EVALUATION OF PESTICIDES FOR CONTROL OF STORED-PRODUCT INSECTS

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Laboratory testing is mandatory for the economic selection of potential pesticides destined for subsequent field experiments and to estimate dosages providing the desired responses. A necessary component for success is to identify and comprehend variables that can alter correlation between laboratory and field data. Although standard testing procedures are ideal, the results can be misleading. Most data, to date, indicate a definite reduction in pesticide toxicity as tests progress to envelope field conditions.

Stored-product insects have little concern for boundaries regarding their distribution or proliferation, unless inhibited by exposure to environmental conditions contrary to their needs. Such needs center on temperature, moisture, food, insect species and stage. Unfortunately these variables are not independent thus providing a series of complex interactions requiring the assistance of multivariant computer analysis. Chemical evaluations of pesticide effectiveness have certain advantages, including reproduceability. However, bioassay still remains the ultimate tool.

Methoxychlor, synergized pyrethrins, and malathion provide primary insecticidal support to supplement an effective sanitation program. These chemicals are applied as dusts, wettable powders, solutions, aerosols and smokes. There still remains a need for evaluating new experimental compounds, including components of natural foods, that have potential for use as direct contact, residue or vapor toxicants to combat stored-product insects.

Insecticides are generally the most effective management method and, in many instances, provide the only method available to reduce insect populations to tolerable levels. We must concentrate on developing compatible systems of chemical and nonchemical methods in proper sequence and timing. Unfortunately this objective is paramount at a time where there is diminishing support for science and technology and a reducing amount of confidence in the use of chemical pesticides. Condemning chemical controls is unrealistic unless consumers are prepared to lower their food standards or have alternate nonchemical procedures established.

Insecticides are, and will remain, essential, to maintain the abundance and quality of stored products in the world. In fact, insecticides are generally the most effective insect management method available to reduce insect populations to tolerable levels.

We must also recognize that insecticides should be used only when no other effective or safer method is available and then only when their use will not produce undue hazards to non-target organisms, including the applicator, or the environment. Subsequently, a continual review of all insecticides and their uses in relation to public safety and concern is mandatory. Such reviews should be carried out objectively by qualified personnel. When new scientific evidence becomes available which may indicate a necessary change in their present usage, appropriate action should be taken immediately.

To evaluate a compound for insecticidal properties, we should review exactly what chemical, physical and biological characteristics it should possess. I shall restrict most of my comments to those insecticides that are contact or stomach poisons since fumigants will be discussed by another speaker.

An insecticide usually consists of one or more toxicants alone or in combination with one or more additives. When additives are involved, as is frequently the case, we refer to the resulting combination as a formulation. Adding or subtracting additives can alter an insecticide's effectiveness. Changing diluents, solvents, penetrants, emulsifiers, synergists, activators, stabilizers and blending agents are prime examples. Whatever formulation we eventually develop, it should fit most of the following qualifications:

1. It should be toxic to the target insect and kill quickly.
2. It should retain its toxic properties for a sufficient time to produce the desired insect control.
3. It should not leave excessive residues but still be stable for reasonable lengths of storage.
4. It should be easy to apply in as many formulations and situations as desired.
5. It should be safe to the applicator and the environment.
6. It should be economical.

In addition to these major qualifications there are many variants we must also consider. One of the basic reviews of the significant variants was published by Parkin in 1951. It covers the specificity of the insecticides including the formulation dilution, method and timing of application [1]. However, no single publication covers the multiple and various factors, including their interrelations, as well as that developed for fumigants by Sun [2]. His variants are represented in Fig. 1.

Any advancement of techniques to evaluate insecticides for managing stored-product insects is due, in part, to our ability to colonize these target insects. In general, stored-product insects do not require sophisticated diets; although each species may have specific requirements for certain carbohydrates, proteins, fats, vitamins, and other nutritional factors. Most have short life cycles and relatively long life spans. Precautions must be taken to separate closely related insects to maintain species specific cultures, and to isolate and protect the cultures from parasites, predators, and diseases. Some of the life history stages, such as eggs or young larvae, may be damaged easily if not handled carefully. The temperature and humidity in the rearing area should be controlled as a basic step in any attempt to maintain uniform cultures. Specific colonizing specifications for

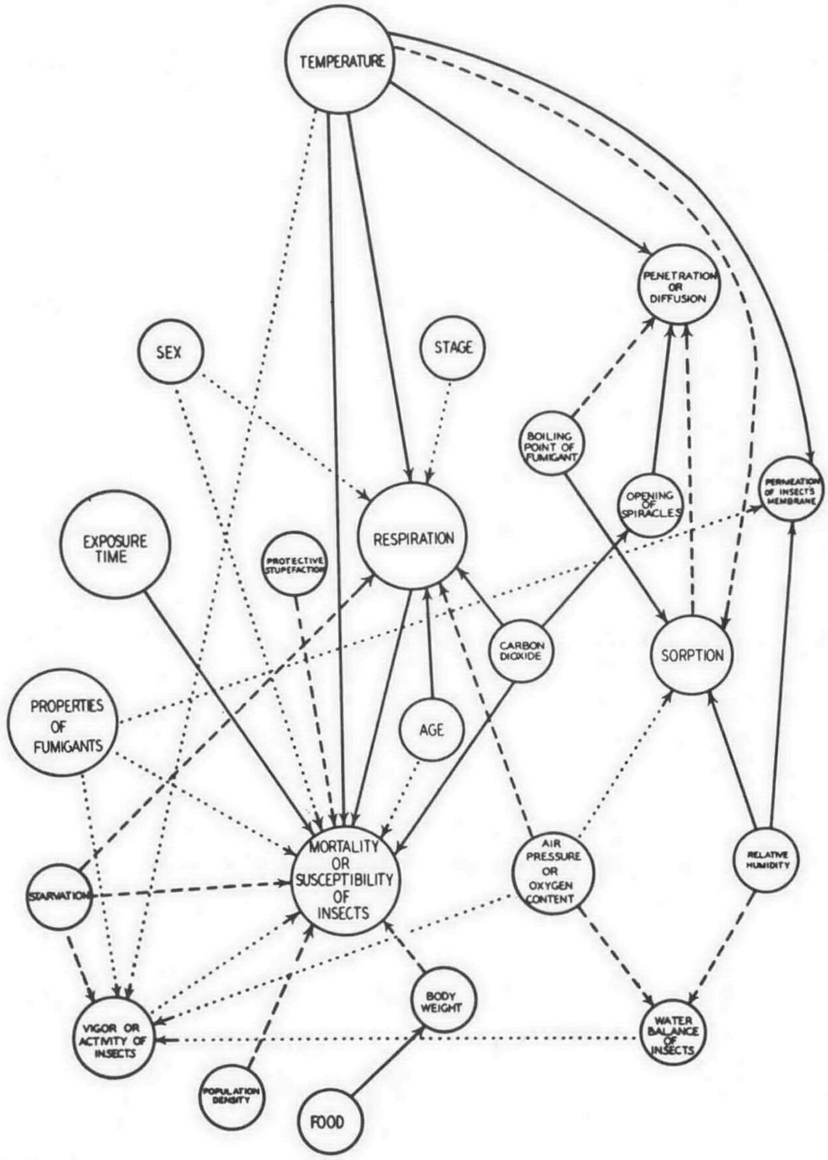

FIGURE 1. Diagram showing the relation of various factors and their counter and parallel effects on the susceptibility of insects to fumigants.

rearing stored-product Coleoptera [3] and Lepidoptera [4] were reviewed in 1966.

However carefully we standardize our rearing techniques, there are variations in stock cultures. Consequently we usually must use large numbers of insects to obtain accurate average figures and further improve the reliability of our results by replicating the studies. Also several species of stored-product insects should be included and, if possible, at more than one stage of development.

A complete knowledge of an insect's biology and behaviour and its environmental needs is necessary to aim at vulnerable phases of the insect's life cycle [5]. As an example, Lovitt and Soderstrom reported that the primary method of insect control in the dried fruit industry is aerosol application of insecticides [6]. They reported that such applications are effective against only the insects that are flying in the air space or are resting on adjacent surfaces. To be most effective, it is necessary to determine when these insects are in the target sites or how changes in environmental conditions could be used advantageously.

We generally use knock-down, mortality or reproduction in determining the effectiveness of an insecticide. Knock-down is usually faster, but it may lead to significant errors. Waiting to ascertain mortality could mean complications of high check-insect mortality because of longevity, starvation and dessiccation. An example of this factor was recently reported when preliminary experiments with pyrethrins indicated that the usual method of correcting for control mortality was not acceptable if the beetles were not fed [7].

Unfortunately, compared to research reported on the effect of fumigants on insect stages and even age of stage, there is relatively little data on the relative susceptibility of different stages to contact insecticides. This lack of information applies to laboratory as well as to field research. There does exist a massive amount of data published on the relative susceptibility of different species of stored-product insects to insecticides. Even the comparative susceptibility of 5 species of adult moths under laboratory conditions to 12 insecticides varies widely as portrayed in Fig. 2. Similar differences were noted for recommended dosages in ppm of 5 insecticides against adult beetles and weevils in Table I [8].

TABLE 1. Recommended dosages to control three species of stored-product insects in wheat under field conditions.

Toxicant	*Tribolium castaneum*	*Rhizopertha dominica*	*Sitophilus oryzae*
DDT	50	50	50
Dipterex	50	100	50
Sevin	50	12.5	100
Malathion	4	6	4
Lindane	10	2	6

Reports of conflicting data on insect control with insecticides is not difficult to find even when considering malathion (0, 0-dimethyl phosphoro-dithioate of diethyl mercapto succinate), one of the most widely used insecticides for stored-product insects. For example, malathion provided the required protection at 10 ppm for stored seeds from potential infestation of *Oryzaephilus* spp., *Tribolium* spp. and *Sitophilus* spp. However the same treatment failed to get adequate control of stored-product moths, although such was obtained by other researchers.

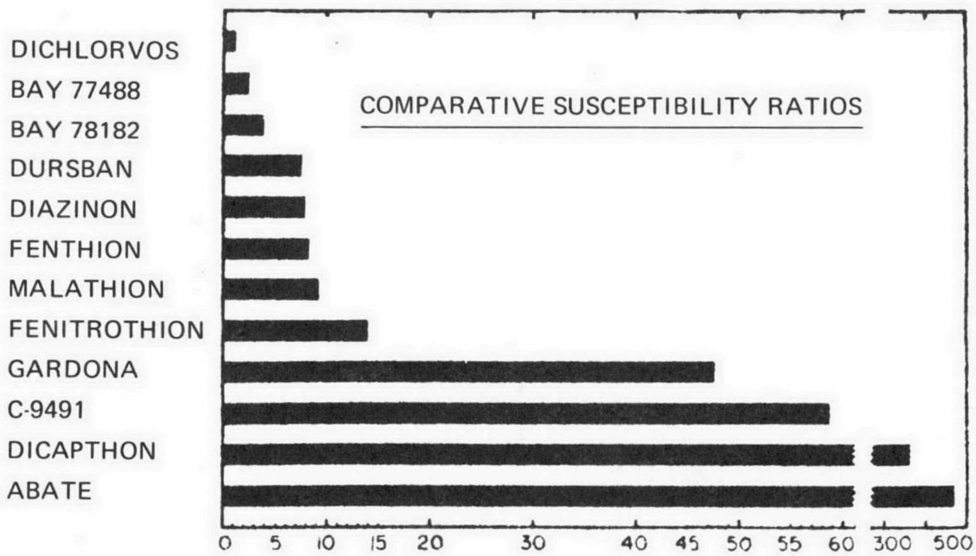

FIGURE 2. Relative effectiveness of 12 insecticides against stored-product moths as indicated by comparative susceptibility ratios calculated from LC_{95} concentrations required for the least susceptible of the 5 species to each insecticide, using a basis of 1 for the most toxic compound.

The insecticidal activity is determined by the residual life of the chemical and the toxicity of any metabolites produced. Contact insecticides for grain should remain on the outside of kernels [10] whereas rapid penetration and dispersion is undesirable. In addition the metabolic fate of an insecticide on grain is altered by the temperature and moisture content of the grain and the method and rate of application.

Temperature has a significant effect on the usefulness of many insecticides against most species of stored-product insects [11]. The comparative toxicities of 4 insecticides against 5 species of insects at 3 temperature levels is well documented in Fig. 3.

The influence of moisture and temperature on the effectiveness of dichlorvos (0,0-dimethyl 2, 2-dichlorovinyl phosphate), diazinon (0, 0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate, naled (1,2-dibromo-2,-dichloroethyl dimethyl phosphate), ronnel (dimethyl 2, 4, 5-trichlorophenyl phosphorothionate) and azinphos-methyl (0,0-dimethyl phosphorodithioate S-ester with 3-(mercaptomethyl)- 1, 2, 3-benzotriazin-4 (3h)-one) was illustrated by reduced mortalities and increased progeny with increases in either moisture or temperature [12]. This direct correlation between insect mortality and reproduction has not always held true

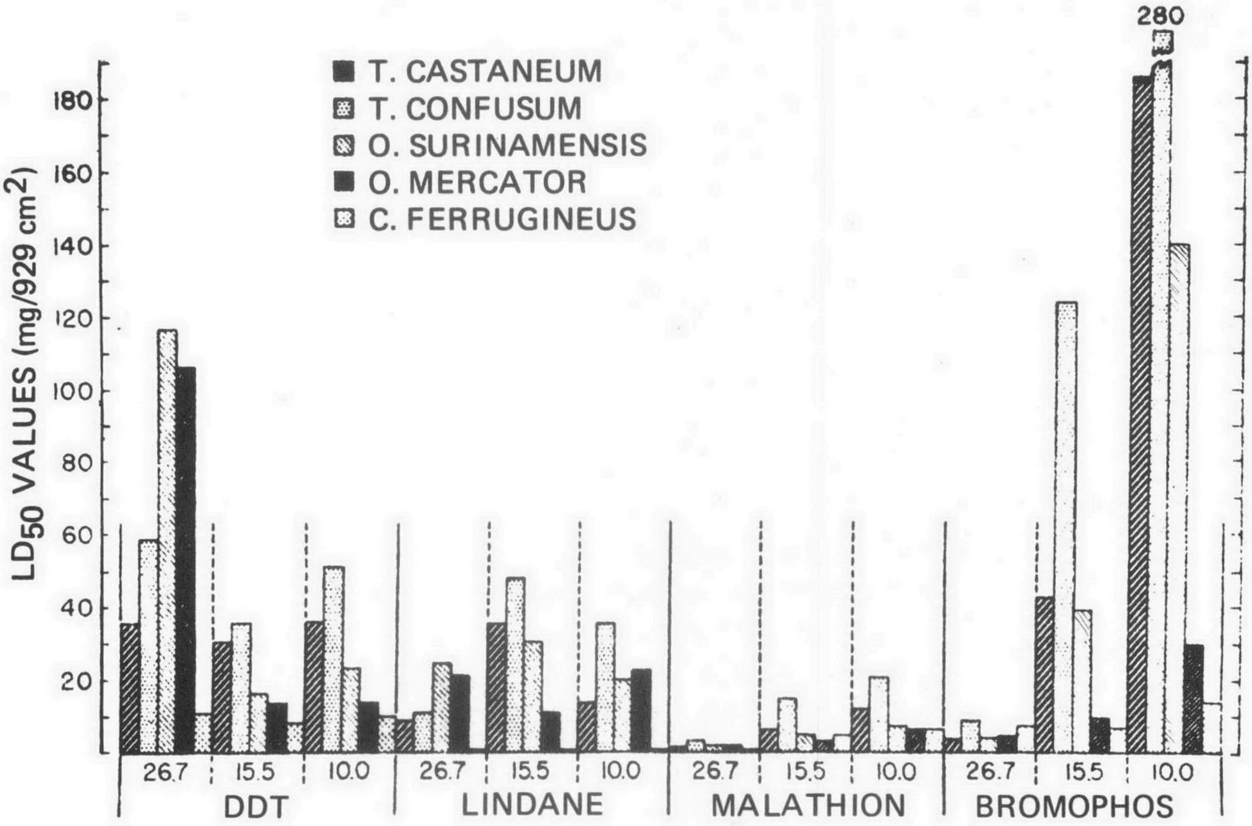

FIGURE 3. Comparative effectiveness of DDT, lindane, malathion and bromophos against 5 species of stored-product insects at 10.0, 15.5 and 27.6°C.

[13] as Harein reported reduction in rice weevil reproduction of 94% following exposure to 1 ppm ronnel that produced 7% mortality. In contrast, Waters noted that an accelerated oviposition occured with *Sitophilus granarius* (L.) exposed to low dosages of malathion despite adult mortalities up to 96% [14]. Reproduction did not differ significantly from the untreated checks with mortalities of 1-5%.

The practical insecticidal value of malathion is modified significantly by other types of surfaces than grain kernels [15]. Malathion residues on unpainted concrete were effective for less than 1 week (Table 2). When the concrete surfaces were painted, the residues of malathion were effective for 17-20 weeks. Effectiveness of malathion on unpainted masonite and glass persisted for at least 22 weeks.

The method of insecticide application varies from gross simplicity to sophisticated complexities; each providing specific characteristics that can be significant in attempts to attain the desired insect mortality. An example of simplicity is a "Drip-On" system developed by the USDA Stored-Grain Research Laboratory in Manhattan, Kansas. The basic unit consists of an inexpensive plastic

TABLE II. Effective time[a] of toxicity to *Trogoderma inclusum* larvae of malathion on latex-painted and unpainted masonite surfaces.

		Effective time (weeks)	
Insecticide	Deposit (mg/ft^2)	Latex-painted masonite	Unpainted masonite[b]
Malathion:			
Emulsion	100	<1	8
Wettable powder	100	7	8
Malathion and Cellosize:			
Emulsion	100+24	>1	8
Wettable powder	100+24	6	8
Cellosize only:	24	0	0

[a]Time during which treatment gave complete mortality
[b]All unpainted masonite panels treated were effective at the time the test was discontinued after 8 weeks.

jug with 2 valves and a measuring cup. The unit, suspended over grain being conveyed into storage, provides a uniform residues over the kernels to protect them against insect infestation.

A more sophisticated method is the ultra low volume (ULV) method of dispensing insecticides. It is a relatively new and precise application method that may have significant advantages [16]. The ULV method can dispense uniform pesticide particles to attain the greatest impingement on an insect. There are probably optimum particle sizes for each insect.

Attempts to find components of natural foods with potential for inhibiting stored-grain insects are not new but have gained interest especially with the increased restrictions on conventional insecticides. Preliminary studies in the United States indicate that natural oils extracted from the peels of various fruits are moderately toxic to *Sitophilus oryzae* (L). In fact, lemon and grapefruit oil have proved most effective. Studies should continue in an effort to isolate and identify the toxic components in these oils.

Some of our current research at the University of Minnesota on stored-product entomology has been designed to evaluate mycotoxins produced by fungi on stored grain, as a possible source of a specific insecticide. The majority of our current efforts is on the use of the whole fungal organism with many metabolities involved simultaneously. As with the citrus oils, the testing of isolated and purified fungal metabolites may add a new clue in the battle against stored-product insects.

As you know, it is important to be able to measure the relationship between the relative toxicities of insecticides in the laboratory and in the field. Some of the variables that make this objective difficult, if not impossible, have already been discussed. Some progress has been made, especially with the aid of computers.

An excellent example of computer analysis was published by Bronswijk et al. [17]. Their primary objective was to measure the influence of insect infestation on specific biotic variates of wheat bulk ecosystem. Changes in temperature, moisture, grain viability, grain weight, dust weight, species of insects and microbes, fat acidity and uric acid content were estimated at monthly intervals and analyzed separately by descriptive and multivariant statistical methods. Their computer analyses provided a descriptive picture of biological and chemical deterioration of the grain.

We use two primary computer programs at the University of Minnesota, in cooperation with statisticians, to assist us in understanding the effect of variables in the correlation of laboratory and field research. One of our programs performs a correlation analysis followed by a multiple linear regression. Once our data has been computed and stored in the memory bank of the computer, any number of regression equations may be conducted. Our 2nd computer program entitled the "General Plot and Scattergram Program" allows us the flexibility of ploting one variable against one or more variables. All variables can be identified and measured for significance.

There are a number of references that are helpful in an effort to improve and standardize insecticide evaluation methods. Shepard [18] [19] covers pertinent differences of insect cuticle, physiological measurements, methods of laboratory and field insecticide application, as well as discussions on variables associated with specific insecticide screening requirements. Busvine's [20] critical review of testing techniques can also be a basic guide in our research. He states our needs precisely, "The best criterion is a full scale field trial; but such trials are expensive, slow and owing to the difficulty of providing adequate replication to make up for great variability, do not always produce unambiguous conclusions."

Undoubtedly, one of our most challenging objectives will be to provide laboratory data that can be correlated with field conditions. Hopefully we all will gain in this respect with our cooperative interest and participation in this 1st International Working Conference on Stored-Product Entomology in the United States.

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