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Toxicity and Acceptance of Some Pesticides Fed to Parasitic Hymenoptera and Predatory Coccinellids[1]

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ABSTRACT

A survey of our present knowledge of the most suitable pesticides and their most effective use in integrated chemical and biological control has indicated that stomach poisons have several advantages. A review of the processes through which the favorable selectivity of stomach poisons on pests and natural enemies may arise suggested the possibility of transforming contact pesticides into stomach poisons to increase their specificity and advantageous selectivity to natural enemies. A method of measuring stomach-poison activity exclusive of contact effect was developed and used to assess the effects of commercial formulations of 61 common pesticides as food contaminants to 2 representative species of parasitic Hymenoptera and 2 coccinellids. Data on the acceptance and toxicity of 2 concentrations of each pesticide are presented. Most materials were at least in part gustatory repellents. Mortality was often unexpectedly rapid, sometimes occurring following tasting and immediate rejection. Many chlorinated hydrocarbons were innocuous as stomach poisons to the natural enemies tested. The most toxic materials were usually among those most poorly accepted. Since a taste of a violent poison was fatal, distastefulness of a very toxic material afforded no protection. Specificity recognizable among contact poisons was exaggerated with ingestion. A probable source of favorable natural-enemy selectivity seemed to lie in the high degree of inactivation of some pesticides in the digestive tracts of the natural enemies tested.

Previous studies on the effects of contact pesticides on a variety of natural enemies have provided some general guides for selection of the contact pesticides most suitable for use in integrated chemical and biological control, and to the best strategies for using these materials so that the natural enemies are protected (Bartlett 1963). Implicit in the development of these guides for the use of contact pesticides were 2 basic premises: (1) that the natural-enemy adults are the stages ordinarily most susceptible to pesticide destruction; and (2) that in considering the effects of pesticide treatment on a varied complement of natural enemies, nearly all the various kinds of natural enemies occurring on the treated crop must enjoy a blanket protection if one pest is not to be traded for another. Guides for the selection and use of contact poisons in integrated chemical and biological control as developed within the framework of these 2 premises may be summarized as (1) selection of materials that are extraordinarily toxic to the pests, i.e., essentially those with unusually high toxicity to the target pest and of ordinary or less toxicity to all the important entomophagous species; (2) selection of pesticides with the most fugitive toxic residues to accentuate the inherent advantages that many natural enemies enjoy because of their protected life stages; (3) use of chosen materials at dosages lowered to the point where they give somewhat less than 100% kill of the pests; and (4) directing placement of the contact pesticides insofar as possible so that they preferentially reach the target pest with least influence on natural-enemy reservoirs.

With only these few very general guidelines for the use of contact pesticides in integrated control, entomologists find themselves in the position of having to avoid most of the highly toxic, broad-spectrum, and persistent insecticides and being forced to rely upon what in essence are often our poorer insecticides. In addition, we must now recognize that the available number of narrow-spectrum, low-persistence insecticides suitable for our integrated control needs is not likely to be greatly expanded, since the pesticide industries now find the high developmental costs and limited markets for such products prohibitive (Persing 1965).

Faced with such restricted prospects for making effective use of contact poisons in integrated control it is imperative that other ways of implementing complementary chemical and biological control be developed, particularly those which might permit use of highly toxic insecticides. Our position then is clear. We should learn how to use our present arsenal of pesticides so that they will be especially available or accessible to our target pests *or* be particularly unavailable to or avoidable by the natural enemies.

To date very little practical attention has been given to the approach of specifically aiming pesticides at target pests or away from natural enemies. The principal effort seems to have been directed toward calling upon the pesticide industry to develop specific

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[1] Paper no. 1718, University of California Citrus Research Center and Agricultural Experiment Station, Riverside. Accepted for publication May 10, 1966.

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pesticides which can be directed exclusively at target pests, and in attempting to make outmoded and ineffective pesticides work in integrated control. Finally, however, we have arrived at the inevitable conclusion that contact poisons offer very few opportunities for exploiting most of our recognizable differentials between pests and natural enemies.

Meanwhile, considerable circumstantial evidence has accumulated suggesting that the stomach poisons seem to have certain intrinsic qualities favoring natural enemies, and that in addition they appear to offer exceptional opportunities for special manipulations to exploit unique behavioristic or functional differences which may exist between the 2 groups. These ideas lead us to a tractable research question. Can high-performance contact pesticides be transformed into stomach poisons, thereby increasing their specificity to target pests and their favorable selectivity to natural enemies?

Before proceeding to a detailed examination of the potentialities for the use of contacts as stomach poisons and to an assessment of the effects that such remodeled materials might have on natural enemies, it is desirable to briefly survey what we do and do not know concerning the favorable natural enemy selectivity of stomach poisons. The following 3 subheadings, therefore, will be devoted to reviewing the extent of our background information on how natural enemies are favored by stomach poisons, and what distinguishing features of feeding behavior or stomach-poison action actually differentiate pest activities and pest responses from those of natural enemies.

SOURCES OF FAVORABLE NATURAL ENEMY SELECTIVITY WITH STOMACH POISONS.—There has been very little interest in recent years in stomach poisons. As a result very little new information has been acquired concerning the differential effects of stomach poisons on pests and on natural enemies. It is clear, however, from the work done on this subject during the period of use of the old-line arsenical and fluoride pesticides, that such materials on the whole affected natural enemies much less severely than do the pesticides in common use today. It is unknown whether this favorable selectivity arose from the high physiological specificity of the early stomach poisons, from their general low toxicity and consequent lack of "overkill" effect, or from some innate difference in the availability of the materials to the pests and to the natural enemies.

Certain observations reported in the older literature strongly support the supposition that both parasites and predators do have some innate or inherent advantages over phytophagous pests in their ability to avoid or to survive stomach-poison action. It was early recognized, for example, that certain natural enemies somehow avoided the effects of dry particulate stomach poisons which were toxic to certain of the chewing pests (Henderson and Holloway 1940–43).[3] It was general knowledge that whereas the very young larvae of Lepidoptera were the stages most readily destroyed by stomach poisons, the surviving stages were those usually most subject to parasite attack; likewise it was observed that parasitized lepidopterous hosts often ceased feeding soon after parasite attack, so only the unparasitized hosts continued their feeding to be killed by the poison. It was also recognized that some internal parasites could complete their late stages of development in the bodies of hosts which had been killed by certain kinds of stomach poisons (Kirkpatrick 1937). The early workers in the field of natural enemy–pesticide relationships appeared to be almost unanimous in their belief that certain stomach poisons were detrimental to particular species of parasites and predators, the feeding or self-cleaning habits of which permitted accidental intake of the poison, whereas other species without such habits remained unharmed. Aside from these observations there were also a few indicative cases wherein early-day stomach-poison programs were recognized as producing outstanding pest control without appreciable upset of natural enemies. Some of the armyworm-bait programs were indicated as being in this category (Pemberton 1948) and the tartar emetic bait-spray program against citrus thrips was a similar operation with which no recognizable or recorded upset of natural enemies was associated (Henderson and Holloway[3]).

Since the period of use of the old-line insecticides, a few revealing but sometimes incompletely explained examples of differential pest, natural enemy selectivity arising from stomach-poison action have been noted. A particularly puzzling circumstance occurred during the Mediterranean fruit fly eradication campaign in Florida (Poucher 1964, Steiner et al. 1961). In this program there was an unexpectedly low general destruction of natural enemies considering the kind and quantities of pesticide employed. The reason the natural-enemy destruction ordinarily attributable to fruit fly bait treatments (Myburg 1948, Pelakassis 1963) failed to materialize and the reason virtually no pests were upset through deprivation of their natural enemies have not been explained. Although the specific attractiveness of the bait to the pest might account for this anomalous effect, other circumstances may have played important roles.

Today's systemic insecticides are illustrative of a well-defined avenue by which natural enemies avoid ingestion of a stomach poison which is directed specifically at phytophagous pests utilizing special feeding sites. Another closely allied mode of stomach-poison action has been suggested by the studies of Ebeling and Pence (1954) and Plaut (1964) wherein some pesticides applied only to the top surface of leaves were shown to be toxic to mites fed on the undersurface. Incomplete studies by the author along these lines suggest that certain pesticides empirically found to be exceptionally favorable to natural enemies may acquire their desirable attributes by virtue of a similar type of foliar penetration in conjunction with a rapid degradation of superficial deposits. Finally, there is some possibility that a few pesticides may be gustatory repellents to some natural enemies (Bartlett 1965).

These few examples illustrate some of the diverse ways in which the insecticidal effects of stomach poisons can be pointed toward target pests or away from natural enemies. Although there is evidence that the differential effects may arise primarily from toxicological specificity, it seems apparent that at times this selectivity could result from differences in the food preferences and feeding habits of the pests and natural enemies.

DIFFERENTIAL FEEDING HABITS OF PESTS AND NATURAL ENEMIES.—Directing the action of a stomach poison toward a phytophagous pest and away from

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the predominantly carnivorous natural enemies superficially would appear to be much simpler than it is. The complication arises from the fact that the distinctiveness between the supposed herbivorous and carnivorous diets of the 2 groups fades with rigorous examination of the feeding habits of the adult stages of the parasites and predators. Many of the adult parasites or predators are now known to obtain considerable quantities of their sustenance and reproductive nutrients from plant sources such as floral and extrafloral plant nectaries, pollens, fruit juices, and sap exudates. The other major apparent difference in feeding habits between natural enemy adults and agricultural pests, i.e., the preference of most of the natural enemy adults for liquid or semifluid foods, likewise does not always discretely divide the 2 groups. Most natural-enemy adults we know to feed, at least in confinement, on dry sugars through external digestive processes (Bartlett 1962); regurgitative processes being employed by the coleopterous predators, salivation by the hymenopterous parasites and by the hemipterous, neuropterous, and acarine predators, and both processes apparently being employed by some of the dipterous parasite adults.

It has been generally believed that in nature many adult parasites and some predator adults rely largely upon honeydew secretions of Homoptera for their primary sustenance nutrients. There is, however, a surprising lack of factual knowledge concerning the kinds and quantities of foods taken by the adults of most entomophagous species, and it is evident that much work is needed to establish the different patterns in both the food sources and in the feeding habits of adult natural enemies before we can hope to fully exploit the principle of poisoning those foods taken only by pest insects and not by natural enemies.

PHYSIOLOGICAL SPECIFICITY OF STOMACH POISONS TO PESTS AND NATURAL ENEMIES.—The dearth of information on the stomach-poison effectiveness of most of our currently used pesticides to phytophagous pests makes it difficult even to speculate on probable differences in physiological susceptibility between pests and natural enemies. Much of the oral-toxicity test data available on current pesticides for pest species has been obtained from trials with house flies, *Musca domestica* L.; *Drosphila;* Tephritidae; grasshoppers; and ants; and data from these sources are so confused by variations in acceptance, developed pesticidal resistance, and incomplete elimination of contact effects, that they often present a misleading index of the true physiological specificity of the material when ingested. The situation is even more confused with respect to specificity effects of stomach poisons on natural enemies. With wide differences in the oral uptake of pesticides by natural enemies being suggested from a diversity of physical habits such as cleaning of body parts, chewing out of coccoons, or feeding on contaminated honeydews and hosts, there is considerable doubt as to whether supposed differential effects might arise from physical or habitudinal rather than physiological differences. We have even less basis for judgment when we recognize that reports in the literature concerning the detrimental effects of the old-line stomach poisons on natural enemies are so very conflicting. From them we may either conclude that the different species of natural enemies are very specific in their pesticide responses or that the data is very inexact. The need then for precise information on the differences in physiological susceptibility of a variety of insects to today's pesticides is clear. Whereas this much-needed data on stomach poisons can be acquired in the laboratory, it should be kept in mind that physiologically induced specificity may at times be of less importance than that arising from the purely physical factors affecting ingestion.

OBJECTIVES OF THE STUDY.—In view of our limited knowledge of the sources of favorable natural enemy selectivity associated with stomach poisons, and of the specificity that may inherently reside in such poisons or which might be built into them as baits, it appeared desirable to seek foundational information on how numerous representative species of natural enemies were affected by ingestion of our most commonly used pesticides supplied as food contaminants. The immediate objectives of the trials were to determine which materials were effective stomach poisons, which were physiologically specific, and which might be distasteful to the natural enemies. The long-range goal of the study was to explore the possibilities of transforming some of our high-performance contact pesticides into effective stomach poisons so that in the latter form they might more easily be directed toward specific target pests or manipulated toward unavailability to natural enemies. The project was necessarily designed as a screening program to be conducted over a 3-year period as test insects became available. For the intended purpose the data did not necessarily have to be rigorously exact. The method had only to be precise enough for discernment of trends and general associations which could serve as sources of interpretive guidance for our long-range research program on the fundamentals of integrated chemical and biological control.

MATERIALS AND METHODS.—To obtain the desired information, a toxicological screening method was needed that would completely isolate stomach-poison effect from that of contact; that would measure acceptance and rejection of the pesticide as well as its toxic effect without the intercession of starvation effects; and that could be standardized to measure the effect of varying concentrations of the toxicants upon a variety of natural enemies, the hunger stress of which would vary from 1 test period to another.

For the study, adults of 2 species of coccinellids, the diaspidine scale-feeding *Lindorus lophanthae* (Blaisdell) and the mealybug destroyer *Cryptolaemus montrouzieri* Mulsant, were chosen as representative predators; and 2 species of hymenopterous parasites, the diaspidine scale-feeding *Aphytis melinus* DeBach [Aphelinidae] and the lecaniine scale-feeding *Metaphycus luteolus* (Timberlake) [Encyrtidae], were selected as representative parasites. The *Cryptolaemus* were obtained through the courtesy of a commercial insectary[4]; the other test species were reared in our laboratories. The choice of these insects was primarily based on the volume of previous knowledge of their responses to the pesticides as contact poisons, to the availability and ease of their insectary culture, and to their proven suitability as test insects.

Sixty-one pesticides were used as commercial formulations (i.e., with their incorporated surfactants) intimately mixed into a honey bait. The honey served

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[4] D. F. Henderson and J. K. Holloway. 1940–43. Manuscript reports. Effect of artificial control practices on natural enemies of insect pests. USDA Agr. Res. Serv. Insect Identification and Parasite Introduction Research Branch files, Washington, D. C.

as an arrestant or food attractant incorporating both sugars and water in proportions attractive to almost all natural enemies and to many pest insects. Each bait was tested at 2 concentrations of the poison in a commercial grade-A honey base (sp gr 1.256). The low concentration represented the dilution at which the poison would customarily be found in a spray-tank liquid when applied to orchard crops as a relatively high-dosage complete-coverage spray. In theory it simulated the concentration of a spray droplet from which a parasite or predator might imbibe during field application of the pesticide. The high concentration was 10-fold that of the low; in theory it represented a concentration of the poison which might be available to the natural enemies after dehydration of a 10% honey bait applied in a water spray. These concentrations afforded some reasonable possibilities for transposition to field use, being readily convertible from percentage (wt/wt) actual toxicant as a contaminant in the honey to ppm, or to pounds of actual toxicant/100 gal of honey by the equivalents 0.0954% = 954 ppm = 1.0 lb actual toxicant/100 gal honey.

Numerous procedures for feeding the contaminated honey were tested in preliminary experiments before a completely satisfactory method of isolating stomach poison effect from contact poison effect was found. The final procedure consisted of offering to a standard number of test insects a standard quantity of the contaminated food (plus a small amount of food dye) ad lib. in the form of very small droplets. The measured droplets of poisoned honey separated by at least 1 cm distance were offered to the test insects on wax paper for a selected period, after which the insects were given uncontaminated food for a toxicity assessment period of 4 days.

Tests were conducted in the following fashion: Preliminary trials having shown approximately how much pure honey each of the test species would consume in a 6-hr test period if prestarved for 12 hr, this amount (or number of measured droplets) of poisoned honey was taken as the standard quantity of food to be offered to each test group of a particular species. These quantities of poisoned honey in the tests and of unpoisoned honey in the controls were: 40 droplets of 1.0-mm diam for 20 *Cryptolaemus* adults, 40 droplets of 0.5-mm diam for 20 *Lindorus*, 20 droplets of 0.5-mm diam for 50 *Metaphycus*, and 20 droplets of 0.25-mm diam for 50 *Aphytis*. Each bait offering of measured droplets to be given to a standard number of test insects was prepared before the feeding by placing the droplets on a strip of waxed paper. Droplet size was measured under a micrometer. The test container was an organdie-covered test tube held before a ventilating fan to eliminate any possible fumigant vapors. Feeding was ad lib. until such time as all the unpoisoned honey in the control was eaten. Then the feeding period on the poisoned baits was terminated at once by replacing the wax papers containing the poisoned honey with others containing pure honey. An index of the acceptance of each poisoned bait was calculated as a percentage of the amount taken in a like period in the unpoisoned honey controls.

Following the toxicant feeding period each insect test group was held for 4 days at 50% RH and 80°F with pure honey as a food and daily mortality counts taken.

The quantities of bait offered to each species during the poison-feeding test period appeared to be reasonably accurate representations of the normal needs of each kind of test animal, based as they were on the amount consumed in preliminary tests of 6-hr exposure of prestarved insects. A starvation period of 12 hr for all insects before offering them the poisoned baits was necessary to reduce the vagaries owing to variable hunger stress and assure somewhat equal avidity among the insects from one time to another. In the tests all insects found the food within ½ hr, and multiple feedings by each individual were necessary for consumption of all the food offered. Although the preliminary trials indicated that 6 hr would ordinarily be required for complete consumption of the unpoisoned honey in the controls and hence termination of the feeding test period, in practice it was found that this period varied by ± 3 hr in different tests. The longest feeding periods in such cases were not so long as to cause starvation weakening of those insects which refused to feed on the poisoned food, and the shortest periods used were still sufficient to assure that the hunger of each individual could be satisfied.

The methods used had some obvious faults, the most disturbing being that of the variable dosage associated with different degrees of acceptance or rejection of the bait. Also the use of measured droplets in the feeding tests while tedious was indispensable for accurate measurement of bait acceptance. The dye added to the poisoned honey proved essential for explaining why the insects in some tests died extremely rapidly with little or no evidence of feeding. In such cases the consistent appearance of a perceptible trace of color in the oesophagus showed that death resulted from a mere tasting of the poisoned bait. Incorporation of the food dye not only demonstrated this trace poison effect wherever it occurred, but also provided visual evidence that there was no external contact of the insects with the poison bait other than upon the insect's mandibles. In this respect it should be pointed out that elimination of all the external contact effect of the pesticides in these tests was substantiated in the preliminary methods trials when aldrin and TDE, both having appreciable contact effectiveness, failed to show any toxicity despite ready acceptance of those poisoned baits.

In the data presented the measurements of acceptance are relatively imprecise with variations presumably owing to unavoidable differences in hunger stress. The toxicity results with most materials were, however, more exact and reproducible. Each of the 488 individual tests were repeated from 2 to 4 times to provide a simple mean value of the effects of each material at each concentration on a total of 40–80 individuals of each predator or 100–200 of each parasite species.

RESULTS AND DISCUSSION.—In Table 1, toxicity data is presented as H (high) if 50% of the insects (after correction for natural mortality) died within 1 day or less after their 1st exposure to the contaminated food; M (medium) if 50% died between 1 day and the termination of the 4-day observation period; L (low) if there was appreciable, but less than 50% kill after 4 days; and (0) if there was no detectable mortality at the end of the 4-day holding period. Variations between replicate tests are presented as ranges where different ratings were obtained in the various replicates.

Table 1.—Percent acceptance and toxicity ratings of pesticides fed exclusively as stomach poisons to certain hymenopterous parasites and coccinellid predators.

			Response to low concentration of toxicant in honey								Response to high concentration of toxicant in honey							
		% toxicant (act.) in honey w/w (low concn)	*Lindorus*		*Cryptolaemus*		*Metaphycus*		*Aphytis*		*Lindorus*		*Cryptolaemus*		*Metaphycus*		*Aphytis*	
Material	Formulation		Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.
Aldrin	40% WP	0.0477	68	O-L[a]	52	O	59	O	29	O-L	18	L	22	O	42	O-L	17	O-L
Aramite®[b]	15% WP	.0429	68	O	60	O	86	O	68	O-L	30	O	28	O	90	O-L	38	O-L
Azinphosmethyl	25% WP	.0477	13	H	8	M-H	22	H	13	H	2	H	3	H	2	H	5	H
Benzene hexachloride	10% γ WP	.0191 γ	84	O	40	L	59	O	78	O	21	L	21	L	47	L	55	O-L
Bidrin	7.5 lb tech/gal.	.0477	16	H	7	H	10	H	13	H	4	H	4	H	15	H	8	H
Bordeaux mixture	10-10-50 2 pkg.	3.8168	28	O	16	O	40	L	6	L-M	3	O	0	O-L	0	L	7	L
Calcium arsenate	70% $Ca_3(AsO_4)_2$	0.2863	30	O	20	L	70	L-M	77	M-H	10	L-M	41	H	28	M	9	H
Captan	50% WP	.0954	61	O	65	O	95	L	70	O	25	L	7	O	68	L	68	O-L
Carbaryl	50% WP	.0477	32	H	9	H	3	H	22	H	13	H	5	H	0	H	10	H
Carbophenothion	25% WP	.0239	39	O-L	40	O	79	O-L	100	M	3	O	2	O-L	50	H	29	H
Chlordane	40% WP	.0954	91	L	52	O-L	88	O	75	O-L	41	O-L	3	O-L	26	O	26	O-L
Chlorobenzilate	25% WP	.0239	88	O-L	59	O	90	O	58	L	11	O	4	O	8	L	12	L
Cryolite (natural)	95%	.2719	65	O	72	O	37	L-M	75	M	16	O-L	14	L	52	M	57	H
DDT	50% WP	.0954	79	O-L	36	L	35	O-L	48	M	14	O-L	15	M	12	L-M	8	M
Demeton	2 lb/gal EC	.0239	82	O-L	46	O-L	44	L	64	M-H	8	H	7	M-H	0	H	21	H
Diazinon	25% WP	.0477	66	O	48	L	87	H	77	M-H	10	O	6	L	10	H	10	H
Dicofol	18.5% WP	.0477	78	O	64	O-L	90	O	88	O-L	9	O	2	O	6	O	20	L
Dieldrin	50% WP	.0477	94	O	64	O	65	O-L	95	L	43	O	18	O	11	L	37	M-H
Dilan®[c]	25% WP	.0954	80	O	31	L	35	O-L	63	L	5	O-L	4	L-M	0	M	9	L
Dimethoate	4 lb/gal EC	.0477	87	M-H	35	M-H	32	H	29	H	13	H	8	H	46	H	18	H
Dimetilan	50% WP	.0477	100	L	30	O	41	O-L	54	M	30	L	9	M-H	10	H	19	H
Dinocap	25% WP	.0239	36	O	51	O-L	50	O-L	77	L	4	O	0	O	13	M	8	M
Dioxathion	25% WP	.0239	80	L	65	L	91	O-L	88	L	50	L	18	L	43	H	24	H
DN-111®[d]	20% WP	.0191	100	O	50	O	53	O	100	O-L	30	O	12	O	12	L	85	O-L
Endosulfan	25% WP	.0477	100	O	76	O-L	91	O-L	87	O	61	O	32	M-H	95	L	100	L
Endrin	50% WP	.0477	61	O-L	35	O-L	45	L	56	L-M	6	L	10	M	17	H	29	H
Ethion	25% WP	.0477	70	O-L	48	O	77	L	73	L-M	11	O	3	O	20	H	5	H
Fenthion	4.0 lb/gal EC	.0477	73	L	60	O-L	10	H	18	H	10	M-H	2	L	5	H	5	H
Ferbam	67% WP	.1279	53	O	70	O	98	O-L	100	O-L	33	O	9	O	32	O-L	8	O-L
Genite 923	50% EC	.0954	9	L	17	O-L	79	O	100	O-L	1	O-L	0	O-L	3	O	11	L
Heptachlor	25% WP	.0477	85	L	59	L	30	L	59	L	45	O-L	15	O-L	12	L	39	L
Lead arsenate (acid)	32% As_2O_5	.2863	75	O	62	O-L	76	O-L	68	O-L	98	O	41	O-L	97	O-L	36	O-L
Lime sulfur soln.	29° Baume	3.9809	24	O	0	O	6	O	8	L	0	O	0	O	0	O-L	0	O-L
Lindane	25% γ WP	0.0239 γ	100	O-L	61	O	44	O	42	L	85	L	15	O	20	M-H	8	L-M
Malathion	25% WP	.0477	45	M-H	12	M	2	H	4	H	11	H	9	H	0	H	3	H
Methoxychlor	50% WP	.0954	84	O	20	M	50	O-L	79	L	33	O-L	7	H	13	M	15	L
Mevinphos	4 lb/gal E	.0239	24	H	6	H	77	M-H	89	H	4	H	1	H	5	H	4	H
Morestan	25% WP	.0477	60	L	41	L	98	O-L	55	L	47	L	10	O-L	75	M	20	L
Naled	8 lb/gal EC	.0477	55	L	67	O-L	59	O-L	61	O-L	95	O-L	6	O-L	34	H	29	H
Neotran	40% WP	.0572	96	O	97	O	87	O-L	45	L	51	O	45	O	56	O-L	6	L
Nicotine sulfate soln.	40%	.0746	85	O	41	O	94	O-L	8	L	16	O	31	O	0	O-L	5	L
Oil, light-medium	92% U.R. Emul	1.0903	77	O	33	O	73	L	90	L	72	O-L	45	O	30	M	37	H
Oil-kerosene	Tech	1.0903	74	O	49	O	41	O	88	L	31	O-L	59	O-L	30	O-L	86	O-L
Ovex	50% WP	.0716	100	O-L	69	O	100	O	71	L	71	O	17	O-L	72	O-L	53	L
Parathion	25% WP	.0477	44	O	34	O-L	25	H	12	H	1	O-L	1	L	2	H	3	H
Perthane	25% WP	.0477	91	O	52	O	24	O	83	L-M	52	O-L	38	O	17	O-L	10	M
Phosphamidon	4 lb gal E	.0239	44	H	31	M	86	H	50	H	19	H	6	H	15	H	11	H

Table 1.—Percent acceptance and toxicity ratings of pesticides fed exclusively as stomach poisons to certain hymenopterous parasites and coccinellid predators.

Material	Formulation	% toxicant (act.) in honey w/w (low concn)	Response to low concentration of toxicant in honey								Response to high concentration of toxicant in honey							
			Lindorus		*Cryptolaemus*		*Metaphycus*		*Aphytis*		*Lindorus*		*Cryptolaemus*		*Metaphycus*		*Aphytis*	
			Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.
Aldrin	40% WP	0.0477	68	O-L[a]	52	O	59	O	29	O-L	18	L	22	O	42	O-L	17	O-L
Aramite®[b]	15% WP	.0429	68	O	60	O	86	O	68	O-L	30	O	28	O	90	O-L	38	O-L
Azinphosmethyl	25% WP	.0477	13	H	8	M-H	22	H	13	H	2	H	3	H	2	H	5	H
Benzene hexachloride	10% γ WP	.0191 γ	84	O	40	L	59	O	78	O	21	L	21	L	47	L	55	O-L
Bidrin	7.5 lb tech/gal.	.0477	16	H	7	H	10	H	13	H	4	H	4	H	15	H	8	H
Bordeaux mixture	10-10-50 2 pkg.	3.8168	28	O	16	O	40	L	6	L-M	3	O	0	O-L	0	L	7	L
Calcium arsenate	70% $Ca_3(AsO_4)_2$	0.2863	30	O	20	L	70	L-M	77	M-H	10	L-M	41	H	28	M	9	H
Captan	50% WP	.0954	61	O	65	O	95	L	70	O	25	L	7	O	68	L	68	O-L
Carbaryl	50% WP	.0477	32	H	9	H	3	H	22	H	13	H	5	H	0	H	10	H
Carbophenothion	25% WP	.0239	39	O-L	40	O	79	O-L	100	M	3	O	2	O-L	50	H	29	H
Chlordane	40% WP	.0954	91	L	52	O-L	88	O	75	O-L	41	O-L	3	O-L	26	O	26	O-L
Chlorobenzilate	25% WP	.0239	88	O-L	59	O	90	O	58	L	11	O	4	O	8	L	12	L
Cryolite (natural)	95%	.2719	65	O	72	O	37	L-M	75	M	16	O-L	14	L	52	M	57	H
DDT	50% WP	.0954	79	O-L	36	L	35	O-L	48	M	14	O-L	15	M	12	L-M	8	M
Demeton	2 lb/gal EC	.0239	82	O-L	46	O-L	44	L	64	M-H	8	H	7	M-H	0	H	21	H
Diazinon	25% WP	.0477	66	O	48	L	87	H	77	M-H	10	O	6	L	10	H	10	H
Dicofol	18.5% WP	.0477	78	O	64	O-L	90	O	88	O-L	9	O	2	O	6	O	20	L
Dieldrin	50% WP	.0477	94	O	64	O	65	O-L	95	L	43	O	18	O	11	L	37	M-H
Dilan®[c]	25% WP	.0954	80	O	31	L	35	O-L	63	L	5	O-L	4	L-M	0	M	9	L
Dimethoate	4 lb/gal EC	.0477	87	M-H	35	M-H	32	H	29	H	13	H	8	H	46	H	18	H
Dimetilan	50% WP	.0477	100	L	30	O	41	O-L	54	M	30	L	9	M-H	10	H	19	H
Dinocap	25% WP	.0239	36	O	51	O-L	50	O-L	77	L	4	O	0	O	13	M	8	M
Dioxathion	25% WP	.0239	80	L	65	L	91	O-L	88	L	50	L	18	L	43	H	24	H
DN-111®[d]	20% WP	.0191	100	O	50	O	53	O	100	O-L	30	O	12	O	12	L	85	O-L
Endosulfan	25% WP	.0477	100	O	76	O-L	91	O-L	87	O	61	O	32	M-H	95	L	100	L
Endrin	50% WP	.0477	61	O-L	35	O-L	45	L	56	L-M	6	L	10	M	17	H	29	H
Ethion	25% WP	.0477	70	O-L	48	O	77	L	73	L-M	11	O	3	O	20	H	5	H
Fenthion	4.0 lb/gal EC	.0477	73	L	60	O-L	10	H	18	H	10	M-H	2	L	5	H	5	H
Ferbam	67% WP	.1279	53	O	70	O	98	O-L	100	O-L	33	O	9	O	32	O-L	8	O-L
Genite 923	50% EC	.0954	9	L	17	O-L	79	O	100	O-L	1	O-L	0	O-L	3	O	11	L
Heptachlor	25% WP	.0477	85	L	59	L	30	L	59	L	45	O-L	15	O-L	12	L	39	L
Lead arsenate (acid)	32% As_2O_5	.2863	75	O	62	O-L	76	O-L	68	O-L	98	O	41	O-L	97	O-L	36	O-L
Lime sulfur soln.	29° Baume	3.9809	24	O	0	O	6	O	8	L	0	O	0	O	0	O-L	0	O-L
Lindane	25% γ WP	0.0239 γ	100	O-L	61	O	44	O	42	L	85	L	15	O	20	M-H	8	L-M
Malathion	25% WP	.0477	45	M-H	12	M	2	H	4	H	11	H	9	H	0	H	3	H
Methoxychlor	50% WP	.0954	84	O	20	M	50	O-L	79	L	33	O-L	7	H	13	M	15	L
Mevinphos	4 lb/gal E	.0239	24	H	6	H	77	M-H	89	H	4	H	1	H	5	H	4	H
Morestan	25% WP	.0477	60	L	41	L	98	O-L	55	L	47	L	10	O-L	75	M	20	L
Naled	8 lb/gal EC	.0477	55	L	67	O-L	59	O-L	61	O-L	25	O-L	6	O-L	34	H	29	H
Neotran	40% WP	.0572	96	O	97	O	87	O-L	45	L	51	O	45	O	56	O-L	6	L
Nicotine sulfate soln.	40%	.0746	85	O	41	O	94	O-L	8	L	16	O	31	O	0	O-L	5	L
Oil, light-medium	92% U.R. Emul	1.0903	77	O	33	O	73	L	90	L	72	O-L	45	O	30	M	37	H
Oil-kerosene	Tech	1.0903	74	O	49	O	41	O	88	L	31	O-L	59	O-L	30	O-L	86	O-L
Ovex	50% WP	.0716	100	O-L	69	O	100	O	71	L	71	O	17	O-L	72	O-L	53	L
Parathion	25% WP	.0477	44	O	34	O-L	25	H	12	H	1	O-L	1	L	2	H	3	H
Perthane	25% WP	.0477	91	O	52	O	24	O	83	L-M	52	O-L	38	O	17	O-L	10	M
Phosphamidon	4 lb/gal E	.0239	44	H	31	M	86	H	50	H	19	H	6	H	15	H	11	H

Table 1.—Percent acceptance and toxicity ratings of pesticides fed exclusively as stomach poisons to certain hymenopterous parasites and coccinellid predators. (Cont.)

			Response to low concentration of toxicant in honey								Response to high concentration of toxicant in honey							
		% toxicant (act.) in honey w/w (low concn)	*Lindorus*		*Cryptolaemus*		*Metaphycus*		*Aphytis*		*Lindorus*		*Cryptolaemus*		*Metaphycus*		*Aphytis*	
Material	Formulation		Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.	Accept.	Tox.
Rotenone	6.4% gr. root	.0244	14	O-L	11	O-L	39	M	25	L	6	H	2	L-M	4	M-H	7	L-M
Ryania	100 gr stem	.3817	24	L	47	O-L	100	L	88	O-L	9	L-M	6	O-L	44	L	93	O-L
Sabadilla	2.25% alkaloid	.0065	87	O	42	O-L	24	L	13	M	73	O-L	51	O-L	0	M	6	H
Schradan	4 lb/gal EC	.0239	100	O	85	O	80	L-M	50	M	61	O	94	O	76	H	5	M-H
Sulfur	325 mesh WP	.2863	81	O	36	O	32	O	47	L	76	O	8	O	20	L	16	M
Sulphenone	50% WP	.1431	80	O	70	O-L	68	L	100	L	15	O	4	O-L	9	L	5	L
Tartar emetic	Tech	.1908	23	O	43	O-L	26	L	34	L-M	14	O	14	L-M	11	H	13	H
TDE	50% WP	.0954	87	O	49	O	24	O-L	58	L	24	O-L	7	O-L	6	L	45	L
Tepp	20% E	.0239	100	O	100	O	100	O	16	O-L	40	O	53	O-L	70	O	8	M
Tetradifon	25% WP	.0353	100	O-L	100	O	100	O	85	O-L	100	O	78	O	84	O	72	O-L
Toxaphene	40% WP	.1908	23	O	13	O	91	O-L	76	L-M	4	O	0	O-L	15	L-M	15	L-M
Trichlorfon	50% sol. pow.	.0477	94	O-L	72	O	100	L	100	L	34	O-L	42	O-L	97	L-M	97	M
Zectran	25% WP	.0477	40	H	16	H	5	H	8	H	12	H	1	H	0	H	1	H
Zineb	75% WP	.1240	99	O-L	100	O	100	O-L	100	O	100	O-L	100	O	70	O-L	93	O-L

[a] Toxicity expressed as H (High) if $LT_{50} < 1$ day; M (Medium) if > 1 day and < 4 days; L (Low) if > 4 days; O if none.
[b] 2(*p*-tert-butylphenoxy)isopropyl-2-chloroethyl sulfite.
[c] A mixture of 1 part of 1,1-bis(*p*-chlorophenyl)-2-nitropropane (Prolan®) and 2 parts of 1,1-bis(*p*-chlorophenyl)-2-nitrobutane (Bulan®).
[d] 2-cyclohexyl-4,6-dinitrophenol, dicyclohexylamine salt.

Assessment of the toxicity of a poison bait with any technique that incorporates variation in acceptance or rejection of the poison by the test animals creates some interpretative difficulty. It seems necessary, however, to accept the variations in ingested dosages associated with rejection as an integral part of the assessment of a poison bait if the data are expected to be at all transposable to field practice.

Since the data presented in Table 1 actually represent the results of 488 separate test combinations, it is impractical to discuss anything other than the particular effects that illustrate principles, trends, and unusual variants or responses that might not be ordinarily expected.

TOXICITY.—One of the most striking results of the tests was the extraordinarily rapid kill caused by some of the materials. Despite the strong rejection of the violently poisonous broad spectrum phosphate and carbamate insecticides such as Bidrin® (3-hydroxy-*N*,*N*-dimethyl-*cis*-crotonamide dimethyl phosphate), carbaryl, dimethoate, azinphosmethyl, malathion, mevinphos, phosphamidon, Zectran® (4-dimethylamino-3,5-xylyl methylcarbamate), and in some cases demeton and fenthion, these materials usually caused death of the test species within 10–15 min after initial tasting of the bait. The insects died with most of the aforementioned poison baits after ingesting quantities insufficient to show anything other than a trace of the incorporated red dye in the pharynx. The effect was most rapid on the parasites and with the high-concentration poison baits. The quick kill particularly at the high-poison concentrations by many of the old-line insecticides was also a surprise. Calcium arsenate and cryolite which were taken as baits in somewhat variable quantities and, in the cases where they were toxic, rotenone, sabadilla, and tartar emetic, produced their effect at unexpectedly rapid rates in these tests. In connection with the arsenicals, it was strange that lead arsenate, which was readily taken as a bait, was one of the most innocuous materials tested.

The stomach-poison activity of the chlorinated hydrocarbon group was peculiar. With the exception of a very few materials such as endrin, methoxychlor, and lindane, which killed certain species, the chlorinated hydrocarbons were not in general potent stomach poisons. Aldrin, benzene hexachloride, chlordane, TDE, and even heptachlor were almost ineffective; and some like DDT, dieldrin, endosulfan, and Perthane® [a mixture of 1,1-dichloro-2,2-bis(*p*-ethyl phenyl)ethane (95% and related reaction products (5%)] were only moderately effective against particular species. An interesting feature of the action of certain of these pesticides was the low acceptance of materials even though they proved to be innocuous.

The botanicals varied greatly in toxicity and acceptance as stomach-poison baits against the different test species. Ryania, for example, while harmless to both parasites and coccinellids, was very distasteful to the beetles. Sabadilla, which was toxic to the parasites but not to the coccinellids, was particularly distasteful to the parasites, where its obnoxious quality was recognized quickly after tasting, although not soon enough to avoid fatal poisoning. Nicotine sulfate was avoided but not toxic, whereas rotenone, which was also avoided, was toxic.

Most of the fungicides were innocuous and accepted in the honey bait. Lime sulfur and bordeaux mixture were objectionable, which was expected consider-

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Methyl Bromide, Ethylene Dibromide, and Other Fumigants for Control of Plum Curculio[1] in Fruit[2, 3]

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ABSTRACT

Laboratory-reared multibrood larvae of the plum curculio, *Conotrachelus nenuphar* (Herbst), were susceptible to methyl bromide as were natural infestations of single-brood larvae in green apples, plums, peaches, or blueberries, or of multibrood larvae in apples and peaches. Pupae and adults appeared to be more susceptible than larvae in fruit at warm temperatures (77°F). A mixture of methyl bromide:ethylene dibromide (3:1) was more effective than methyl bromide alone when the dosage was 2 lb per 1000 cubic feet in fumigations of small (less than 3% of the capacity of the chamber) loads of fruit at temperatures near 77, 53, and 41°F, but the efficiency was lower and more variable with an additional heavy load of uninfested fruit, especially when the load was green peaches. However, both fumigants gave complete control of multibrood larvae in nearly mature Jonathan apples in a few tests with full load at dosages of 2 lb for 2 or 2.25 hours at temperatures near 73°F or for 3.5 or 4 hours at temperatures near 53°F. Red and Golden Delicious, Lady, Cortland, and several other varieties of apples and other fruit tolerated either fumigant satisfactorily at temperatures near 73 or 53°F and tolerated methyl bromide alone at temperatures near 41°F. McIntosh apples were somewhat intolerant, and some mature pears were severely injured. Residues of bromide from either fumigant varied from 2 to 5 ppm in apples. Curculio larvae also appeared to be very susceptible to ethylene dibromide alone and less so to ethylene chlorobromide.

Tests of the effectiveness of fumigation were started in 1957 to develop a quarantine treatment for plum curculio, *Conotrachelus nenuphar* (Herbst), and the apple maggot, *Rhagoletis pomonella* (Walsh), in apples, blueberries, and other fruit. These insects occur in the Eastern United States but not in Western areas. This report is a summary of 350 fumigations (1957–62) of plum curculio made at various temperatures and dosage schedules with methyl bromide, ethylene dibromide, and some other fumigants. Ethylene dibromide was included in the tests because its efficiency against the apple maggot (Richardson 1955) indicated that it might be used by itself or in a mixture with methyl bromide (a mixture of methyl bromide and ethylene dibromide in any proportion from 5–95% is covered by US Patent 2,606,857 (Dawson Fumigants)), as a single treatment against both pests (California Dep. Agr. 1960). More than 150 tests of fruit tolerance and some tests to determine the residue of bromide were also made.

METHOD AND MATERIALS.—The method of laboratory rearing developed by E. H. Smith (1957) for multibrood curculio was used in 1957 and 1958 to provide test insects: 4575 green apples infested in the laboratory with larvae and eggs and some laboratory-reared pupae and adults were fumigated. Later we tested field collections of fruit (mostly green) that were naturally infested with single or multibrood plum curculio; 22,693 apples from Indiana, Massachusetts, New Jersey, New York, Ohio, and Pennsylvania, 45,209 blueberries from New Jersey; 21,238 peaches from New Jersey, Pennsylvania, North Carolina, and West Virginia; and 19,609 plums from Ohio and Pennsylvania were used.

All fumigations were made at normal atmospheric pressure in 7.4- or 8.1-ft^3 fumigation drums (Fig. 1). The dosage schedules are given in lb/1000 ft^3, the temperatures in degrees Fahrenheit. Concentrations of methyl bromide were checked with thermal conductivity units. Dosages of ethylene dibromide were measured with a microburet inserted through a small opening in the top of the drum into a small, stainless-steel pan, the drum opening was then immediately closed. We found that when an ammeter was connected in series outside the drum (Fig. 1) we could determine positively whether the 110-w heater for the pan was in operation during the 3 min required for complete vaporization and we did not need an observation window in the drum to determine whether vaporization was complete.[5] In some tests gas concentrations were checked by a modified Volhard analysis.

In fumigations made with a mixture of the 2 gases, the methyl bromide was injected into the drum immediately after the ethylene dibromide so that the 2 chemicals vaporized almost simultaneously. Fan cir-

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[1] Coleoptera: Curculionidae.

[2] Accepted for publication May 16, 1966.

[3] Mention of trade names or companies herein does not necessarily imply endorsement of these products or companies by the USDA.

[4] Retired December 30, 1965.

[5] Such practical use of ammeters has since been made in the New York Port Authority 4400-ft^3 fumigation tanks at Port Newark, N. J., in the ethylene dibromide fumigation of various imported fruits. The operation of other electrical equipment, such as fans, inside the tank may also be checked with ammeters. A simple, low-cost-type of ammeter is usually sufficient.