, 10.6, 9 and 9 days.

Table 2. Twenty-six hour LC_{50} values of various insecticidal formulations to H. hampei adults in whole green berry, green pulp and endosperm of C. arabica L.

Formulations	$LC_{50} \times 10^3$ Whole berry (B)	Pulp (P)	Endosperm (E)	Difference E/P	E/B
Thiodan EC35	0.32	0.016	3.15	196.9	9.8
Perfekthion EC60	0.40	0.019	3.47	182.8	8.7
Carbicron SC100	0.44	0.022	5.59	254.0	12.7
Decis EC25	0.52	0.075	11.97	157.5	22.9
Actellic EC50	0.88	0.224	12.3	54.9	14.8
Basudin EC60	0.90	0.246	15.34	62.2	17.0
Belmark EC10	1.16	0.268	16.51	61.6	14.2
Ciodrin EC85	1.24	0.276	16.7	60.5	13.5
Thiodan EC3	1.31	-	-	-	-
Malathion EC60	1.42	0.327	16.86	51.6	11.8
Folimat SC50	2.17	0.371	18.52	49.5	8.5
Bidrin Tech.80	2.32	0.591	20.26	34.3	8.7
Aldicarb Tech.99	3.12	-	-	-	-
Lindane Tech.96	3.27	0.672	22.7	33.8	6.9
Nexion EC40	4.56	1.819	34.22	18.8	7.5
Tiovel EC3	4.74	2.301	43.37	45.6	10.3
Dursban EC23.5	6.27	-	-	-	-
Supona Tech.96	11.41	2.43	59.6	24.5	5.2
Methomyl Tech.99	11.81	-	-	-	-
Kelthane Tech.99	12.83	-	-	-	-
Chlordane Tech.99	16.02	7.64	85.9	11.2	5.4
Aldrin Tech.94	17.36	-	-	-	-
Dimilin WP25	18.05	8.42	97.8	11.6	5.4
Chlorfenvinphos EC40	20.44	10.2	130.2	12.8	6.4
Phosdrin EC69	20.83	-	-	-	-
Sevin WP85	21.12	-	-	-	-
Methoxychlor Tech.91	21.53	-	-	-	-
Dieldrin Tech.97	25.26	-	-	-	-
Nexagon EC40	34.03	11.39	339.7	34.8	10.0
Azodrin Tech.78	43.45	-	-	-	-
Fenitrothion Tech.96	69.97	20.33	1397.6	64.7	20.0
Bimarit EC30	136.6	-	-	-	-
Chlorpyrifos Tech.99	280.6	-	-	-	-
Gardona Tech.98	959.53	-	-	-	-

Relative Susceptibility of Developmental Stages

Generally, the tolerance to insecticides is greatest in eggs, followed by adult and larval H. hampei, the differences between the developmental stages being 1.1 to 2.7-fold. The reported higher susceptibility of eggs in red berries than adult or larval stages may be an experimental artifact, reflecting the presence of relatively advanced stage embryo in the ripe than in the green berries (Mansingh and Rhodes, 1983).

Toxicity of Different Formulations of an Insecticide

Data in Table 2 show that different formulations of endosulfan (thiodan and tiovel), dicrotophos (carbicron and bidrin), bromophos (nexagan and nexion), chlorpyrifos (dursban and technal grade), chlorfenvinphos (supona and technical grade) and dimethate (perfekthion technical grade and rogor) varied significantly in their toxicity to H. hampei in the pulp or endosperm of green, red and dry berries (Rhodes and Mansingh, 1981; Mansingh and Rhodes, 1983, 1985; Rhodes, 1987).

Thiodan EC35 was about 4 and 15-fold more effective than thiodan EC3 and tiovel respectively against the borer in green whole berry, 5.5 and 18.5-fold in red endosperm and 5 and 15.5-fold in dry endosperm, respectively. In the pulp of green berries, thiodan EC35 was about 144 fold more toxic than tiovel but in the endosperm, the difference was only about 15-fold.

Carbicron was about 27, 5 and 4-fold more toxic than bidrin to borers in green pulp, green whole berry and endosperm of green, red or dry berries respectively. Similarly, nexion was 7 to 10-fold more toxic than nexagan, dursban, about 45-fold more than chlorpyrifos and supona was less than 2-fold more effective than chlorfenvinphos. The persistence and residual toxicity of perfekthion > dimethoate > rogor, the differences being 1:1.3:1.7

Chemical Control of H. hampei

After trying for nearly quarter of a century to find an effective means of controlling H. hampei, the Brazilians were rewarded with the finding that BHC dust had eradicated the pest from experimental plots (Sauer et al, 1947). Encouraged by the results, they wasted no time in introducing wide spread mechanized and aerial application of 1 to 2% BHC dust in plantations in the same year (Sauer, 1947; Seixas, 1948; Duval, 1949; Lepage and Gianotti, 1950).

In the late 1940s and early 1950s, BHC dust was tried in Africa also but failed to provide satisfactory control because of more frequent rainfall pattern. Replacement of dust with wettable powder solved the problem and BHC WP became the most widely used insecticide against H. hampei in Africa (Monti, 1954).

Continuous and wide spread use of BHC in Brazil caused suspicion of development of resistence to the chemical by the borer, but Figueirado et al (1959) could not confirm it. However, the scare was enough for Africans to use parathion and methyl parathion successfully for a few years (Monti, 1954; Schmitz and Crisinel, 1957). Dimethoate was also tried in Brazil with limited success (Almeida et al, 1966; Alvarenga and Paulini, 1975).

The adverse effects of BHC on the flavour of coffee (Amaral et al, 1973) and the increasing outcry about the environmental hazards of its residues led to virtual abandonment of the OC by the coffee farmers. Since the late 1960s, BHC has been completely replaced by endosulfan applied at the rate of 0.5 to 0.75 kg/ha in Brazil, Peru and Philliopines (Zarate et al, 1977; Morallo-Rejesus et al, 1981), or at 0.35 kg/ha in Central America and the Caribbean (Reis et al, 1974; Reid, 1981). Usually, two sprayings at 4 to 6 week intervals is recommended, but must be sychronized with crop phenology.

Sooner or later, alternatives to endosulfan will have to be found. Already, there is reports of resistance to insecticide in H. hampei populations in New Caledonia (Miyata, personal comm., 1988). Two applications of sevidan WP (thiodan + carbaryl) at 1.4 kg/ha or endrin (0.73 L/ha have been suggested by Zarate et al, (1977). However, these formulations are unlikely to provide long-term answer; endrin is banned in many countries and reduced dosage of thiodan may increase build up of resistance in the pest.

The solution may be found in specially formulated OPs such as dimethoate, diazinon or actellic, with greater penetration and stickability on the berry surface, and controlled release. The pest is susceptable to a number of OPs, SPs and carbamates but the problem is to develop a formulation which would enable these compounds to persists for at least 3 weeks in the field. It must, however, be remembered that no insecticide can provide satisfactory results unless it is a component of integrated management of the pest and pesticide.

Bergamin (1944) had emphasized the need for 'repasse' - ground sanitation and stripping of unharvested berries from trees, for eliminating residual population of H. hampei, as a key to successful control of the pest. Indeed many Brazilian plantations manage the pest culturally and use insecticide only when needed (Personal observations, 1981). Bardner (1978) has also highlightened the successful management of the berry borer in Africa, mainly by cultural methods.

Unscientific and untimely spraying of trees with endosulfan and ground with chlordane provided absolutely no control of H. hampei in Jamaica and of the distribution of the pest continued unabated in the island during the late 1970s (Rhodes and Mansingh, 1986). In her classical studies on the management of the pest, Reid (1987) has developed various unathematical models wihich used further validation and possible modifications. Her results confirm the importance of synchronizing the endosulfan spraying with crop phenology and integrating it with (1) pruning of trees to make them accessable to applicators and for better coverage of berries with insecticidal droplets, (2) ground sanitation and regular removal of fallen infested berries, (3) general crop husbandry, and (4) stripping of unharvested berries at the end of crop season.

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