ECOLOGICAL AND PHYSIOLOGICAL MECHANISMS INFLUENCING FOOD FINDING IN BLATTARIA

By

MICHAEL DONOVAN MIESCH, JR.

Bachelor of Science
Texas A & M University
College Station, Texas
1956

Master of Science
Purdue University
West Lafayette, Indiana
1959

Submitted to the Faculty of the Graduate School
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY
August, 1964

ECOLOGICAL AND PHYSIOLOGICAL MECHANISMS

INFLUENCING FOOD FINDING IN BLATTARIA

Thesis Approved:

D E Howell
Thesis Adviser

P R Walton

J. E. Webster

Dean of the Graduate School

PREFACE

The author, while employed by Thuron Industries, Inc. of Dallas, conferred with Dr. D. E. Howell, Professor and Head of the Department of Entomology on possible dissertation research for a doctorate program at Oklahoma State University, Stillwater, Oklahoma. It was agreed that the research program should be initiated before coming to Oklahoma State University.

The author was primarily interested in a laboratory problem so that experiments could be conducted during free time, and one that would be of interest to the Company so that part of the research could be conducted on company time. After extensive reviewing, the author decided to investigate food preferences of cockroaches, with the possibility of developing a bait for the control of cockroaches. The program broadened into the study of ecological and physiological mechanisms influencing food findings in Blattaria.

The author wishes to express his appreciation to Dr. D. E. Howell, under whose guidance, criticism, and encouragement this research was conducted.

Indebtedness is expressed to Drs. Thurmond A. Williamson and Byron Williamson, owners of Thuron Industries, Inc., for their thoughtful guidance, criticisms, and for the use of company facilities where part of this research was conducted.

The author is deeply grateful to Dr. Richard N. Lyness of the Uni-

versity of California, Berkley, California, formerly with Thuron Industries, Inc., for encouragement and constructive criticism during the initiation of this study.

Appreciation is expressed to Dr. James E. Webster, Professor of Biochemistry, for helpful suggestions and the supplying of several samples of chemicals used in this research.

The author is grateful to Mr. Charles F. Henderson, Professor of Entomology, for help in constructing a turntable for use in this research.

The photographs were taken by Dr. Harvey L. Chada, Professor of Entomology, to whom the author is grateful.

Indebtedness is expressed to the National Pest Control Association for financial assistance during part of this study, and to Dr. Philip J. Spear, Technical Director, for encouragement and help.

Sincere appreciation is acknowledged to Dr. R. R. Walton, Professor of Entomology, Dr. James E. Webster, and Dr. Jack R. Harland, Professor of Agronomy, for their valuable suggestions and criticisms in the composition of this paper.

Appreciations are due to Mrs. Edna Mae Milburn for typing a rough draft of the dissertation.

The author is especially grateful to his wife, Lanetta Ann, for her constant encouragement and reading of the manuscript, and whose valuable suggestions contributed greatly toward this paper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Of the 3500 species of cosmopolitan cockroaches, less than one per cent are domiciliary pests. According to Rhen (1945), the four major species of cockroaches, the American cockroach, Periplaneta americana (Linn.), the Oriental cockroach, Blatta orientalis (Linn.), the German cockroach, Blattella germanica (Linn.), and the brown banded cockroach, Supella supellectilium Serv., are all natives of Africa.

Cockroaches are outstanding among omnivorous insects which are of significance in the contamination of food and water as a result of their association with the food and excreta of man and animals. Eads et al. (1954) reported the connection of homes to sewer lines had greatly reduced the access of houseflies to human feces but certain species of cockroaches were able to thrive in sewers. Marked cockroaches were demonstrated to enter homes from sewer lines as far as one block away from release site. They also demonstrated experimentally that these insects can enter homes through plumbing traps. Dow (1955) and Haines (1955) also reported cockroaches were thriving in sewers and privies. Over 50% of the sewer manholes in Austin, Houston, Galveston, and Corpus Christi, Texas were reported infested with cockroaches.

In 1957, Roth and Willis showed that at least 18 species of domiciliary cockroaches have been incriminated, naturally or experimentally in the transmission of infectious agents or have been claimed to bite man. The following pathogens have been reported to be associated with

cockroaches: four strains of poliomyelitis virus, 40 species of bacteria, two species of fungi, three species of protozoa, and the eggs of seven species of helminths. These insects have been found to serve as intermediate hosts for 12 species of helminths. In 1960, Roth and Willis compiled records, in addition to those reported in 1957, on other organisms associated with cockroaches which are non-pathogenic to vertebrates. These include 45 species of bacteria, 40 fungi, 6 yeasts, 90 protozoa, and 45 helminths. According to Roth and Willis, there is no question concerning the ability of cockroaches to carry pathogens in or on their bodies.

Cockroaches have developed resistance to various insecticides as reported by Heal et al. (1953), Frisk and Isert (1953), and Laake and Williamson (1955), and as a consequence, they are becoming more difficult to control.

All these factors indicate that cockroaches are serious pests and a thorough investigation should be conducted to find new and better means of control.

REVIEW OF LITERATURE

BAITS AND ATTRACTANTS. Dethier et al. (1960) designated the following terms to describe responses of insects to chemicals:

1. Attractant - a chemical which induces insects to make oriented movements toward its source.
2. Arrestant - a chemical which causes insects to congregate when coming in contact with it.
3. Feeding, mating, or ovipositional stimulant - a chemical which induces feeding, mating, or oviposition in insects.
4. Repellent - a chemical which induces insects to make oriented movements away from its source.
5. Deterrent - a chemical which prevents feeding and oviposition in a place where insects normally feed or oviposit.

Extensive reviews on the history, development, and the uses of baits and chemical attractants as useful means of insect control, have been written by Dethier (1947,1956), Green et al. (1960), Beroza and Green (1963), and others. To avoid repetition, efforts were made to limit the following discussion to information pertaining to research covered in this paper.

A bait containing a mixture of plaster of Paris and flour in one plate and water in another plate was recommended by Tepper (1900). Cockroaches, after eating this bait, became thirsty, and drank water. The plaster of Paris, as a consequence, clogged up the stomach, and the

cockroaches disappeared in a few weeks.

In 1902, Howard and Marlatt noticed that cockroaches fed on book-binding paste. Stale beer and ale were reported to be effective in trapping cockroaches.

Several baits were used by Washburn (1913) to demonstrate the effectiveness of a cockroach trap. Banana was the most attractive bait, while liquid chocolate gave the poorest results. Milk was found to be effective only in dairy buildings.

Zappe (1917) reported that phosphorous paste (flour, glucose, honey, and two to four per cent yellow phosphorous), and a paste of borax, flour, and banana were effective against Pycnoscelus surinamensis (Linn.), Surinam cockroach, in green houses. Anise oil was found to improve an effective bait of borax and powdered sugar. Fifteen additional bait formulations were evaluated, but most were found to be ineffective.

Borax mixed with sugar, spread on apple, or banana peel was reported by Walter (1918) as an effective means of cockroach control.

An attractive bait for Periplaneta americana (Linn.) was developed by Pettit (1920). The bait consisted of cotton seed meal and molasses cooked in a steam cooker with yeast added to induce fermentation. Lead arsenate was used as the toxicant. Water had to be added daily, since the bait was ineffective when it became dry.

Doucette et al. (1925) reported that a sugar syrup and butyric acid mixture was the most attractive bait for the control of P. surinamensis in greenhouses. Sugar syrup and borax, butyric acid, and rose petals were found to be attractive. On the other hand, dry manure and lactic acid were fair, and liquid manure, dead cockroaches, and anise oil were

not attractive.

Of the 32 essential oils evaluated by Cole (1932) in a Y-tube olfactometer for attractiveness to Blatta orientalis Linn., oils of sweet oranges, pineapple, apple, peppermint (diluted), sassafras, nutmeg, and banana were found to be the most attractive. An effective poison bait was formulated with gelatin, beef broth, mercuric chloride, and a drop of one of the attractants mentioned above.

American cockroaches were reported by Rau (1940) to be omnivorous insects, because they fed on jam, soda crackers, pastry, bread, cheese, sweet corn, carrot, apple, peach, lettuce, cabbage, cantaloup, etc.

Gould and Deay (1940b), Rau (1940), and McCroddan (1963) reported that cannibalism was common among cockroaches, especially under crowded conditions in the laboratory.

Banana was found by Gould and Deay (1940b) to be the most attractive bait for trapping cockroaches. P. americana cockroaches were reported to be fond of chocolate and mixed food containing honey. Hamburger was found to be an effective bait in meat packing plants. Commercial baits containing honey, cereal, and phosphorous were attractive to P. americana.

In a food warehouse, 8,430 cockroaches were trapped in three months by Hardy (1940) with the following baits: banana peel, bread, meats, or vegetables, plus a little beer or aniseed. Borax and pyrethrum, sweetened with chocolate or plaster of Paris with sugar, were found to be effective in the control of cockroaches.

The $L.D._{50}$ of phosphorous paste diluted with syrup to P. americana cockroaches was found by Chen and Campbell (1940) to be 0.02 milligram per gram body weight. Blattella germanica (Linn.), were not readily

attracted to phosphorous paste, and the L.D.$_{50}$ was 6.5 times greater than for American cockroaches.

An aqueous solution of 1.5% boric acid was reported by Barnhart (1943) to be effective in controlling B. germanica. The bait was dispensed in vials stoppered with an absorbent pad, which receded into the vials as the water evaporated or was consumed.

Tate and Klostermeyer (1943) reported that cockroaches will feed on soaps, bookbindings, glue on wallpaper and cardboard boxes when the preferred food is lacking.

While evaluating food preferences of B. orientalis cockroaches by the number of insects caught in traps containing a test candidate, Rau (1945) found that cinnamon bun and white bread were the most attractive. Boiled potato and banana were fair, while celery, boiled egg, and bacon were ignored. Traps baited with live cockroaches or their odor with no food, did not lure other cockroaches.

In 1945, Bare reported that butter, honey, powdered sugar were promising bait material for B. germanica. Malt extract and stale beer, when mixed with boric acid bait increased the rate of mortality 70%, but there were no significant differences in the time required for complete control.

Five per cent boric acid in a water bait test was reported by Marcovitch and Stanley (1946) to 100% mortality to B. germanica in four days.

Baits of dog food tablets containing cornstarch, and gamma BHC, were found by Piquett (1948) to give 100% mortality to P. americana cockroaches, when confined in a container with bait for ten days.

P. americana were reported by Eisa (1951) to be attracted to odors of food rich in sugar such as honey and molasses. Green salad, flour, eggs, and cooked meat were shown to be less attractive.

Eisa and Soliman (1953) evaluated the chemoattractive powers of various carbohydrates, proteins, and fats to P. americana. Maltose was found to be five times as attractive as glucose, sucrose, lactose or starch. Animal fats were twice as effective as plant oil. Of the proteins evaluated, pepsin was shown to be 35 times as attractive to cockroaches as gelatin, casein, and soybean. When pepsin, maltose, and animal fat were compared, an attractant ratio of 20 : 3 : 2, respectively, was obtained.

Raisins, boiled in water to a syrupy consistency, were used by Webster and DeCoursey (1954) in traps to collect B. germanica and P. americana cockroaches.

A bait of corn meal, Coca Cola syrup, Dipterex was found by Keller et al. (1956) to give excellent control of Periplaneta brunnea Burm., Periplaneta australasiae (F.), and P. americana cockroaches in homes for 30 to 60 days. Dried ox blood, starch paste, root beer syrup, malt extract, dextrin, and honey were among the best food materials, while Bayer L 13/19, Shell O.S. 2046, and diazinon were the best toxicants. The baits were sprinkled under sinks, behind refrigerators, stoves, cupboards, etc. Effectiveness of various treatments was based on the number of days that no live cockroach could be found.

Dextrin, cornstarch, and powdered sugar, alone or in combination with each other or different food materials, were found by Lofgren and Burden (1958) to be the most effective dry baits against P. americana

cockroaches, while Coca Cola, root beer, and vanilla syrups were the most effective liquid baits. Powdered sugar solution was the most effective liquid bait against B. germanica cockroaches, however these cockroaches accepted liquid baits more readily than dry baits, whereas P. americana cockroaches showed little preference. Bait tests in homes did not give satisfactory control of B. germanica cockroaches, while 75 to 95% control was obtained with baits against Periplaneta species in dairy barns. Per cent control was determined by taking flash pictures at night.

The analyses of crop and fecal materials of cockroaches by Gangwere (1961) gave characteristic indications of scavengers. They have been found to feed on cardboard, paste board, wallpaper, glue, paste, clothing, water color paints, bookbindings, leather, hair, and foodstuff particularly items rich in starchy material.

Bekun was claimed by Pfister Chemical Work, Inc. (Spear - 1962) to be an effective cockroach attractant.

Jacobson et al. (1963) isolated a highly potent sex attractant from the female of P. americana, which was chemically described as 2,2-dimethyl-3-isopropylidenecyclopropyl propionate.

Of the 32 compounds evaluated by Price (1963) as effective repellents at higher concentrations, 29 compounds showed some attractiveness at concentrations of 0.001 and 0.01% against at least one cockroach species. Compounds which acted as attractants were Phillips R-14177 and piperonyl butoxide with B. germancia, N-pentylsuccinimide and 2- hydroxyethyl tert-hexyl sulfide with P. americana, 2-hydroxyethyloctyl sulfide with B. orientalis, and bis(3-chloropropyl) disulfide, 2-hy-

droxyethyl octyl sulfide and Tabutrex with both B. germanica and B. orientalis. The ether extract of crushed B. germanica cockroaches and caged odors absorbed on Kleenex showed some attractiveness to B. germanica.

While screening low concentrations of chemicals in water bait against P. americana, McCroddan (1963) found the following to be attractive: L-glutamic acid (0.1%), 5-(4-pyridyl-N-oxide) isothiuran chloride (0.00001%), 2-acetamidopyridine (0.1%), 2-amino-4 chloro-6 methyl pyrimide (0.1%), and ethyl alcohol (0.01%). L-glutamic acid was the most attractive.

Inquiline cockroaches (Attaphila fungicola Wheeler) were reported by Moser (1964) to respond to trail-making pheromone of the Texas leaf cutting ant, Atta texana (Buckley). The pheromone was obtained by crushing the poison sac of the ant in one ml of carbon tetrachloride. This substance was not attractive to P. americana, P. fuliginosa, B. germanica, S. supellectilium, and Parcoblatta species.

CSMA fly media, malt syrup, or beer were used by Whitlaw and Smith (1964) as baits to trap cockroaches.

Cockroaches have been reared in laboratories for experimental purposes on a wide variety of foods. Ground whole wheat, dried skim milk and dry baker yeast was used by McCay and Melampy (1937), Melampy and Maynard (1937), and McCay (1938). Griffith and Tauber (1942) reared cockroaches on whole wheat bread, banana, and raw meat. Raw potatoes supplemented monthly with raw lean meat, unassorted potato scraps or Purina Dog Chow was used by Gier (1947), while Noland et al. (1949), and Husain and Fisk (1955) used ground dog food. Gould and Deay (1940a,

1940b) used raw potatoes and later changed to Haydak's mixture consisting of corn meal, whole-wheat flour, wheat bran, dried skim milk, powdered yeast, honey and glycine.

METHODS OF EVALUATION. Various methods have been used by different workers to measure the responses of insects to different kinds of chemicals, foods, odors, etc. Wharton et al. (1954) used three methods to study odorous attractants to P. americana cockroaches, the spot test, the 50% end-point test, and the counterpoint test. The spot test was used to determine the strength of an unknown attractant by the percentage response of 140 cockroaches to some selected dilution rate on successive days.

The 50% end-point test was devised by Reed and Muench (1938). It was assumed that cockroaches responding to any given dosage would respond to all higher dosages, while insects not responding to any given dosage would not respond to any lower dosage. This will not work with one individual, but was justified with a large number of individuals. Wharton et al. (1954) found considerable variation existed with this test.

The counterpoint test was designed to eliminate the variability in response of cockroaches over a long period of time by making comparisons of standards and unknowns on the same day, and preferably at the same time. By alternating the standard with the unknown in successive rounds of the test, it was expected that the influence of adaptation or fatique on the response of the insects to the standard on the one hand, and unknown on the other, would be more nearly equalized. This procedure was found to have a statistical error of ± 40% at the 95% significant level.

In 1954, Wharton et al. found that the behavior of male P. americana toward a specific odor attractant emitted by virgin females was proportional to the log concentration over a wide range. Although it was found that cockroaches varied considerably in response during either short or long intervals of testing, they could be safely tested daily.

Experiments were conducted in a box by Eisa (1951), whereby sixteen P. americana cockroaches had a choice of entering two traps, one containing test food and the other with no food. The results were evaluated by the number of insects in the trap, as compared to the control.

A means of evaluating the attractancy and repellency of various chemicals to cockroaches was described by Goodhue and Tissol (1952). This method was based on the insect's habit of hiding in sheltered areas away from light. The cockroach was given a choice of two cartons, in which one was treated with a chemical. If the chemical was an attractant, more cockroaches would be found in the treated carton and vice versa if the chemical was a repellent.

In 1953, Eisa and Soliman evaluated food preferences of P. americana by releasing 100 starved cockroaches into a 250 ft^3 glass cage containing a number of traps with different kinds of food. The traps were constructed from a glass tube 60 cm in length and 5 cm in diameter. At each end of tube, a muslin funnel was fitted, being directed inward to serve as a valve to prevent the insects from escaping after entering the trap.

Two methods were described by Goodhue (1960) for screening repellents against cockroaches. The slanting card method was based on the tendency of cockroaches to rest on a slanting surface. The treated cards were placed inside a container, and evaluated by the number of cockroach-

es on the treated card as compared to the untreated card. The ground glass cylinder method employs three intercommunicating glass cylinders, in which the two other cylinders contained treated filter papers on the bottom. The results were determined by comparing the number of cockroaches on the treated and untreated surfaces.

Several techniques mentioned by Gangwere (1961) as a means of studying food selection in Orthoptera were: (1) analysis of crop contents and fecal materials, (2) observation of individual feeding in natural habitats, (3) analysis of food found near and around the dwellings, and (4) the utilization of different feeding tests.

Thin wafers were used by Price (1963) to evaluate taste repellents and attractants. The wafers were treated with test candidates and mounted on insect pins approximately $\frac{1}{4}$ inch above the center of a small cardboard block. A clear plastic disc marked off in halves, quarters, and eighths was used to measure the amount of food consumed by the cockroaches during the test. In repellent tests with B. germanica, Price showed that there was little difference in results from different sexes or stages of development.

McCroddan (1963) developed and perfected a method for evaluating a variety of liquid baits to P. americana cockroaches. This procedure consisted of a circular arrangement of glass tubes containing liquids suspended vertically from a lid into a container.

An olfactometer designed by Howell and Goodhue (1964), was used by Price (1963), and Kahn (1963) to evaluate vapor attractants and repellents to various insects. An index devised by Howell and Goodhue was used to rate the test materials. Cockroaches were held one day by Price before using in another test.

Public health officials (Anon. 1964) found a chicken watering unit, modified by inserting a cellulose sponge in the trough to prevent clogging by dead flies, was an effective device for dispensing liquid bait.

MODE OF ACTION. The presence of chemoreceptors on the antennae, maxillary and labial palps of P. americana were demonstrated by Glaser (1927). Starved cockroaches with antennae amputated did not come to food like normal insects. Cockroaches with only antennae amputated could find food much easier than those that had antennae, maxillary, and labial palps amputated. The latter insects had to taste food in their mouth before knowing it was food.

Pringle (1938) made an attempt to show that the campaniform sensilla on the legs of P. americana was similar in action to those on the palps. He found these sensilla to have no sensitivity to olfactory stimuli.

The maxillary palps of inquiline roaches were reported by Moser (1964), to be in constant contact with the artifical trail made from the trail-making pheromone of the Texas leaf cutting ants. The antennae of the cockroaches moved vigorously but never touched the trail.

Chemoreceptors were demonstrated by Frings and Frings (1949) to be located on the palpi, hypopharynx, and ligula. A P. americana cockroach walking through a sugar solution did not stimulate feeding response, while touching the solution with maxillary palpi did. The antennae and cerci were found to lack contact chemoreceptors. The removal of maxillary palpi induced cockroaches to lower their body so that the tips of the labial palpi touch the substrate as they walked. Feeding commenced upon touching a sugar solution. If a food or a sugar

water drop touched the mouthpart of a palpectomized cockroach, feeding occurred immediately.

A cockroach with all the suspected loci of contact chemoreceptors removed, fed readily on water, but also on a salt water solution, which no normal or palpectomized insect did. This experiment, when conducted on B. germanica cockroaches, gave the same results.

The legs of cockroaches, not known to contain olfactory receptors, were shown by Roy (1954) to be stimulated by repellent vapors.

Behavorial and electrophysiological experiments by Roys (1956, 1958) indicated a close correlation between behavioral responses to four basic tastes, salt (sodium chloride), sour (hydrochloric acid), sweet (sucrose) and bitter (quinine), and electrophysiological responses from nerve unspecialized for taste exposed to the same chemicals. This suggests that chemical sensitivity may be a basic property of many nerves in cockroaches rather than limited to taste receptors.

Prat (1956) demonstrated that P. americana cockroach ceased to react to the odor of the opposite sex or alcohol vapors, when the antennae of an active cockroach were antennectomized.

In 1963, Price demonstrated that P. americana cockroaches were able to sense the presence of repellents even though entire segments or portions of a head appendage of known sensory devices had been removed. This suggests that chemoreceptor sites were probably scattered over the appendages and the body of the cockroach, and the removal of one or a group of receptors on an appendage does not affect the reception of others.

CADMIUM CHLORIDE. Cadmium chloride and cadmium lactate were report-

ed by Parizek and Zahor (1956) to sterilize male laboratory rats. One ml of 0.03 M aqueous solution of cadmium salt injected subcutaneously produced macroscopic lesions in testes, while no morphological lesions were detected in the ovaries of female rats.

In 1957, Parizek found that 0.02 mM of cadmium chloride/kg body weight caused testicular damage to male rats, while a tenth of this dosage produced no change in ten days. Cadmium chloride injected at 0.04 mM/kg body weight in both rats and mice, produced total destruction of all tubular epithelium, while in the interstitial tissues, there were hemorrhages, vascular thromboses and slight inflammatory reaction. The whole testis was replaced in ten days by masses of eosinophilic tissue.

Cadmium chloride, 1 mg/100 gm body weight was found by Kar, Das, and Karkun (1959) to induce profound cellular and vascular changes in the ovaries of prepuberal rats. However, after 168 hours, the ovary features were normal.

Testes of cadmium chloride treated mice were shown by Meek (1959) to be swollen in 12 and 24 hours. There was extensive damage in 48 hours, and complete destruction of the cells within the tubules in 96 hours. These organs were distinctly shrunken and yellow in three weeks.

Testicular changes due to cadmium chloride were reported by Parizek (1960) in mice, rabbits, guinea-pigs, and golden hamsters. A single intratesticular injection of cadmium chloride was reported by Kar (1961) to sterilize male Rhesus monkeys.

Gunn, Gould, and Anderson (1961a, 1961b) found that 0.3 mM of cadmium chloride/kg of body weight in rats produced marked injury to the testes, while no pathological changes were noticed in the female sex organs.

ECOLOGICAL STUDIES. Hilchey and Patton (1952) found that the sex-ratio of male to female varied from 0.67 to 2.57 in ten egg capsules of B. germanica cockroaches.

A formula was devised by Webster and DeCoursey (1954) for estimating the population of cockroaches by the number of insects caught in traps over an extended period of time.

MATERIALS AND METHODS

The objective of this undertaking was to investigate the ecological and physiological mechanisms influencing food finding in Blattaria. This includes the study of food preference of the major species of cockroaches, how they find their food, the development of an effective bait for their control, and the study of their habits and population distribution in homes, and the effect of cadmium chloride and its possible use for control.

TEST INSECTS. Three major species of pestiferous cockroaches were used in this study. The American and German cockroaches were obtained from Thuron Industries, Inc. of Dallas, Texas where the colonies have been maintained for eight years or so. The Oriental cockroaches were trapped in the vicinities of Dallas and Clarksville, Texas. A small number of B. orientalis was obtained through the courtesy of Dr. Harry D. Pratt of the Communicable Disease Center, Atlanta, Georgia, to start a colony.

The cockroaches to be used in laboratory tests were fed raw potatoes and Purina Dog Chow at Thuron Industries, Inc., while only dog chow was used at Oklahoma State University. The cockroaches were reared in 20 gallon garbage cans containing a series of shelves which provided sufficient surface area for the insects.

TEST LOCATION. Laboratory tests were conducted in the laboratories of Thuron Industries, Inc. and the Entomology Department of Oklahoma

State University. A constant temperature of 80 F ± 2 was maintained for experimental work at Thuron Industries, Inc., whereas the laboratory experiments at Oklahoma State University were conducted at a temperature of 80 F ± 4.

A number of houses and apartment housing units in Dallas, which were characterized by poor housekeeping and a heavy infestation of cockroaches, were chosen for field studies. Foods and garbages were readily available to the cockroaches. Field evaluations were also conducted in Stillwater, Oklahoma.

TEST MATERIALS. Laboratory evaluations were made with over 80 different foodstuffs, including starches, sugars, proteins, salts, fats, vegetables, mixtures, etc. A number of chemicals, which were reported to be attractive to cockroaches, were tested. Ninety-one different formulations of foods, chemicals, and attractants were evaluated as semi-solid, solid formulation or liquid, while 110 formulations were evaluated as liquid baits.

The dehydrated type foods evaluated were obtained through the courtsey of California Vegetable Concentrates, Inc., Modesto, California; Hathaway Allied Products, Los Angeles, California; HEFSE, Inc., Yucaipa, California; Meer Corporation, North Bergen, New Jersey; Vitamin Products Company, Milwaukee, Wisconsin; and The Borden Company, New York, New York.

A number of chemicals were recieved through the courtesy of Phillips Petroleum Company, Bartlesville, Oklahoma. The other foods were purchased from local sources.

BAIT PREPARATION. Baits were evaluated as semi-solid formulations,

or as liquids. The semi-solid baits were made from dehydrated food by water until they had a paste-like consistency. Chemicals were evaluated in water-liquid bait in concentrations from 0.0001% to 1.0%.

LABORATORY TEST PROCEDURES. Four types of tests were conducted in the laboratory evaluation of food preferences of cockroaches: (1) evaluation of solid or semisolid baits, (2) the evaluation of liquid baits, (3) the olfactometer test, and (4) the bait trap procedures.

Solid and Semi-Solid Baits. Several methods were used in developing a precise technique for evaluating the attractiveness of various solid or semi-solid foods to cockroaches.

Randomized Block Design. The first method, conducted in four one-half bushel tubs, was analyzed by the randomized block design. In order to provide adequate surface area for the cockroaches, a series of shelves was placed in each tub. Three pieces of 0.25 inch plywood were mounted horizontally on a 1 inch dowel spindle at 1.5 inch intervals. Each plywood shelf was ten inches square. Vertical partitions 2 by 6 inches were attached to each side to provide access for the insects between the shelves. Four baits were placed in metal containers, 1.5 inches in diameter and 0.38 inch deep, and were arranged equidistant from the walls of the container, and from each other on the top shelf. These baits were replicated in each of the four tubs in different positions. Approximately 500 B. germanica cockroaches were placed in each tub. Of this number, approximately 50% were males, 28% were non-egg capsule carrying females, and 22% were nymphs.

Latin Square Design. The Latin square design, illustrated in figures 1 and 2, was the second method used. This test was conducted in a 20 gallon garbage can, 20 inches high, 18 inches in diameter at the top,

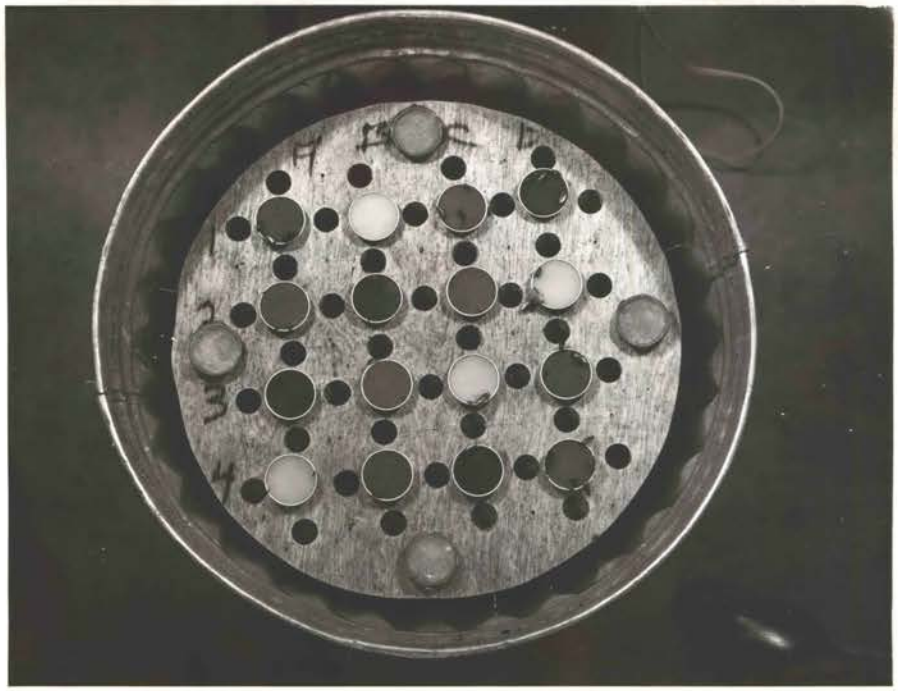
and 15.75 inches in diameter at the base. A series of shelves to provide surface area for the insects was placed in the container. Eight pieces of 0.25 inch plywood, 10.5 inches square, were mounted horizontally on 4 vertical plywood partitions at 1.5 inch intervals. The vertical partitions, 3.5 inches wide and 13 inches long, were placed in the middle of each side in order to provide access between shelves for cockroaches.

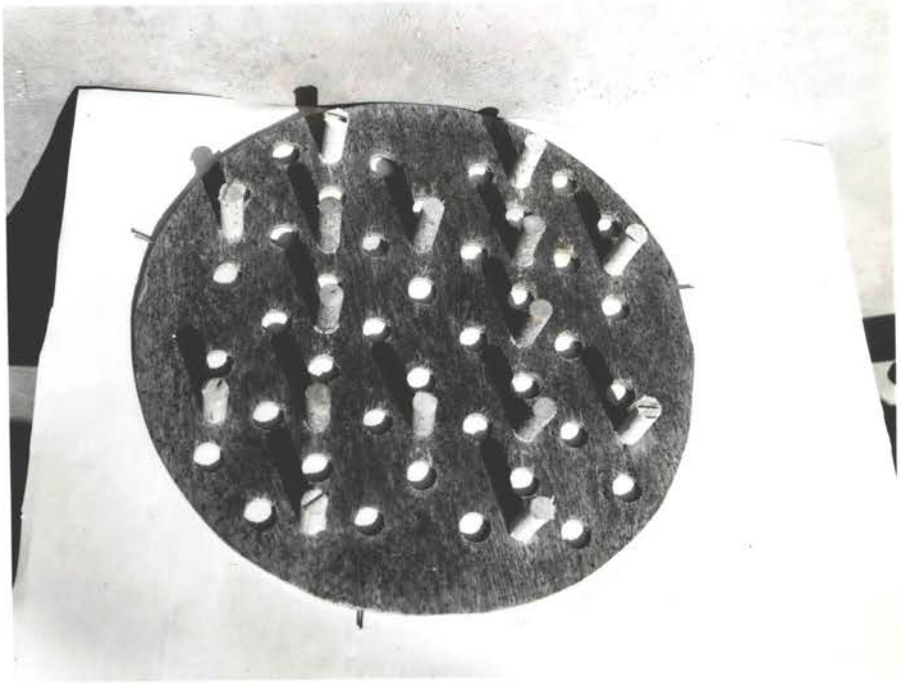
On the top shelf, a circular 0.25 inch plywood device, 16 inches in diameter, was designed to test 4 treatments and 4 replicates. An 11.25 inch square was drawn on this circular board. This square was further divided into 16, 2.81 inch squares. Forty holes, 0.81 inch in diameter, were cut on the board to enable the cockroaches to come up through the board and feed at random. Each hole was cut in the center of each line that formed a small square.

In order to insure equal distribution of cockroaches on the top board, 16, 0.75 inch dowel pegs, 2 inches long, were placed vertically on the bottom of the board. Each line of 5 pegs, which started on the margin, 2.81 inches from each corner of the large square, formed 2 sets of parallel lines at right angles to each other (figure 2). These lines intercepted each other 2.81 inches from each margin. The pegs were located in a line at 2.81 inch intervals. Two 3.5 square inch pieces of 40 mesh to an inch screen wire were placed on opposing sides of the garbage can, near the bottom to allow for ventilation. The top of the garbage can was modified to adapt a water suction device to remove odor in the test container. In the center of the lid of the garbage can, a one inch inside diameter bearing was secured, which allowed the connecting hose to fit snugly to provide for rotation with very little air loss.

Figure 1. The Latin square experimental unit showing B. germanica cockroaches feeding.

Figure 2. The bottom part of the Latin square design showing the arrangement of dowel pegs.



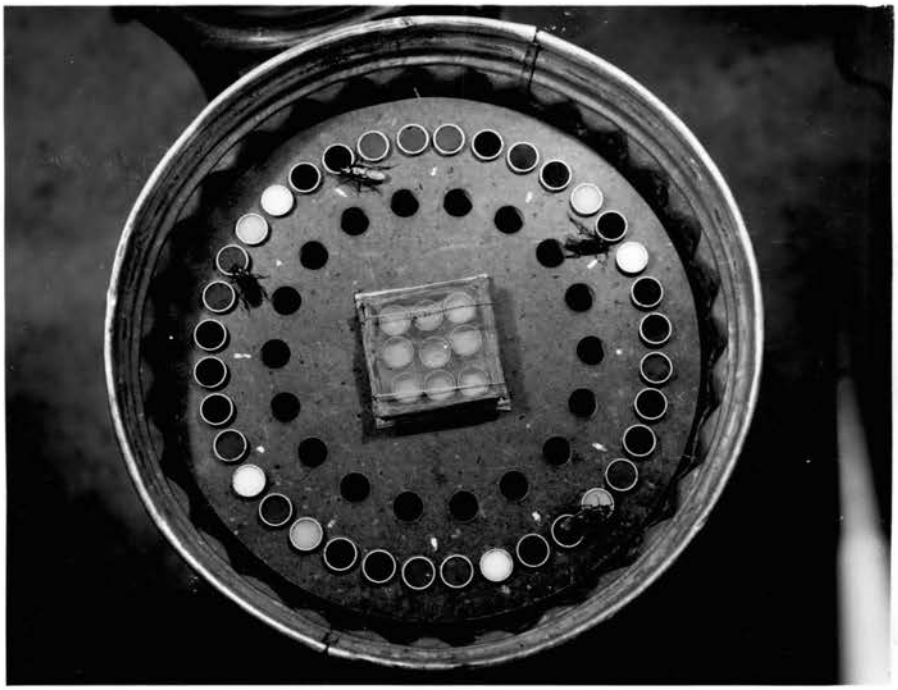


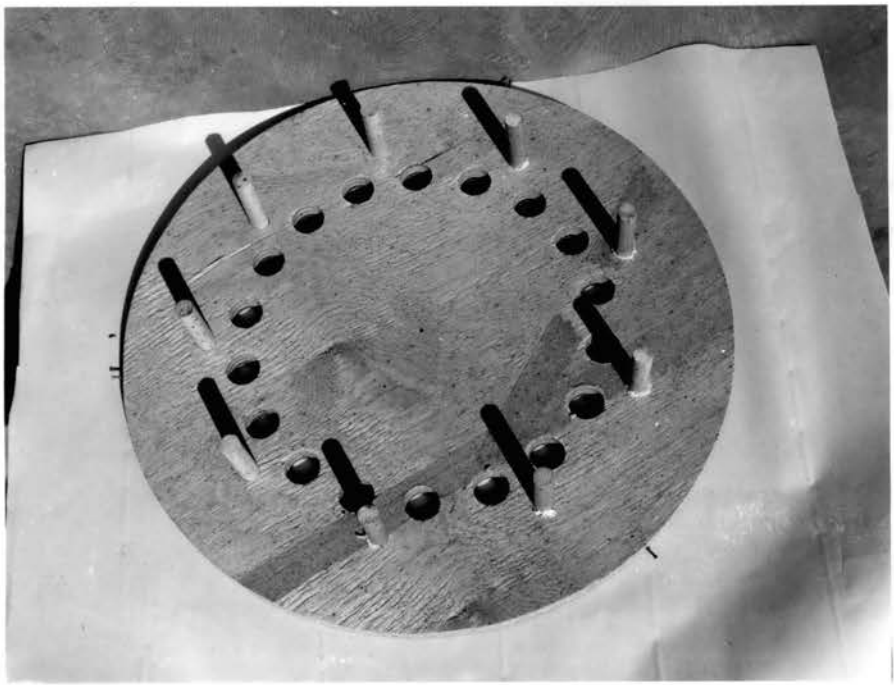
This also aided in reducing variation between replicates. The baits, which were in the same size lids as used in the method, were placed in the center of each small square.

Incomplete Block Design. The third method, shown in figures 3 and 4, was conducted in a 20 gallon garbage can with the same procedure as the second method, except for a modified board, which was placed on the top shelf. This top board consisted of a circular 0.5 inch plywood with tempered masonite glued on top. The board had 36 receptacles, 0.94 inch in diameter, for holding lids containing test foods. These receptacles were located in a perimeter radius of 6.8 inches. Eighteen holes, the same diameter as the receptacles, were cut in a perimeter radius of 4.9 inches, halfway between every other receptacle. Nine pegs, two inches long were placed vertically under the board intermediate between holes in a perimeter radius of six inches to insure equal distribution of cockroaches on the top board. This method, which was designed to evaluate 9 treatments and 4 replicates, was analyzed statistically by the incomplete block design.

The baits were placed in metal lids 0.94 inch in diameter and 0.38 inch deep and weighed. The test materials were exposed to B. germanica for four hours and to P. americana and B. orientalis for 45 minutes. The baits were reweighed to determine the amount consumed. The liquid baits, which were evaluated in metal lids, were soaked in cotton to prevent the insects from falling into the liquid.

Since some of the baits contained volatile matter such as water or oil, control samples were set up to account for the loss in weight due to evaporation. Each control sample was covered with 40 mesh to the inch screen wire to keep cockroaches from eating the food. The weight losses





in the control samples were subtracted from the weight of the test bait samples to correct for this weight factor. Four control samples were evaluated to determine the variation of weight loss due to evaporation. The insects were starved 24 hours before testing.

In order to establish the reliability of the above procedures, initial tests of the first, second, and third methods were repeated several times. Differences between the treatments were analyzed using the Duncan's multiple range test.

The Latin square and randomized block designs, consisting of four treatments and four replicates, were used to evaluate food preferences of B. germanica cockroaches. Borden's dehydrated potatoes plus water to make a paste, arbitrarily given a rating of 100, was used as a standard to directly compare all other foods. For example, the cockroaches consumed ten grams of dehydrated potatoes plus water and six grams of dehydrated apple plus water. Thus the comparative rating for dehydrated apple = 6/10 X 100 = 60.

A bait composed of 10% dehydrated potato, 15% powdered sugar, and 75% water was used as the standard for tests conducted with P. americana, and B. orientalis. These foods were further classified into four index catergories for ease in comparison. The index number 1 included foods which have a rating above 90 in comparison to the standard bait index of 100. The index number 2 equals 56 to 90, index number 3 equals 21 to 55, and index number 4 equals 0 to 20.

Preference Test. An experiment was conducted to determine if cockroaches would develop preferences for certain food. Cockroaches were fed dehydrated potato paste, moist Purina Dog Chow, raw potato or peanut butter for 135 days. Preference tests were conducted at the end of 38

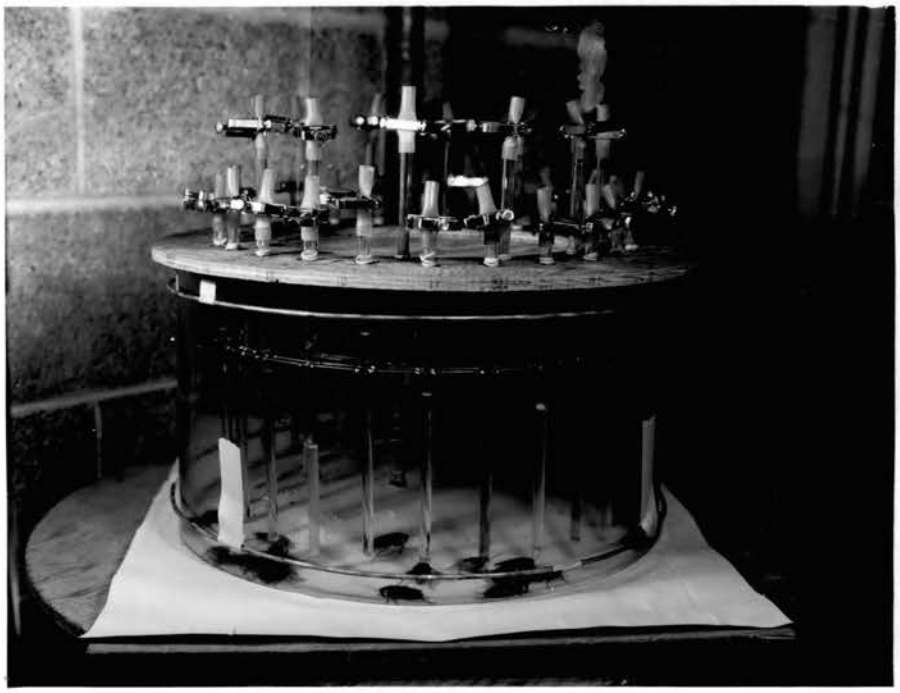
and 135 days.

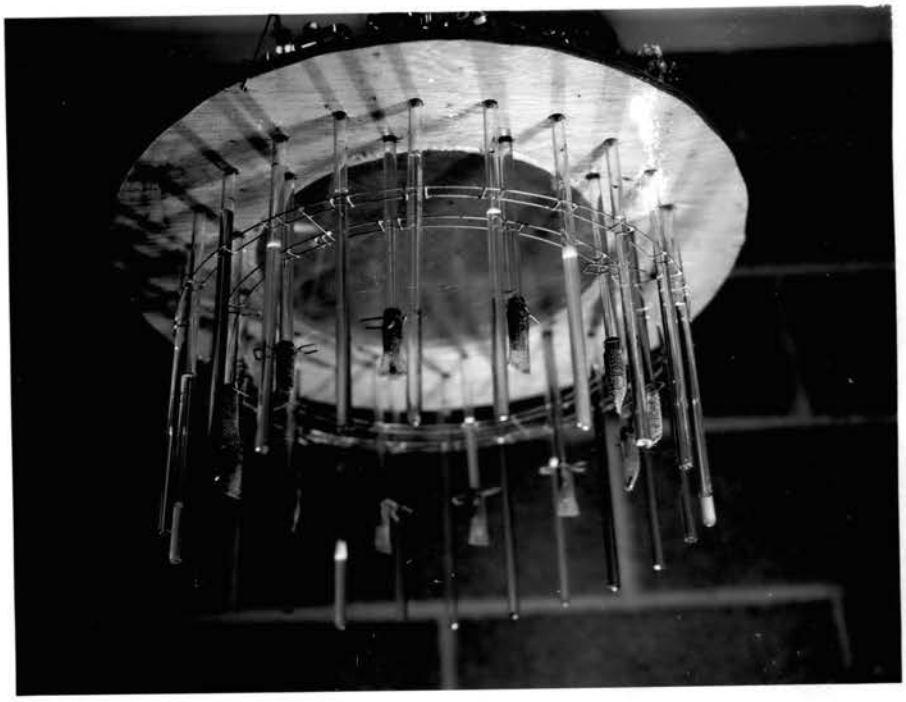
Color Test. Four colors, red, blue, green, or yellow (French's Food Colors, The R. T. French Co., Rochester 9, New York) in a potato bait were evaluated both in the dark and light with B. germanica cockroaches. The Latin square method described above was used for this test.

Odor Masking Test. A test was designed to determine if cockroaches depend on the sense of smell or taste in choosing their food. An effort was made to mask the food odors of the nine foods evaluated with P. americana to establish the reliability of the incomplete block design. Alpunod G was recommended by Florasmunth Laboratories, New York 62, New York as a masking perfume to neutralize the food odors. The technical material in a wire covered container was exposed to P. americana cockroaches for five hours prior to and during the test.

Liquid Bait. The procedure developed by McCroddan (1963) was used to study the acceptability of liquid baits to cockroaches. The experimental design shown in figures 5 and 6 consisted of a circular arrangement of glass tubes suspended vertically from a lid placed on top of a clear plastic cylindrical container. The cylinder container was 16 inches in diameter, was cut from plywood and had a 9.75 inch circular hole in the center covered with nylon tulle to allow ventilation.

Eight- millimeter glass tubes with an inner diameter of six millimeters, were arranged in two rings, an outer ring of 13.25 inches in diameter consisting of 24 evenly-spaced consumption tubes, and an inner ring of 11 inches in diameter consisting of 12 evenly-spaced evaporation check tubes. A light wire frame was used approximately three inches below the lid to stabilize the tubes. Consumption tubes refer to those tubes from which liquid could be consumed. The evaporation check tubes





refer to those tubes fitted with a screen cage on the lower end to prevent consumption.

Short lengths of rubber tubing and screw-type clamps were used to close the top of glass tubes. The tubes were filled by sucking the liquid above a mark at uniform height on each tube and then adjusting the level to the mark by manipulating the screw clamp. The lower ends of the tubes were carefully wiped to reduce frame contamination. The tubes were adjusted with a small rubber band to a height of 0.8 inch off the base.

Each treatment was replicated twice with four water checks in the outer consumption ring of 24 tubes. One replicate of each treatment and two water evaporation checks were placed in the inner ring. The test unit was placed on a turntable making one revolution per minute to eliminate variations due to temperature, light, and position.

The results were recorded after 24 hours by carefully measuring the distance from the liquid level to the original level mark. The datum was obtained by subtracting the evaporation measurement from the consumption measurement to give the amount of liquid consumed.

Thirty-five cockroaches in the test unit were found to give the best results. The test liquid was considered to be attractive, if the consumption rate was significantly greater than that of water.

To avoid the effect of light on the activity of the cockroaches, it was excluded by the use of a large cardboard box with a black cloth around the base. Water was used to check the validity of the evaporation and consumption rates. The analyses indicated that there were no significant differences in evaporation rate between the inner and outer rings at 20% level of probability, and in the consumption rate at the 10%

level of probability.

A solution of sulfuric acid saturated with potassium dichromate was used to clean tubes and other glasswares to remove any trace of chemical remaining from a previous test. At the end of the test, the cockroaches were anesthetized with CO_2, to facilitate removal of the liquid test unit for recording data.

Twenty per cent sucrose solution was used as the standard bait with P. americana and B. germanica, while 50% root beer syrup and 50% water solution was used as the standard bait for B. orientalis. The test baits were compared to the standard bait for a comparative rating using the procedure described above.

Olfactometer. An olfactometer, developed by Howell and Goodhue (1964), was used to evaluate vapor attractants to cockroaches. The unit consisted of a vertical ground glass cylinder with a partition in the lower two-thirds to separate the flow of air from two flared tubes. The test material was placed on a small square of a Kleenex tissue, which was tied around one flared tube in each cylinder. An aspirator pump pulled the air through the cylinder, giving the insects on top of a wire screen a choice of the odor of the test material or fresh air. An index rating devised by Howell and Goodhue was used to rate the test materials.

Bait Traps. Bait traps were used in an effort to evaluate odor attractants to cockroaches.

Trap I. A bait trap shown in figure 3, similar to the one developed by Eisa and Soliman (1953), was used to evaluate the attractiveness of various test materials to P. americana. This device consisted of a cylindrical tube 1.75 inches in diameter and 15 inches long, with an in-

verted funnel valve at each end, which prevented the cockroaches from escaping. The test material was placed in a metal container in the center of the trap. Approximately one hundred cockroaches were released into a tight room 6 feet long, 6 feet wide, and 6 feet high.

Four traps, containing three baits, and one control, were placed in the room. Each trap was placed diagonally across a corner with each end one foot from the walls. Baits were evaluated by the number of cockroaches caught in the traps in 24 hours.

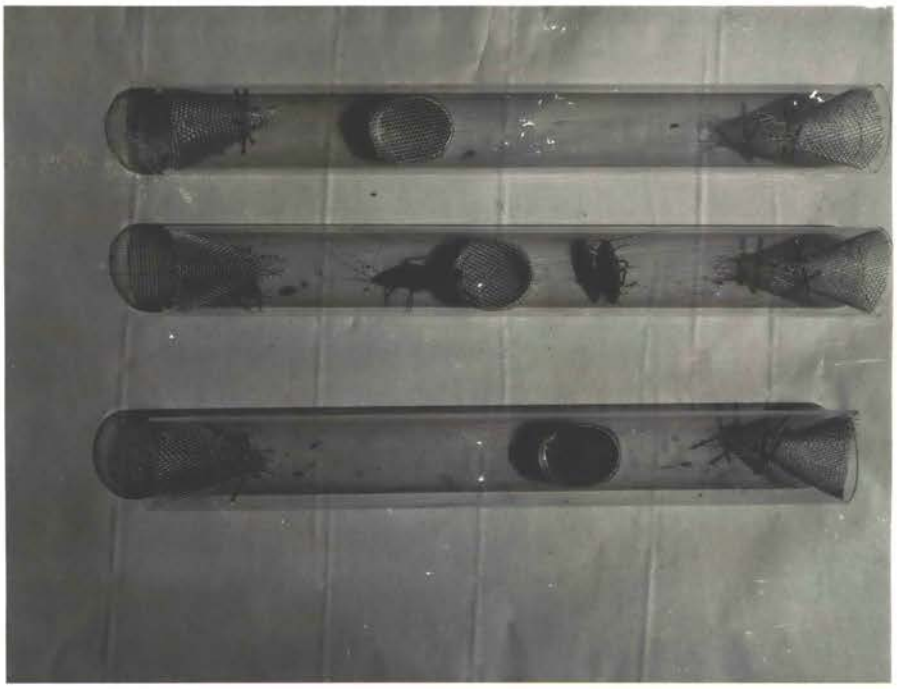
Trap II. This trap was a modification of the one above using B. germanica. The trap was constructed from a small vial, 1 inch in diameter and 3.75 inches long. The unit consisted of 9 traps which were arranged in a circle on the top shelf of the incomplete block design unit as shown in figure 8.

Trap III. This test was conducted with B. germanica. Using the top shelf of the equipment used in the incomplete block design, nine 0.5 pint jar lids with a hole 0.94 inch in diameter, were nailed to the bottom shelf over every other hole as shown in figures 9 and 10. The bait was placed in jars which were oiled around the rim with vegetable oil to prevent the cockroaches from escaping after entering. The test, which included 2 replicates of 3 treatments and 3 controls, was run for 24 hours.

Smoked Plate Test. The purpose of this test was to assist in determining how cockroaches find their food. A smoked glass plate with potato paste bait in the center was used to study the trails of cockroaches in finding foods. A glass plate 2 ft by 2 ft was smoked or coated with magnesium oxide.

Figure 7. Trap I experimental unit with P. americana in the middle trap.

Figure 8. The experimental unit of trap II showing the arrangement of traps.



Comparative Bait Test. A test was conducted with P. americana to compare the acceptability of a semi-solid bait containing 10% dehydrated potatoes, 15% powdered sucrose, and 0.5% dichlorvos with phosphorous paste (Common Sense, Buffalo, New York), a well known accepted bait. The treatments were replicated nine times using the incomplete block design test equipment.

Another test was set-up to compare the relative effectiveness of commercially available cockroach baits with a semi-solid formulation containing 10% dehydrated potatoes, 15% powdered sugar and 0.5% dichlorvos. The other baits tested were Common Sense phosphorous paste, 0.25% Kepone bait (Allied Chemical Corp. New York, New York), and Bayer 2% 39007 bait (Chemagro, Kansas City, Missouri). Each bait was placed in a plastic container, 9 inches in height and 16 inches in diameter with 20 roaches, starved for 24 hours. Mortality was recorded in 24 hours.

FIELD EVALUATION. Field tests were conducted to substantiate laboratory investigations.

Semi-Solid Bait Test. A number of houses and apartment housing units, heavily infested with B. germanica, were chosen for evaluation of various baits and cockroach insecticides.

One of the problems in evaluating the effectiveness of a roach control material was measuring the roach population density. In an effort to provide such a measure, the Roach Mortality Index (RMI) was designed. The RMI shows the mortality rates during the test period based on the percentage of the total number of dead cockroaches picked up during the study. It was calculated by the equation:

$$RMI = \frac{\text{Number of dead roaches picked up per time period}}{\text{Total number of dead roaches picked up during study}} \times 100$$

The dead cockroaches were picked up daily the first week, and then every every other day thereafter.

Test Number I. The most effective semi-solid bait developed during the laboratory studies was used to determine its effectiveness in comparison to various household sprays for the control of B. germanica. The semi-solid bait consisted of 10% Borden's dehydrated potatoes, 15% powdered sucrose, 0.5% dichlorvos (dichloro divinyl phosphate), and 74.5% water.

Three commercial cockroach sprays containing the following components were purchased in the Dallas area.

Spray A	
Hexachloro-expoxyoctahydro dimethanonaphthalene	0.425%
N-octyl bicycloheptene dicarboximide	0.150%
Piperonyl butoxide	0.900%
Pyrethrins	0.450%
Spray B	
Dieldrin	0.300%
Diazinon	0.200%
N-octyl sulfoxide of isosafrol	0.100%
Pyrethrins	0.046%
Spray C	
Diazinon	0.33%
Pyrethrins	0.06%
Piperonyl butoxide	0.90%
N-octyl bicycloheptene dicarboximide	0.15%
Chlordane	1.00%

The bait was applied from a squeeze bottle to the walls and sides behind the cabinet, under the sink, pantries, and places where cockroaches may frequent. One pint of bait was used for each treatment. The spray was applied throughout the kitchen, under the sink, inside the cabinet, under the refrigerator, in the pantry, under tables, in bedroom and bathroom closets, dresser drawers, etc. From 0.25 to 0.75 pint of

spray was used in each treatment. The spray was applied as long as the cockroaches were active and running about.

At the end of the experiment a pyrethrum "flushout" was used, in the houses treated with baits, to determine the number of cockroaches left. This treatment was applied at least twice in the same manner as the household sprays above. A 0.5% pyrethrins, and 5.0% piperonyl butoxide formulation was used for the final evaluation.

Test Number II. A comparison was made between a powdered sugar semi-solid bait and the dehydrated potato and powdered sucrose semi-solid bait used in test I with dichlorvos as the toxicant. A house was first treated with the powdered sugar bait and four days later with the potato bait in same manner as in test 1.

Test Number III. A test was set up to evaluate the comparative effectiveness of a dry bait and wet bait. The dehydrated potato and powdered sucrose semi-solid bait was placed on a two inch band of paper tape, and allowed to dry for one week before putting in the test houses. The dry bait was evaluated for two weeks before treating with moist semi-solid bait.

Test Number IV. The objective was to evaluate the dehydrated potato and powdered sucrose bait in tablet and semi-solid forms in metal lids against B. germanica. The bait was compressed into a cylindrical tablet, 0.5 inch in diameter and 0.5 inch in height. Each tablet weighed two grams. Twenty-two ml of water was placed into large lids, 2.25 inches in diameter and 0.38 inch in depth, with 4 tablets to give a 0.5% dichlorvos concentration in the bait. Eight ml of water was placed in small lids, 1.5 inches in diameter, and 0.38 inch in depth, with one tablet to give the same concentration of dichlorvos in the bait.

Treatment A consisted of four bait tablets in each metal lid. Treatment B employed semi-solid bait in large metal lids. Three to six lids of treatment A and B were placed in each house. In treatment C, one bait tablet was placed in a small lid. Twelve lids of treatment C were used in the test house.

The baits were distributed throughout the kitchen, on top and within the cabinets, under the sink, refrigerator, etc. Water was added to the metal containers, as needed, to keep the bait moist. Fresh bait was placed in each lid of treatment A and B after two weeks. After one week the house used in treatment C was locked for two weeks. Water was added to the dried bait during the fourth week. Fresh bait was placed in the lids during the fifth week.

Test Number V. The purpose of this test was to evaluate two methods of applying bait. A semi-solid potato and sucrose bait containing 0.5% dichlorvos was used in this study. In application I the bait was applied from a squeeze bottle to the walls and sides behind the cabinet, under the sink, pantries, refrigerator, and other places frequented by cockroaches. One pint of bait was used for each treatment. In application II the bait was applied from a squeeze bottle to cards, two inches square. Approximately 20 cards were distributed at random in each test house in the area mentioned above. Several pyrethrum "flushouts" were used after two weeks, to determine the effectiveness of the treatment.

Test Number VI. The purpose of this study was to obtain comparative field data on the relative effectiveness of Entex and diazinon for cockroach control. Entex and diazinon were used at the manufacturers recommended dosages of 1.9% and 0.5% respectively in a water emulsion.

Liquid Bait Test. A group of unoccupied Oklahoma State University furnished apartment houses was used to study the effectiveness of the most attractive liquid bait developed during studies. Approximately 175 B. germanica cockroaches were released in each test unit. These insects were allowed three days in the unit before initiating the test.

The apartments were divided into two groups. One group contained food which was the semi-solid dehydrated potato and powdered sucrose bait without the toxicant, and the other section contained no food.

The liquid bait consisted of:

Sucrose	20.0%
Dichlorvos	0.5%
Water	79.5%

The bait was placed in modified type baby chicken watering unit. A station was established under each kitchen sink and in the bathroom of each apartment. The RMI was used to evaluate the effectiveness of the bait.

CADMIUM CHLORIDE. Cadmium chloride has been reported as an effective chemosterilant against several male laboratory animals by different workers. The objective of this study was to determine its effects on cockroaches when injected subcutaneously or fed to them.

The following concentrations of cadmium chloride were injected into the coxa of the adult male P. americana by micrometer syringe: 0.1, 0.01, 0.001, 0.0001, 0.00001, 0.000001, and 0.0000001 mM/kg of body weight. The highest concentration of cadmium chloride was injected into the adult females. The cockroaches were dissected in 2 and 14 days, and the sex organs were preserved for sectioning.

To determine the range of acceptability, the following concentrations were evaluated in the liquid tube test using a 20% sucrose solution: 1.0%, 0.1%, 0.01%, 0.001%, 0.0001%, 0.00001%, and 0.000001%.

RESULTS

LABORATORY TESTS. The results of solid or semi-solid and liquid bait tests are given below.

Solid and Semi-Solid Baits. Three types of semi-solid test were used to evaluate food preferences of cockroaches.

Randomized Block Design. A typical test with the randomized block procedure with B. germanica, showing the variation between replicates and the amount of food consumed, is presented in table 1. Three tests were conducted to establish the reliability of the randomized block design. The results shown in table 2 indicated that there was a general consistency in food preference in different tests.

Latin Square Design. In a typical test using the Latin square procedure with B. germanica, the variation of data and amount of food consumed are shown in table 3. To establish the reliability of the procedure, four tests were evaluated. The data, presented in table 4, indicated that there was a general consistency in food preference in different tests.

The results of tests using both the randomized block and the Latin square designs are shown in table 5. A 10% dehydrated potato and powdered sucrose semi-solid bait was the foremost attractive bait to B. germanica. The analyses of variance indicated that the treatments were highly significant at the 1% level.

Incomplete Block Design. Semi-solid baits of persimmon, date, date

sugar, and sucrose were found to be highly attractive to P. americana including the 10% dehydrated potatoes and 15% powdered sucrose semi-solid bait, which was the foremost attractive bait to B. orientalis.

The variation between treatments and amount of food consumed in a typical test with P. americana are shown in table 6. Several tests were conducted to establish the reliability of the incomplete block design. The results presented in table 7 show a general consistency in food preference. The list of semi-solid foods in the order of preference exhibited by P. americana are shown in table 8. The semi-solid food preferences of B. orientalis are presented in table 9. The analyses of variance indicated that the treatments were highly significant at the 1% level.

Preference Test. Data shown in table 10 indicated that B. germanica had not developed a preference for a particular food at the end of 38 and 135 days. The cockroaches fed raw potatoes, seemed to prefer Purina Dog Chow, while the insects in other units preferred semi-solid dehydrated potatoes. There were some differences in the preference of the two least preferred foods.

Color Test. The analyses of variance indicated that there were no significant differences between color baits in tests conducted both in the light and dark.

Odor Masking Test. The P. americana cockroaches were not affected by the masking agent in selecting their foods since they fed on the nine foods in the same order as in tests without masking agent.

Liquid Baits. The food preferences of P. americana in order of their attractiveness are shown in table 11. Twenty and thirty per cent sucrose in water were the most attractive baits to P. americana. Table

12 shows the rating of foods evaluated with B. orientalis. Potato water containing 5% or 20% sucrose was the preferred bait of B. orientalis and B. germanica. The food preferences of B. germanica are presented in table 13. The analyses of variance indicated that the treatments were highly significant at the 1% level.

OLFACTOMETER. The use of the olfactometer to study odor attractants to cockroaches was not successful. Cockroaches were definitely repelled by a strong repellant, but the reading was inconclusive where attractants were used.

BAIT TRAPS. Several types of bait traps were used in an effort to evaluate odor attractants to cockroaches.

Trap I. This test was not conclusive since a large number of P. americana cockroaches were caught in the control (unbaited) trap.

Trap II. The traps were not effective in trapping B. germanica cockroaches.

Trap III. An equal number of cockroaches was trapped in the control and treatments, indicating that this procedure can not be used to evaluate cockroach attractants.

SMOKED PLATE TEST. In a test with american cockroaches, one cockroach moved in a zig-zag pattern over the plate. The maxillary palpi were continously sensing the smoked surface of the plate until the food was found in the center. Another cockroach came directly to food. While the two cockroaches were feeding, the third cockroach discovered the food in the same manner as the first.

A plate coated with magnesium oxide was used to study the food habits of German cockroaches. The plate with food in the center was left over night on a table in an area infested with German cockroaches.

When the plate was examined in 12 hours, many cockroach tracks were found around the bait containers and many random trails led to the food.

COMPARATIVE BAIT TEST. American cockroaches consumed 2.14 grams of a semi-solid dehydrated potato, powdered sucrose, and 0.5% dichlorvos bait in contrast to 0.74 gram of phosphorous paste bait. The cockroaches were all dead in one hour.

The phosphorous paste, semi-solid potato bait, and 2% Bayer 39007 cockroach bait provided 100% mortality in 24 hours, while Kepone showed no mortality in three days.

FIELD EVALUATION. The RMI is divided into two components, the initial and the residual index. The initial index refers to the dead cockroaches picked up the day after treatment. The residual index refers to the dead cockroaches picked up during the test after the initial index period.

Semi-Solid Bait Test.

Test Number I. In the bait tests, the RMI in table 14 shows that a high percentage of dead cockroaches was picked up in eight houses after the first night of treatment. A small percentage of dead insects was picked up during the residual index period. There was an additional treatment after two week in each test. A pyrethrum flushout at the end of the test indicated that a very small percentage of the cockroaches were left.

In the household spray tests, there was almost no residual mortality. For this reason, the commercial sprays were applied weekly. The RMI shows that comparable numbers of cockroaches were killed with each application and with the pyrethrum flushout, indicating that these materials did not substantially reduce the overall population.

Test Number II. The RMI showed that 9% of the 352 German cockroaches picked up, were killed in three days with the semi-solid powdered sucrose bait, while the initial index indicated that approximately 67% of the dead cockroaches collected, were killed overnight with dehydrated potato and powdered sucrose bait. Powdered sucrose bait appeared to be ineffective against B. germanica.

Test Number III. In two tests with B. germanica, the RMI showed that dried dehydrated potato and powdered sucrose bait killed 18 to 20% of the cockroaches in two weeks, and as a consequence was not as effective as the moist bait.

Test Number IV. The RMI in table 15, shows that the population of cockroaches were greatly reduced in two out of three houses with dehydrated potato and powdered sucrose in tablets or semi-solid forms. There was no noticeable difference in effectiveness between the tablet or semi-solid forms in metal containers against B. germanica.

The RMI in treatment C shows that 65.8% of the dead cockroaches collected, were killed the first week. The dried bait, three weeks old, when watered, killed 17.4% of the cockroaches during the fourth week. Fresh bait, applied during the fifth week, killed 10.9% of the cockroaches. No cockroaches were seen during the pyrethrum "flushout".

Test number V. The RMI in table 16 shows that there was a significant difference in the methods of application. The initial index shows that an average of 66.8% of the cockroaches killed by application I (squeeze bootle) were picked up the next morning, as compared to an average of 35.1% of the dead insects resulting from application II (card method). The pyrethrum "flushout" index shows that an average of 14.7% of the insects was left by application I as compared to an average of

37.5% by application II.

Test Number VI. Comparable mortalities were obtained with both 1.9% Entex and 0.5% diazinon as shown by the RMI in table 17. A pyrethrum "flushout" during the third and fourth week, indicated that 0.5% diazinon did not eliminate all the cockroaches. A 2.8% Entex treatment, which was used instead of a pyrethrum "flushout" during the fourth week, indicated that the initial treatment did not substantially reduce the population. Conditions in test houses treated with 1% diazinon were such that data for this material was not conclusive. However, 1% diazinon was believed to be effective.

Liquid Bait Test. The RMI in table 18 shows that 20% sucrose and 0.5% dichlorvos water bait greatly reduced the number of German cockroaches in four out of six houses. There was no significant difference between houses with and without food.

CADMIUM CHLORIDE. Examination of the testes of P. americana in 2 and 14 days after treatment indicated considerable swelling and tissue destruction had occurred. In two days, swelling was marked and some germarial tissue destruction noted. In 14 days, the testes had resumed approximately normal shape, but the germarial tissue was almost completely destroyed. The testes of the nymphs were arrested and never completely developed. The ovaries were not affected at low concentration but were affected at 0.1 mM/kg of body weight. Some of the affected ovaries showed reddish-brown hyperplasias.

Table 19 shows the range of acceptability of cadmium chloride in a 20% sucrose solution to American cockroaches. Cadmium chloride was repellent at high concentrations. This was especially so without the sucrose. At 0.01% and below, cadmium chloride was acceptable in a 20%

sucrose solution.

In a test where male and female cockroaches were fed 0.01% or 0.000001% cadmium chloride in a 20% sucrose solution, both male and female sex organs were affected in the manner described above.

ECOLOGY AND POPULATION STUDY OF COCKROACHES IN HOMES. Table 20 shows that a total of 64,345 dead German cockroaches were picked up in 77 homes while evaluating various methods of controlling cockroaches. The average of the percentages of males, females, and nymphs were 28.0%, 32.9%, and 39.1%, respectively.

The distribution of males and females in 77 homes is shown in tables 21 and 22. Though the population was approximately a 50:50 ratio, extreme ratios were found on both sides of the normal distribution curve as shown in figure 11.

The number of homes and the average percentages of males, females, and nymphs in each population group are shown in table 22. The data were analyzed by the seasons, months of the year, ratio of females to nymphs, etc., but there was no noticeable trends. The German cockroaches produced offspring all seasons of the year.

Table 23 shows the distribution ratios of females per egg capsule in 16 homes. There was an average of 4.5 females per egg capsule.

An analysis of two laboratory colonies of B. germanica cockroaches in table 24 shows that identical percentages of 33.6% males and 66.4% females were obtained from both colonies. The number of females per egg capsule were found to be 1.6 and 2.3.

Of interest is the percentage of males, females, and nymphs; and the number of females per egg capsule in a house in which 24,918 dead cockroaches were picked up. Of this number, there were 20.5% males,

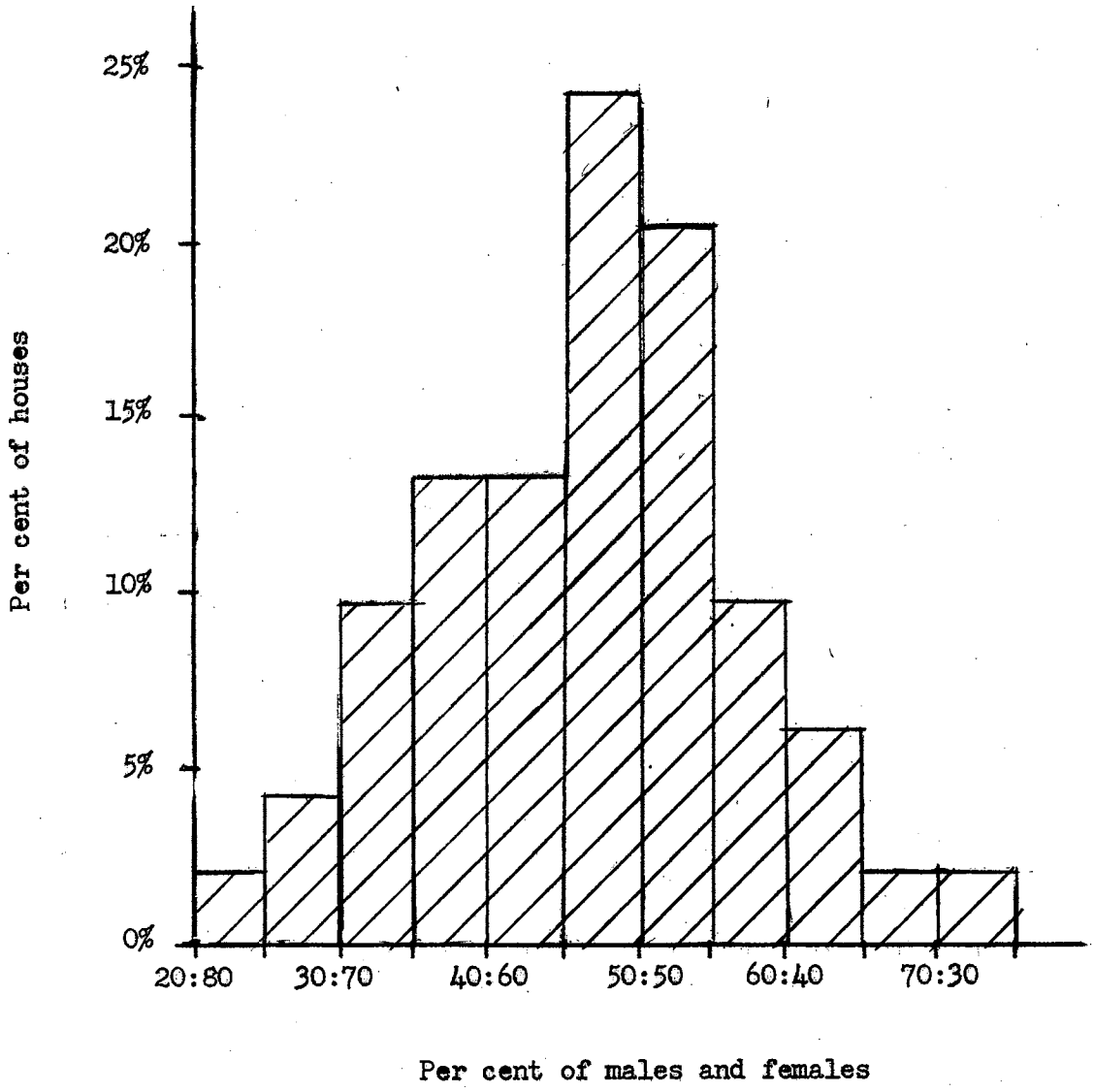


Figure 11. Percentage of Dallas homes containing German cockroach populations of various male and female ratios.

21.4% females, and 58.1% nymphs, and a ratio of 3.8 females per egg capsule.

DISCUSSION

LABORATORY TESTS. Laboratory tests involving three species of cockroaches and solid, semi-solid, or liquid bait formulations of many kinds of foods or pure chemicals were carried on over a period of two and one-half years to determine the food preferences of cockroaches.

Solid or Semi-Solid Baits. Three designs were used to evaluate solid and semi-solid food preferences of cockroaches.

Randomized Block Design. Valid data were obtained from the randomized block design run in 4.5 bushel tubs for about a month. After this period, more cockroaches had died in one tub than in others, and variation between replicates resulted. As a consequence, this procedure was impractical for long term tests due to the sorting and counting of cockroaches that was entailed in keeping balanced numbers of insects.

Latin Square Design. A 20 gallon garbage can was used for this test. The arrangement of dowel pegs on the bottom of the top shelf was important to insure adequate distribution of cockroaches on the top board and to eliminate variation within replicates.

The analyses of variance indicated that there were no significant differences within replicates in both the randomized block and the Latin square designs. The Latin square design eliminated the tedious process of sorting and counting cockroaches, that was encountered with the randomized block design.

The foods evaluated by the above designs, which consisted of four

treatments and four replicates, were compared directly or indirectly to a semi-solid dehydrated potato bait for rating.

A semi-solid bait of 10% dehydrated potatoes, 15% powdered sucrose, and 75% water was found to be the most attractive bait to B. germanica.

Incomplete Block Design. This test, which consisted of nine treatments and four replicates, was conducted with P. americana and B. orientalis. The incomplete block design has the advantages of evaluating more treatments. The analyses of variance indicated that there were no significant differences between replicates. However, there was more variation in this test than with the Latin square or the randomized block designs.

Although the analyses of variance indicated each test to be statically valid, there were some variations in food preferences of cockroaches in different tests, especially with the incomplete block design. Nevertheless, there was a general trend in the three tests conducted to establish the reliability of the procedure. Because of variations in food preferences in different tests, there may be some questions concerning the reliability of the comparative rating of foods. These ratings were divided into four catergories, whereby each catergory covered a board range. Index I includes those foods which have a rating above 90. Index 2 equals 56 to 90, index 3 equals 21 to 55, and index 4 equals 0 to 20. As a consequence, these foods could have a considerable amount of variation, and still fall within the same rating.

In each of the three designs, it was essential to have a large number of hungry cockroaches in the test unit to insure equal distribution and to reduce the variation within treatments.

In tests with B. orientalis and P. americana, 10% dehydrated potatoes, 15% powdered sucrose and 75% water were used as the standard bait for comparative rating of other baits.

The semi-solid bait of 10% dehydrated potatoes, 15% powdered sucrose and 75% water was the most attractive bait to B. orientalis, while the following semi-solid baits were highly attractive to P. americana: persimmon, date sugar, date, sucrose, and a combination of dehydrated potatoes and powdered sucrose.

Preference Test. German cockroaches were fed one of four foods for 135 days, and were given a choice of the four foods at the end of 38 and 135 days. The results of this test indicated that cockroaches did not develop a food preference to a particular food. These data suggest that cockroaches can be expected to perform in bait tests without bias due to their laboratory food.

Color Test. Cockroaches showed no preference for colored baits in tests conducted both in the light and dark, and bait color would have little importance except for recognition or warning purposes by the person using the bait.

Odor Masking Test. To further investigate the mechanisms of food finding by cockroaches, a test was conducted using a masking perfume, Alpunod G, in an effort to mask or alter the food odors received by cockroaches. The nine foods, which were used to establish the reliability of the incomplete block design, were used with P. americana in this test.

Cockroaches fed on the nine foods that were supposedly masked with Alpunod G in the same order as those without the masking agent. This indicates that the ability of cockroaches to find preferred foods was not affected by the perfume. It is the opinion of the author, based on this

and other tests, which will be discussed later, that cockroaches depend on the sense of taste, and maxillary palpation more than the sense of smell. Sucrose, one of the most preferred food, is generally considered odorless.

Liquid Baits. Twenty and thirty per cent sucrose solutions were the most attractive baits to P. americana, while potato water (5% dehydrated potato in water) containing 5% and 20% sucrose was the preferred bait of B. orientalis and B. germanica.

The baits were rated in the same manner as the semi-solid baits. A test containing only different concentrations of sucrose, the author believes, would not be acceptable in this rating. The least preferred sucrose, especially the low concentration (5%), would have a high rating in a test where few or no sucrose treatments were used. The results of a test with different concentrations of sucrose are shown in table 24.

Bait Traps. Eisa and Soliman (1953) reported pepsin to be highly attractive to cockroaches. Because pepsin, Bekun, and other reported cockroach attractants were not shown to be attractive to cockroaches in the semi-solid bait tests, the liquid bait tests, or the olfactometer, an effort was made to duplicate Eisa and Soliman's technique. Three trap designs were used to demonstrate the attractiveness of pepsin, Bekun, and several other chemicals with no success. The inability of the author to obtain clear cut evidence of selective attractiveness with these devices further substantiates the viewpoint expressed earlier that odor plays a small part in food finding by cockroaches.

Smoked Plate Test. A glass plate, smoked or coated with magnesium oxide, was used to study the food finding habits of cockroaches. The

American and German cockroaches left marks showing their zig-zag paths in locating food in the center of the plate. This supports the viewpoint mentioned above that cockroaches do not rely on odor in finding food.

FIELD EVALUATION. The most attractive baits developed in the laboratory were evaluated under field conditions for the control of cockroaches, and a roach mortality index was used to express the effectiveness of the bait.

Solid and Semi-Solid Baits.

Test Number I. The dehydrated potato and powdered sucrose semi-solid bait containing dichlorvos was demonstrated to be very effective for the control of B. germanica cockroaches. Although this bait killed the majority of the cockroaches overnight, a following treatment within two weeks was necessary for control of these insects.

Test Number II. Powdered sucrose and dichlorvos semi-solid bait was ineffective for the control of B. germanica. Semi-solid food preference tests indicated that B. germanica cockroaches did not feed readily upon concentrated sucrose.

Test Number III. Moist dehydrated potato and powdered sucrose bait containing 0.5% dichlorvos was demonstrated to be more effective than dry bait. Nevertheless, the bait was still effective after it was dry.

Test Number IV. The population of cockroaches was greatly reduced in two out of three houses with treatments of dehydrated potatoes, powdered sucrose, and 0.5% dichlorvos using the tablet or paste forms in metal containers. Water was added as needed.

The RMI indicated that there was no noticeable difference between the two forms of bait. Though three to six bait stations were used, two

or three appeared to have been the most effective. The desirable positions were under the sink and refrigerator. Baits that were left in open areas such as the cabinet top, dried out faster than those under the refrigerator or within the cabinets. Two or three well placed bait stations will greatly reduce or eliminate the cockroaches.

At the end of a test in one house, a pyrethrum "flushout" indicated that there were no cockroaches around the refrigerator, cabinets, or sink where the bait was used. However, an 18.6% pyrethrum "flushout" index was obtained in a chest on the opposite side of the kitchen (living room-kitchen combination). Some cockroaches were observed resting on a cabinet door hinge, next to the bait, during the first two weeks of the test, before disappearing. This indicates that some cockroaches do not readily accept the bait or will not move very far to find a bait station.

Test Number V. The results presented in table 16 indicated that there were significant differences in the methods of applying bait. The squeeze bottle application gave a greater reduction in the number of cockroaches than the card procedure.

Though the squeeze bottle procedure was somewhat messy, the results were not noticeable, as the bait was usually applied under the sink, on the cabinet walls, or other places which were out sight. The problem of clean-up is more evident with squeeze bottle.

Test Number VI. Diazinon and Entex were applied in several test houses, at the manufacturers recommended dosage for evaluation of their comparative effectiveness against B. germanica cockroaches. The RMI indicated that these chemicals did not eliminate the cockroaches from these houses. Data from several houses, treated with 1% diazinon were inconclusive, but 1% diazinon was considered by the author to be an effective

spray for cockroach control.

The most common cockroach species encountered was B. germanica, but a number of houses were infested with one or more of the following species: P. americana, B. orientalis, and S. supellectilium. The RMI indicated dehydrated potatoes and powdered sucrose bait containing dichlorvos was effective with all of these species of cockroaches.

Liquid Bait Test. A 20% sucrose and 0.5% dichlorvos liquid bait greatly reduced the population of German cockroaches in four out six houses. The presence of food did not seem to influence the effectiveness of the bait.

In test house number 5, as shown in table 18, a pyrethrum "flushout" revealed a colony of cockroaches in the living room near the front door. It appeared that these cockroaches did not find the bait located under the sink in the kitchen or bathroom.

In test house number 6, a new occupant removed the bait in the bathroom. There was a leak in the kitchen sink, which covered the base with water. It was the author's opinion that the German cockroaches avoided the damp surface, and as a consequence, the effectiveness of the bait was reduced.

CADMIUM CHLORIDE. Cadmium chloride, either when injected subcutaneously into the coxa or fed to cockroaches in a bait, was shown to destroy the germarial tissue of male cockroaches. The female ovaries in several individuals were affected at high concentrations causing a reddish-brown hyperplasia. The testes of male nymphs were arrested and never developed fully.

These experiments indicate that cadmium chloride may have potential uses as a chemosterilant in bait for the control of insects.

ECOLOGY AND POPULATION STUDY OF COCKROACHES IN HOMES. While evaluating various methods of controlling cockroaches in Dallas homes for one and one-half years, the number of males, females, nymphs, and number of egg capsules of B. germanica were recorded. Efforts were made to observe the habits and habitats of all species of cockroaches during all seasons of the year. German cockroaches were the most commonly encountered. Cockroaches were found mostly under the sink and refrigerator and in the bathroom. It was observed that cockroaches preferred different habitats during different seasons of the years. On cold days, cockroaches preferred the upper part of the room near the ceiling where it was warm; in contrast, the lower part of the room was preferred during the summer.

In a house heavily infested with B. germanica and P. americana cockroaches during the summer, the American cockroaches were located under the sink, while the German cockroaches were situated in the cabinets near the ceiling. This was probably due to the incompatibility of the two insects, with the larger American cockroaches taking the preferred location.

German cockroaches were found throughout the house wherever food occurred. It was believed that cockroaches developed habits of resting and looking for food in certain areas of the house. In several cases, cockroaches were exterminated in the kitchen where the bait was applied such as under the sink and cabinets while in other parts of the house, the cockroach colonies were not reduced. This was observed in a house where colonies of more than 1500 cockroaches were exterminated under the sink and cabinets where the bait was applied, while a heavy infestation existed under the refrigerator undisturbed during the four week test. These insects probably fed on crumbs on the floor and obtained water from

the refrigerator or on top of the sink, and as a consequence, they did not wander under the sink and into the cabinets where the bait was applied. This, and other tests, indicated that cockroaches developed habits of living and feeding in restricted areas. Because of this habit, it is important to distribute baits in several areas in the kitchen, primarily under the sink and refrigerator, to get adequate control.

Cockroaches have been observed wandering aimlessly while searching for food on the floor, sensing or nibbling on a crumb and then going on to another one in a zig-zag line. These observations support the opinion that cockroaches do not depend on the sense of smell in locating food.

In summarization of the conclusions based on the odor masking test, the olfactometer, the three bait trap tests, the smoked plate test, and observations, it is the author's belief, that cockroaches wander about looking for food, depending on the contact of the maxillary palpi, and the sense of taste more than the sense of smell in locating their food.

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APPENDIXES

APPENDIX A

Table 1. Grams of baits consumed by B. germanica in a randomized block design test.

Replicates	Dehydrated potatoes - 14%, water - 86%	Fresh banana	Peanut Butter	Gelatin - 19%, water - 81%	Total
1	2.1	1.0	0.4	0.2	3.7
2	2.6	0.9	0.3	0.1	3.9
3	2.7	0.9	0.3	0.0	3.9
4	1.8	0.9	0.2	0.2	3.1

Table 2. Amounts of baits consumed by B. germanica in three randomized block design tests.

	1st test		2nd test		3rd test	
	g	%	g	%	g	%
Dehydrated potatoes - 14%, water - 86%	11.3	48.5	13.9	55.4	9.2	63.2
Fresh banana	8.3	35.6	8.9	35.4	3.7	25.2
Peanut butter	2.8	12.0	1.4	5.6	1.2	8.2
Gelatin - 19%, water - 81%	0.9	3.9	0.9	3.6	0.5	3.4

Table 3. Grams of baits consumed by B. germanica in a Latin square design test.

Replicates	Dehydrated potatoes - 14%, water - 86%	Fresh banana	Peanut butter	Gelatin - 19%, water - 81%	Total
1	3.2	1.6	0.7	0.1	5.6
2	4.4	1.6	0.7	0.1	6.8
3	3.4	1.7	1.1	0.1	6.3
4	4.2	1.8	0.9	0.2	7.1

Table 4. Amounts of baits consumed by B. germanica in four Latin square design tests.

	1st test		2nd test		3rd test		4th test	
	g	%	g	%	g	%	g	%
Dehydrated potatoes - 14%, water - 86%	7.6	58.2	10.3	67.6	15.1	59.5	14.6	67.4
Fresh banana	4.2	34.2	2.7	17.6	6.6	25.8	4.6	21.5
Peanut butter	0.9	7.6	1.7	11.2	3.3	13.1	1.9	8.8
Gelatin - 19%, water - 81%	0.0	0.0	0.6	3.6	0.4	1.6	0.5	2.3

Table 5. List of baits evaluated as solid or semi-solid formulations, or liquids in order of their rating in comparison to dehydrated potato as a standard bait against B. germanica.

Composition of baits	Index number*
Dehydrated potato - 10%, p. sucrose - 15%, water - 75%	1
Baked potato	1
Purina Dog Chow - 40%, water - 60%	1
Boiled potato	1
Dehydrated potato - 14%, water - 86% (Standard bait)	1
Roast beef gravy	1
Fresh pineapple	1
Swift's dog food - 40%, water - 60%	1
P. lettuce - 14%, water - 86%	2
P. banana and papaya - 15%, water - 85%	2
White wheat bread	2
Dehydrated molasses - 60%, water - 40%	2
Roast beef	2
White grape	2
P. green bean - 12%, water - 88%	2
P. apple - 22%, water - 78%	2
P. cabbage - 11%, water - 89%	2
Brewer's yeast - 56%, water - 44%	2
P. pumpkin - 14%, water - 86%	2
P. date - 33%, water - 67%	2
P. fig - 32%, water - 68%	2
P. carrot - 12%, water - 88%	2
Fresh banana	2
Cooked green bean	2
Raw potato	3
Cream of rice - 56%, water - 44%	3
P. persimmon - 30%, water - 70%	3
Swift's dog food	3
Cheese	3
P. date sugar - 50%, water - 50%	3
Corn meal - 52%, water - 48%	3
Purina Dog Chow	3
Raw apple (ground)	3
Raw beef (ground)	3
Red plum	3
P. asparagus - 11%, water - 89%	3
Cream of wheat - 68%, water - 32%	3
P. turnip - 12.5%, water - 87.5%	3
P. mustard green - 16%, water - 84%	3
P. prune - 33%, water - 67%	3
Hershey's chocolate	3
P. papaya - 16%, water - 84%	3
Brown sugar - 90%, water - 10%	3

Table 5. Continued.

Composition of baits	Index number*
Oatmeal - 20%, water - 80%	4
P. banana - 24%, water - 76%	4
P. date sugar	4
P. tomato - 21%, water - 79%	4
Dehydrated molasses	4
P. lima bean - 43%, water - 57%	4
Peanut butter	4
P. egg - 44%, water - 56%	4
P. sucrose - 85%, water - 15%	4
Cooked bacon	4
Dextrose - 75%, water - 25%	4
Levulose - 85%, water - 15%	4
P. banana and papaya	4
Caramel	4
P. peach - 22%, water - 78%	4
P. pepper - 17%, water - 83%	4
P. milk - 58%, water - 42%	4
Apple jelly	4
Strawberry preserve	4
Plum jam	4
Gelatin - 19%, water - 81%	4
Corn starch - 58%, water - 42%	4
Lactose - 78%, water - 22%	4
Grape jam	4
Olive oil	4
P. apricot - 25%, water - 75%	4
P. peppermint leaves - 22%, water - 78%	4
P. onion - 14%, water - 86%	4
Bacon grease	4
P. okra - 10%, water - 90%	4
P. lemon - 15%, water - 85%	4
P. grapefruit - 14%, water - 86%	4
P. orange - 27%, water - 73%	4
Corn oil	4
Peanut oil	4
Butter	4
Shortening	4
Mayonnaise	4

* Based on the comparative index number, those above 90 equal 1, 56 to 90 equal 2, 21 to 55 equal 3, and 0 to 20 equal 4.

Table 6. Grams of baits consumed by P. americana in uniformity test.

	Replicates				
	1	2	3	4	Total
P. date - 33%, water - 67%	2.43	1.45	2.52	2.28	8.68
Sucrose - 15%, water - 85%	2.08	2.04	1.99	2.34	8.45
P. potato - 10%, sucrose - 15%, water - 75%	1.52	2.32	1.93	2.18	7.95
Date sugar - 50%, water - 50%	2.03	2.08	1.43	1.88	7.42
P. persimmon - 30%, water - 70%	1.42	1.60	2.26	1.59	6.87
Purina Dog Chow - 40%, water - 60%	0.90	1.05	1.05	1.05	4.05
P. potato - 14%, water - 86%	0.30	0.45	0.57	0.53	1.85
P. carrot - 12%, water - 88%	0.42	0.30	0.59	0.40	1.71
P. prune - 33%, water - 67%	0.35	0.68	0.34	0.32	1.69

Table 7. Amounts of baits consumed by P. americana in three incomplete block design tests.

	Tests		
	1	2	3
P. date - 33%, water - 67%	(1) 11.40	(1) 8.68	(4) 4.00
Date sugar - 50%, water - 50%	(2) 9.87	(4) 7.42	(1) 5.30
P. potato - 10%, p. sucrose - 15%, water - 75%	(3) 9.23	(3) 7.95	(5) 2.85
P. persimmon - 30%, water - 70%	(4) 7.75	(5) 6.87	(1) 5.30
Sucrose - 85%, water - 15%	(5) 7.43	(2) 8.45	(3) 4.13
Purina Dog Chow - 40%, water - 60%	(6) 4.50	(6) 4.05	(6) 1.91
P. potato - 14%, water - 86%	(7) 3.40	(7) 1.85	(9) 0.19
P. carrot - 12%, water - 88%	(8) 3.35	(8) 1.71	(8) 0.26
P. prune - 33%, water - 67%	(9) 3.14	(9) 1.69	(7) 1.35

Table 8. List of baits evaluated as solid or semi-solid formulations in order of their rating in comparison to 10% dehydrated potato, 15% powdered sucrose, and 75% water as a standard bait against P. americana.

Composition of baits	Index number*
P. persimmon - 30%, water - 70%	1
P. date sugar - 50%, water - 50%	1
P. date - 33%, water - 67%	1
Dehydrated potato - 10%, p. sucrose - 20%, water - 70%	1
Dehydrated potato - 10%, p. sucrose - 15%, water - 75%	1
Dehydrated potato - 10%, p. sucrose - 10%, water - 80%	1
Sucrose - 85%, water - 15%	1
Sucrose - 80%, water - 20%	1
Sucrose - 75%, water - 25%	1
Dehydrated potato - 10%, p. sucrose - 5%, water - 85%	2
P. banana - 24%, water - 76%	2
Brown sugar - 90%, water - 10%	2
Purina Dog Chow - 40%, water - 60%	2
P. prune - 33%, water - 67%	3
Dehydrated potato - 10%, p. sucrose - 2.5%, water - 87.5%	3
P. fig - 32%, water - 68%	3
P. apple - 22%, water - 78%	3
P. carrot - 12%, water - 88%	3
Dehydrated potato - 10%, water - 90%	3
Dehydrated potato - 14%, water - 86%	3
Apple jelly	3
Strawberry preserve	3
P. peach - 20%, water - 80%	3
P. pumpkin - 14%, water - 86%	3
Peanut butter	4
P. papaya - 16%, water - 84%	4
P. turnip - 12.5%, water - 87.5%	4
P. green cabbage - 11%, water - 89%	4
P. green bean - 12%, water - 88%	4
P. lima bean - 43%, water - 57%	4
P. peppermint leaves - 22%, water - 78%	4
P. asparagus - 11%, water - 89%	4
P. lettuce - 14%, water - 86%	4
P. okra - 10%, water - 90%	4

* Based on the comparative index number, those above 90 equal 1, 56 to 90 equal 2, 21 to 55 equal 3, and 0 to 20 equal 4.

Table 9. List of baits evaluated as solid or semi-solid baits in order of their rating in comparison to 10% dehydrated potato, 15% powdered sucrose, and 75% water as a standard bait against B. orientalis.

Composition of baits	Index number*
Dehydrated potato - 10%, p. sucrose - 15%, water - 75%	1
P. date sugar - 50%, water - 50%	3
Dehydrated potato - 14%, water - 86%	3
Sucrose - 85%, water - 15%	3
Purina Dog Chow - 40%, water - 60%	3
P. pumpkin - 14%, water - 86%	3
P. carrot - 12%, water - 88%	3
Brown sugar - 90%, water - 10%	3
P. green bean - 12%, water - 88%	4
P. fig - 32%, water - 68%	4
P. prune - 33%, water - 67%	4
P. turnip - 12%, water - 88%	4
P. persimmon - 30%, water - 70%	4
P. banana - 24%, water - 76%	4
P. apple - 22%, water - 78%	4
Strawberry preserve	4
Peanut butter	4

* Based on the comparative index number, those above 90 equal 1, 56 to 90 equal 2, 21 to 55 equal 3, and 0 to 20 equal 4.

Table 10. Food preference of B. germanica for four baits after being fed a given food for 38 or 135 days.

Initial diets	Days fed	Per cent of total diet				
		D. potato-14%, water	P. Dog Chow-40%, water	Raw potato	Peanut butter	Total in grams
Dehydrated potato - 14%, water - 86%	38	45.5	37.9	12.3	4.0	11.4
	135	51.0	44.0	1.5	3.5	10.2
Purina Dog Chow - 40%, water - 60%	38	48.6	42.5	4.7	4.7	10.7
	135	50.5	35.5	2.1	11.9	12.8
Raw potato	38	41.1	44.1	8.9	5.9	17.9
	135	35.3	51.4	6.7	6.6	2.5
Peanut butter	38	51.1	24.8	22.3	1.8	13.7
	135	44.0	42.1	13.2	0.2	9.1

Table 11. List of liquid baits evaluated with P. americana in order of their preference using 20% granulated sucrose solution as the standard bait.

Composition of baits	Index number*
Sucrose - 30%, water - 70%	1
Sucrose - 20%, water - 80%	1
Sucrose - 10%, water - 90%	1
Sucrose - 20% in potato water (5% d. potato in water)	1
Sucrose - 20%, L-glutamic acid - 0.1%, water - 79.9%	2
Root beer syrup - 50%, water - 50% **	2
Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	2
Honey - 50%, water - 50%	2
Frostex (a mixture of polysaccharides from corn) - 20%, water	3
Coca Cola syrup - 25%, water - 75%	3
Honey - 20%, water - 80%	3
Honey - 10%, water - 90%	3
Root beer syrup - 25%, water - 75%	3
Root beer syrup - 10%, water - 90%	3
Blackstrap molasses - 75%, water - 25%	3
Prune juice	3
Pabst beer - 85%, water - 15%	3
Coca Cola syrup - 50%, water - 50%	3
Maltose - 20%, water - 80%	3
Coca Cola syrup - 10%, water - 90%	4
Dextrose - 10%, water - 90%	4
Potato water (5% dehydrated potato in water)	4
Pepsin - 1%, water - 99%	4
Maltose - 10%, water - 90%	4
Butyric acid; o.1%, 0.01% or 0.001% in water	4
H F acid soluble oil - 0.1%, water - 99.9%	4
O-ethyl-S-tert-butyl sulfenyl xanthate; 0.1%, 0.01%, or 0.001% in water	4
2-Aminoethyl-tert-butyl sulfide; 0.1%, 0.01%, or 0.001% in water	4
Water	4
Sodium chloride - 1%, water - 99%	4
Chlorodiisopropyl benzene; 0.1%, 0.01%, or 0.001% in water	4
Rennet - 1%, water - 99%	4
Karo syrup	4
Butadiene-furfural copolymer COOH; 0.1%, 0.01% or 0.001% in water	4
Butadiene amination products - 0.1%, water - 99.9%	4
Valeric acid; 0.1%, 0.01% or 0.001% in water	4
Vanilla extract - 0.1%, water - 99.9%	4
Honey - 100%	4
Dextrose - 20%, water - 80%	4
1,4-Piperazinedithiocarbonyl-bis-(n-butyldisulfide); 0.1%, 0.01% or 0.001% in water	4

Table 11. Continued.

Composition of baits	Index number*
Tetraethylene pentamine derivative of penta-tert-butylsulfenyl dithiocarbamate - 0.1%, water - 99.9%	4
Phosphorous paste - 1%, water - 99.9%	4
Rennet - 1%, water - 99%	4
Pepsin - 1%, distilled water - 99%	4
Distilled water	4
Bekun - 1%, distilled water - 99%	4
Cinnamon - 1%, water - 99%	4
Piperidinosuccinonitrile; 0.1%, 0.01% or 0.001% in water	4
Milk	4
Trypsin - 1%, water - 99%	4
Pineapple oil; 1.0%, 0.01% or 0.0001% in water	4
Strawberry oil; 1.0%, 0.01% or 0.0001% in water	4
Walnut oil; 1.0%, 0.01% or 0.0001% in water	4
Rum oil; 1.0%, 0.01% or 0.0001% in water	4
Ripe banana oil; 1.0%, 0.01%, or 0.0001% in water	4
Peppermint oil; 1.0%, 0.01%, or 0.0001% in water	4
Sassafras oil; 1.0%, 0.01% or 0.0001% in water	4
Safrole oil; 1.0%, 0.01% or 0.0001% in water	4
Geraniol; 1.0%, 0.01% or 0.0001% in water	4
L-glutamic acid - 0.1%, water - 99.9%	4

* Based on the comparative index number, those above 90 equal 1, 56 to 90 equal 2, 21 to 55 equal 3, and 0 to 20 equal 4.

** Triple A Root Beer Company, Oklahoma City, Oklahoma.

Table 12. List of liquid foods in order of their preference to B. orientalis using 50% root beer syrup and 50% water as the standard bait.

Composition of baits	Index number*
Sucrose - 20% in potato water (5% dehydrated potato in water)	1
Sucrose - 5% in potato water	1
Root beer syrup - 50%, water - 50%	1
Frostex - 20%, water - 80%	1
Maltose - 20%, water - 80%	2
Root beer syrup - 75%, water - 25%	2
Sucrose - 20%, water - 80%	3
Root beer syrup - 25%, water - 75%	3
Brewer's yeast - 10%, water - 90%	3
Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	3
Sucrose - 10%, water - 90%	4
Coca Cola syrup - 25%, water - 75%	4
Dextrose - 20%, water - 80%	4
Dehydrated molasses - 10%, water - 90%	4
Dr. Pepper syrup - 25%, water - 75%	4
Water	4

Table 13. List of liquid baits evaluated with B. germanica in order of their preference using 20% sucrose solution as the standard bait.

Composition of baits	Index number*
Sucrose - 20% in potato water	1
Invert sugar - 20%, water - 80%	1
Sucrose - 20%, water - 80%	1
Sucrose - 5% in potato water	1
Fructose - 20%, water - 80%	1
Papst beer	2
Coca Cola syrup - 50%, water - 50%	2
Root Beer syrup - 50%, water - 50%	2
Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	2
Prune juice	2
Maltose - 20%, water - 80%	2
Water	3
Honey - 100%	4
Blackstrap molasses - 75%, water - 25%	4

Table 14. Roach Mortality Index (RMI) comparing the percentage of cockroaches killed by semi-solid dehydrated potato and powdered sucrose bait or household sprays over a period of five weeks.

Roach bait	House no.	Total no. of roaches	1st week		2nd week		3rd week		4th week		5th week
			I I 1 day	R I* 1 wk	I I 1 day	R I 1 wk	I I 1 day	R I 1 wk	I I 1 day	R I 1 wk	Pyrethrum "flushout"
	1	386	86.0	4.9	-	4.4	2.3	1.8	-	0	0.2
	2	191	80.6	3.3	-	3.0	7.3	2.1	-	0	2.6
	3	513	72.0	10.9	-	1.6	6.8	3.7	-	0	1.9
	4	167	42.5	25.2	-	11.4	12.0	7.8	-	0	1.2
Average		314.2	70.3	11.1		5.1	7.1	3.8		0	1.5
Household sprays											
A_1	5	223	16.1	0	-	-	26.4	0	-	-	57.4
A_2	6	225	16.4	0	-	-	34.7	0	44.0	0	4.9
B	7	491	9.2	0	10.6	6.5	6.5	0	43.9	0.8	23.2
C	8	1966	11.2	0	8.0	0	-	-	40.6	0	40.2
Average		724	13.2		9.3		22.5		42.8		31.4

* Initial Index
Residual Index

Table 15. Roach Mortality Index (RMI) in test number IV comparing the effectiveness of dehydrated potato and powdered sucrose bait used as a semi-solid bait or tablet form in metal containers for the control of B. germanica.*

Treatments	House no.	No. of lids	Total no. of roaches	Initial Index 1 day	Residual Index 1st wk	Residual Index 2nd wk	2nd Treatment Index - 3rd wk	Pyrethrum "flushout" Index - 4th wk
A - Tablet bait in large lids	1	3	44	11.4%	22.7%	0%	0%	65.9%
	2	6	538	14.1%	50.7%	23.8%	4.1%	7.2%
	3	6	1144	24.7%	48.1%	21.3%	5.4%	0.5%
B - Semi-solid bait in large lids	4	3	671	14.3%	50.5%	14.5%	2.1%	18.6%
	5	4	48	14.6%	22.9%	39.6%	8.3%	14.6%
	6	4	131	9.9%	3.0%	0%	27.5%	59.5%

Treatment	House no.	No. of lids	Total no. of roaches	Initial Index 1 day	Residual Index 1st wk	Residual Index 2nd wk	4th wk, water added to dried bait	2nd Treatment Index 5th wk	Pyrethrum "flushout" Index
C - Tablet bait in small lids	7	12	717	31.2%	34.6%	5.9%	17.4%	10.9%	0%

* Water was added as needed to prevent the bait from drying.

Table 16. Roach Mortality Index (RMI) in test number V comparing the percentage of B. germanica cockroaches killed by a semi-solid dehydrated potato and powdered sucrose bait using two methods of application.

Method of application	House no.	Total no. of roaches	Initial Index	Residual Index 1st wk	Residual Index 2nd wk	Pyrethrum "flushout" index
Applied from squeeze bottle	1	906	50.0%	16.4%	14.2%	19.3%
	2	1,084	66.1%	12.2%	3.4%	18.4%
	3	172	89.5%	7.6%	0%	2.9%
	4	67	55.2%	16.4%	0%	28.4%
	5	63	84.1%	9.5%	0%	6.4%
	6	63	55.6%	27.0%	4.7%	12.7%
Average		375	66.8%	14.9%	3.7%	14.7%
Applied on cards	7	48	35.4%	16.7%	10.4%	37.5%
	8	48	72.9%	14.6¢	4.2%	8.3%
	9	721	38.3%	13.3%	4.8%	43.6%
	10	2,176	15.3%	23.5%	32.1%	29.1%
	11	2,719	19.3%	18.9%	16.4%	45.5%
	12	484	29.3%	7.4%	2.3%	61.0%
Average		1,032.6	35.1%	15.7%	11.7%	37.5%

Table 17. Roach Mortality Index (RMI) in test number VI comparing the percentage of cockroaches killed by Entex and diazinon.

Insecticides	House no.	Total no. of roaches	Initial Index 1 day	Residual Index 1st wk	Residual Index 2nd wk	3rd wk Initial Index	3rd wk Residual Index	4th wk Initial Index	4th wk Residual Index
Entex			Treated 1.9%					Treated 2.8%	
	1	196	18.4%	41.8%	27.0%	-	-	12.8%	-
	2	82	23.2%	14.6%	52.4%	-	-	9.8%	-
	3	159	11.3%	54.1%	-	-	22.6%	6.9%	5.0%
	4	229	15.3%	47.6%	12.7%	-	11.8%	10.0%	2.6%
	5	242	-*	49.2%	11.6%	-	-	27.3%	12.0%
Diazinon			Treated 0.5%			Pyrethrum "flushout"		Pyrethrum "flushout"	
	6	343	16.9%	33.8%	21.9%	16.9%	0%	7.5%	-
	7	15	73.3%	0%	20.0%	6.7%	0%	0%	-

* Unable to get into the house.

Table 18. Roach Mortality Index comparing the percentage of B. germanica cockroaches killed by a 20% sucrose and 0.5% dichlorvos solution in furnished apartments with or without food.

	House no.	Total no. of roaches	Initial Index 1 day	Residual Index 1st wk	Residual Index 2nd wk	Pyrethrum "flushout" Index - 3rd wk
With food	1	115	8.7%	49.6%	37.4%	4.3%
	2	125	48.8%	47.2%	4.0%	0%
	3	123	17.9%	54.5%	24.4%	3.2%
Without food	4	91	39.5%	38.5%	22.0%	0%
	5	143	28.7%	32.9%	15.4%	23.0%
	6	401	4.5%	20.0%	12.2%	63.3%

Table 19. A test with American cockroaches showing the acceptability of different concentrations of cadmiun chloride in a 20% sucrose solution.

Cadmiun chloride	Consumption in millimeter
1.0%	0.6
0.1%	2.1
0.01%	6.9
0.001%	9.4
0.0001%	10.8
0.00001%	9.6
0.000001%	5.7
Water	1.1

APPENDIX B

Table 20. Percentage of males, females, and nymphs of dead German cockroaches picked up in 77 homes.

Test number	Total	Per cent males	Per cent females	Per cent nymphs
1	10	30.0	40.0	30.0
2	15	46.6	53.3	0.0
3	19	26.3	42.1	31.6
4	19	36.8	36.8	26.3
5	21	38.1	28.6	33.3
6	27	14.8	40.7	44.4
7	38	31.6	28.9	39.5
8	40	50.0	27.5	22.5
9	40	12.5	25.0	62.5
10	44	15.9	31.8	52.3
11	45	42.2	26.7	31.1
12	48	41.7	27.1	31.2
13	48	25.0	29.2	45.8
14	48	33.3	27.1	39.6
15	60	43.3	16.7	40.0
16	63	31.7	25.4	42.9
17	63	38.1	33.3	28.6
18	67	37.3	26.9	35.8
19	67	40.3	34.3	25.4
20	73	31.5	41.1	27.4
21	78	42.3	35.9	21.8
22	82	30.5	41.5	28.0
23	112	12.5	8.9	78.6
24	115	43.5	20.0	36.5
25	129	27.9	54.3	17.8
26	131	24.4	25.2	50.4
27	134	34.3	32.1	33.6
28	144	33.3	33.8	29.9
29	159	41.5	40.2	18.2
30	159	34.5	25.2	40.3
31	160	27.5	49.4	23.1
32	175	16.6	53.1	30.3
33	176	26.1	20.5	53.4
34	182	15.9	18.7	65.4
35	188	13.8	13.8	72.3
36	196	26.5	48.0	25.5
37	198	21.7	64.6	13.6
38	202	29.7	31.1	31.2
39	207	33.3	29.0	37.7
40	227	35.7	33.5	30.8
41	230	20.9	32.6	46.5
42	242	34.3	36.4	29.3

Table 20. Continued.

Test number	Total	Per cent males	Per cent females	Per cent nymphs
43	246	30.5	36.2	33.3
44	253	18.5	35.6	45.8
45	264	33.3	64.4	2.3
46	295	23.4	34.2	42.4
47	302	30.5	48.7	20.8
48	328	26.5	43.0	30.5
49	333	29.1	37.5	33.3
50	343	38.5	32.4	29.1
51	380	23.7	29.2	47.1
52	451	15.7	41.9	42.4
53	463	20.5	22.2	57.2
54	486	24.5	27.8	47.7
55	521	28.4	44.1	27.4
56	538	20.6	27.1	52.2
57	542	32.5	39.1	28.4
58	554	20.7	31.1	43.2
59	566	18.7	18.9	62.4
60	661	26.4	23.6	49.9
61	671	22.4	21.2	56.5
62	717	19.4	22.6	58.0
63	721	29.8	33.6	36.6
64	799	28.2	43.8	28.0
65	906	34.6	40.0	25.4
66	1,084	25.6	29.4	44.9
67	1,144	11.3	21.4	67.3
68	1,393	26.9	42.2	30.8
69	1,463	19.5	16.9	63.6
70	1,583	30.1	42.6	27.2
71	1,746	30.6	39.0	30.4
72	2,176	18.2	20.1	61.6
73	2,272	16.0	30.7	53.3
74	2,719	27.4	29.5	43.0
75	2,994	22.1	13.9	64.0
76	4,032	22.7	22.5	54.8
77	25,918	20.5	21.4	58.1
Total	64,345			
Average	835.6	28.0	32.9	39.1

Table 21. Total number and percentage of males and females of German cockroaches picked up in 77 homes.

Test number	Total	Per cent males	Per cent females
1	7	42.9	57.1
2	13	38.5	61.5
3	14	57.1	42.9
4	14	50.0	50.0
5	15	26.7	73.3
6	15	46.6	53.3
7	15	33.3	66.7
8	21	33.3	66.7
9	23	52.2	47.8
10	24	58.3	41.7
11	26	46.2	53.8
12	29	55.2	44.8
13	31	64.5	35.5
14	31	61.3	38.7
15	33	60.6	39.4
16	36	72.2	27.8
17	36	55.6	44.4
18	43	58.1	41.9
19	45	53.3	46.7
20	50	54.0	46.0
21	52	50.0	50.0
22	53	43.4	56.6
23	59	42.4	57.6
24	61	54.1	45.9
25	63	46.0	54.0
26	65	49.2	50.8
27	73	68.5	31.5
28	82	56.1	43.9
29	89	51.7	48.3
30	95	57.9	42.1
31	101	47.5	52.5
32	106	34.0	66.0
33	122	23.8	76.2
34	123	35.8	64.2
35	123	39.0	61.0
36	129	53.5	46.5
37	130	50.8	49.2
38	137	34.3	65.7
39	139	43.2	56.8
40	146	35.6	64.4
41	157	51.6	48.4
42	164	45.7	54.3
43	170	40.6	59.4
44	171	25.1	74.9
45	171	48.8	51.2

Table 21. Continued.

Test number	Total	Per cent males	Per cent females
46	198	48.0	52.0
47	201	44.8	55.2
48	213	49.8	50.2
49	222	43.7	56.3
50	228	38.2	61.8
51	239	38.5	61.5
52	243	54.3	45.7
53	254	46.9	53.1
54	257	43.2	56.8
55	258	34.1	65.9
56	260	27.3	72.7
57	292	51.4	48.6
58	301	46.2	53.8
59	315	36.5	63.5
60	331	52.9	47.1
61	374	34.5	65.5
62	378	39.2	60.8
63	388	45.4	54.6
64	457	47.0	53.0
65	533	53.7	46.3
66	575	39.1	60.9
67	597	46.6	53.4
68	676	46.4	53.6
69	835	47.5	52.5
70	963	38.9	61.1
71	1,062	34.3	65.7
72	1,079	61.5	38.5
73	1,152	41.4	58.6
74	1,215	44.0	56.0
75	1,550	48.1	51.9
76	1,821	50.2	49.8
77	10,857	49.0	51.0
Total	31,626		
Average	410.7	46.4	53.6

Table 22. Population groups, numbers, and average percentages of males, females and nymphs of B. germanica collected in 77 homes.

Number of cockroaches in homes	Number of houses	Average percentages of males	Average percentages of females	Average percentages of nymphs
0 - 100	22	33.6	32.7	33.6
101 - 200	15	26.7	33.9	29.3
201 - 500	17	27.6	36.7	35.7
501 - 1000	11	25.6	31.8	42.5
1001 - 5000	11	22.8	28.0	49.2
25,918	1	20.5	21.4	58.1

Table 23. The total number of B. germanica cockroaches, the number of females, and the number of females per egg capsule in 16 homes.

House number	Total number of cockroaches	Number of females	Number of females per egg capsule
1	176	36	3.0
2	1,084	319	3.4
3	48	14	3.5
4	1,144	245	3.6
5	25,918	5,542	3.8
6	717	162	3.9
7	906	362	4.1
8	721	242	4.2
9	63	21	4.2
10	48	13	4.3
11	2,719	804	4.5
12	538	146	4.6
13	2,176	438	4.7
14	486	135	6.1
15	343	142	6.5
16	67	23	7.7

Table 24. The total number and percentages of males and females, and the number of females per egg capsule in two laboratory colonies of B. germanica cockroaches.

Colony	Total number of males and females	Per cent males	Per cent females	No. of females per egg capsule
1	420	33.6	66.4	1.6
2	744	33.6	66.4	2.3

Table 25. A comparison of the consumption of different concentrations of sucrose solutions by P. americana.

Composition of baits	Consumption in millimeters
Sucrose - 5%, water - 95%	0.6
P. sucrose - 5%, water - 95%	1.0
Sucrose - 10%, water - 90%	1.8
P. sucrose - 10%, water - 90%	2.5
Sucrose - 15%, water - 85%	3.0
Sucrose - 20%, water - 80%	6.8
P. sucrose - 20%, water - 80%	4.6
Sucrose - 20%, L-glutamic acid - 0.1%, water - 79.9%	5.2
Sucrose - 20%, ripe banana oil - 0.05%, water - 79.95%	2.2
Sucrose - 20%, potato water - 80%	6.1
Water	1.5

APPENDIX C

Table 26. Individual test results with B. germanica using both the Latin square and the randomized block designs.

Test no.	Baits	Grams Consumed*
1	P. turnip - 12.5%, water - 87.5%	8.25
	P. peach - 22%, water - 77%	3.00
	P. okra - 10%, water - 90%	0.70
	P. lemon - 15%, water - 85%	0.10
2.	P. carrot - 12%, water - 88%	9.95
	P. cabbage - 11%, water - 89%	9.20
	P. mustard green - 16%, water - 84%	4.65
	P. grapefruit - 14%, water - 86%	0.00
3.	P. lettuce - 14%, water - 86%	6.50
	P. persimmon - 30%, water - 70%	5.60
	P. prune - 33%, water - 67%	2.25
	P. lima bean - 43%, water - 57%	1.60
4.	P. potato - 14%, water - 86%	9.35
	P. banana and papaya - 15%, water - 85%	2.00
	P. banana - 24%, water - 76%	1.90
	P. papaya - 16%, water - 84%	2.20
5.	P. potato - 14%, water - 86%	13.30
	P. banana and papaya - 15%, water - 85%	11.50
	P. banana and papaya	1.60
	P. onion - 14%, water - 86%	0.30
6.	P. green bean - 12%, water - 88%	7.85
	P. fig - 32%, water - 68%	7.05
	P. asparagus - 11%, water - 89%	4.15
	P. tomato - 21%, water - 79%	2.30
7.	P. potato - 14%, water - 86%	13.90
	Fresh banana	8.90
	Peanut butter	1.40
	Gelatin - 14%, water - 86%	0.90
8.	P. molasses - 60%, water - 40%	3.50
	P. date sugar - 50%, water - 50%	2.20
	P. date sugar	0.95
	P. molasses	0.90

Table 26. Continued.

Test no.	Baits	Grams consumed*
9.	Cream of rice - 56%, water - 44%	4.30
	Corn meal - 52%, water - 48%	3.55
	Cream of wheat - 88%, water - 12%	2.80
	Corn starch - 58%, water - 42%	0.60
10.	P. pumpkin - 14%, water - 86%	9.35
	P. date - 33%, water - 67%	9.25
	P. pepper - 17%, water - 83%	1.35
	P. appricot - 25%, water - 75%	0.45
11.	Brewer's yeast - 56%, water - 44%	7.50
	Brown sugar - 90%, water - 10%	2.55
	P. egg - 44%, water - 56%	1.80
	P. milk - 50%, water - 50%	1.50
12.	Apple jelly	2.30
	Strawberry preserve	1.80
	Plum jam	1.55
	Grape jam	0.80
13.	Cheese	2.70
	Bacon grease	0.30
	Butter	0.05
	Shortening	0.00
14.	P. sucrose - 85%, water - 15%	1.85
	Dextrose - 75%, water - 25%	1.55
	Levulose - 85%, water - 15%	1.50
	Lactose - 78%, water - 22%	0.50
15.	P. apple - 22%, water - 78%	7.00
	P. turnip leaves - 17%, water - 83%	1.75
	P. peppermint leaves - 22%, water - 78%	0.25
	P. orange - 27%, water - 73%	0.00
16.	Hershey's chocolate	3.05
	Peanut butter	2.75
	Apple jelly	1.65
	Caramel	1.10
17.	Hershey's chocolate	1.50
	Peanut butter	1.00
	Caramel	0.70
	Mayonnaise	0.00

Table 26. Continued.

Test no.	Baits	Grams consumed*
18.	Fresh pineapple	10.70
	Cooked roast beef	7.85
	Cooked green bean	6.20
	Oatmeal - 20%, water - 80%	2.50
19.	Brown sugar	3.95
	Olive oil	0.45
	Corn oil	0.00
	Peanut oil	0.00
20.	Cooked roast beef gravy	12.95
	Cooked roast beef	9.40
	Raw ground beef	4.65
	Cooked bacon	1.65
21.	Baked potato	14.95
	Boiled potato	12.20
	P. potato - 14%, water - 86%	12.05
	Raw potato	6.40
22.	Fresh grape	12.15
	Fresh peaches	11.45
	Fresh apple	4.35
	Fresh plum	4.20
23.	Purina Dog Chow - 40%, water - 60%	14.00
	Swift's dog food - 40%, water - 60%	11.05
	Swift's dog food	5.95
	Purina Dog Chow	4.95
24.	P. carrot - 12%, water - 88%	11.40
	P. date - 33%, water - 67%	9.90
	P. turnip - 12.5%, water - 87.5%	5.95
	P. sucrose - 85%, water - 15%	2.95
25.	P. potato - 14%, water - 86%	16.15
	P. carrot - 12%, water - 88%	9.15
	P. banana and papaya - 15%, water - 85%	8.85
	Hershey's chocolate	3.65
26.	P. potato - 14%, water - 86%	12.10
	P. molasses - 60%, water - 40%	8.80
	P. fig - 32%, water - 68%	7.65
	Cream of rice - 56%, water - 44%	3.50

Table 26. Continued.

Test no.	Baits	Grams consumed*
27.	P. potato - 14%, water - 86%	14.95
	P. green bean - 12%, water - 88%	8.90
	Apple jelly	6.35
	Raw potato	4.40
28.	P. potato - 14%, water - 86%	13.70
	P. apple - 22%, water - 78%	9.50
	Raw apple	5.50
	P. peach - 22%, water - 78	3.50
29.	P. potato - 14%, water - 86%	12.70
	Wheat bread	10.40
	White grape	8.95
	Red plum	4.50
30.	P. carrot - 12%, water - 88%	11.40
	P. turnip - 12.5%, water - 87.5%	5.95
	P. date - 33%, water - 67%	9.90
	P. sucrose - 85%, water - 15%	2.95
31.	P. fig - 32%, water - 68%	7.70
	P. apple - 22%, water - 78%	7.65
	P. lettuce - 14%, water - 86%	7.20
	P. cabbage - 11%, water - 89%	5.80
32.	P. green bean - 12%, water - 88%	7.80
	P. pumpkin - 14%, water - 86%	7.60
	Brewer's yeast - 56%, water - 44%	7.45
	Cheese	5.60

* Baits not connected by the same vertical line are significantly different at the 95% level of probability.

Table 27. Individual test results with P. americana using the incomplete block design.

Test no.	Baits	Grams consumed*
1.	P. potato - 10%, p. sucrose - 15%, water - 75%	8.10
	Strawberry preserve	2.56
	Apple jelly	2.54
	P. pumpkin - 14%, water - 86%	2.32
	P. green cabbage - 11%, water - 89%	0.22
	P. lima bean - 43%, water - 57%	0.19
	P. asparagus - 11%, water - 89%	0.08
	P. lettuce - 14%, water - 86%	0.04
2.	P. potato - 10%, p. sucrose - 15%, water - 75%	9.90
	P. banana - 24%, water - 76%	7.14
	Brown sugar - 90%, water - 10%	6.53
	P. apple - 22%, water - 78%	3.53
	P. fig - 32%, water - 68%	1.64
	P. papaya - 16%, water - 84%	1.63
	P. turnip - 12.5%, water - 87.5%	0.98
	P. green bean - 12%, water - 88%	0.17
	P. peppermint leaves - 22%, water - 78%	0.11
3.	P. potato - 10%, p. sucrose - 20%, water - 70%	4.23
	Sucrose - 75%, water - 25%	3.87
	Sucrose - 85%, water - 15%	3.58
	P. potato - 10%, p. sucrose - 15%, water - 75%	3.53
	Sucrose - 80%, water - 20%	3.32
	P. potato - 10%, p. sucrose - 10%, water - 80%	3.16
	P. potato - 10%, p. sucrose - 5%, water - 85%	2.54
	P. potato - 10%, p. sucrose - 2.5%, water - 87.5%	1.51
	P. potato - 10%, water - 90%	0.89

Table 28. Individual test results with B. orientalis using the incomplete block design.

Test no.	Baits	Grams consumed*
1.	P. potato - 10%, p. sucrose - 15%, water - 75%	3.86
	P. date sugar - 50%, water - 50%	1.43
	P. potato - 14%, water - 86%	1.16
	Sucrose - 85%, water - 15%	0.97
	Purina Dog Chow - 40%, water - 60%	0.80
	Brown sugar - 90%, water - 10%	0.75

Table 28. Continued.

Test no.	Baits	Grams consumed*
1.	P. persimmon - 30%, water - 70%	0.30
	P. banana - 24%, water - 76%	0.25
	P. apple - 22%, water - 78%	0.24
2.	P. potato - 10%, p. sucrose - 15%, water - 75%	1.80
	P. pumpkin - 14%, water - 86%	0.52
	P. carrot - 12%, water - 88%	0.44
	P. green bean - 12%, water - 88%	0.30
	P. fig - 32%, water - 68%	0.27
	P. prune - 33%, water - 67%	0.24
	P. turnip - 12%, water - 88%	0.19
	Strawberry preserve	0.04
	Peanut butter	0.03

Table 29. Individual test results with liquid baits using P. americana.

Test no.	Baits	Mean consumption in millimeters*
1.	Sucrose - 30%, water - 70%	6.5
	Sucrose - 20%, water - 80%	6.1
	Sucrose - 50%, water - 50%	6.0
	Root beer syrup - 50%, water - 50%	4.5
	Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	3.7
	Coca Cola syrup - 25%, water - 75%	2.6
	Root beer syrup - 10%, water - 90%	1.9
	Coca Cola syrup - 50%, water - 50%	1.4
	Coca Cola syrup - 10%, water - 90%	1.2
	Root beer syrup - 25%, water - 75%	0.5
	Water	0.5
2.	Sucrose - 20%, water - 80%	6.1
	Sucrose - 10%, water - 90%	5.5
	Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	4.0
	Maltose - 20%, water - 80%	1.4
	Dextrose - 10%, water - 90%	1.2
	Pepsin - 1%, water - 99%	0.9
	Water	0.8
	Dextrose - 20%, water - 80%	0.3
	Rennet - 1%, water - 99%	0.2

Table 29. Continued.

Test no.	Baits	Mean consumption in millimeters*
3.	Sucrose - 20%, water - 80%	13.5
	Blackstrap molasses - 75%, water - 25%	3.8
	Papst beer - 85%, water - 15%	3.3
	Sodium chloride - 1%, water - 99%	0.9
	Karo syrup	0.8
	Vanilla extract - 1%, water - 99%	0.7
	Phosphorous paste - 1%, water - 99%	0.5
	Cinnamon - 1%, water - 99%	0.2
	Milk	0.0
4.	Sucrose - 20%, water - 80%	13.8
	Honey - 50%, water - 50%	6.3
	Honey - 20%, water - 80%	5.4
	Honey - 10%, water - 90%	5.2
	Sucrose - 20%, water - 80%	4.8
	Prune juice	3.6
	Date sugar - 20%, water - 80%	2.2
	Sucrose - 5%, potato water - 95%	1.0
	Honey	0.7
	Potato water (5% d. potato in water)	0.4
	Water	0.2

Table 30. Individual test results with liquid baits using B. orientalis.

Test no.	Baits	Mean consumption in millimeters*
1.	Root beer syrup - 50%, water - 50%	16.0
	Sucrose - 5%, potato water - 95%	12.5
	Sucrose - 20%, water - 80%	6.3
	Root beer syrup - 25%, water - 75%	5.1
	Sucrose - 5%, L-glutamic acid - 0.1%, water - 94.9%	3.5
	Sucrose - 10%, water - 90%	2.3
	Coca Cola - 25%, water - 75%	1.8
	Dr. Pepper syrup - 50%, water - 50%	1.2
	Potato water (5% d. potato in water)	0.8
	Dr. Pepper syrup - 25%, water - 75%	0.6
	Water	0.2

* Baits not connected by the same vertical line are significantly different at the 99% level of probability

Table 30. Continued.

Test no.	Baits	Mean consumption in millimeters
2.	Sucrose - 20%, potato water - 80%	4.6
	Sucrose - 5%, potato water - 95%	3.5
	Root beer syrup - 50%, water - 50%	3.5
	Frostex (a mixture of polysaccharrides from corn) - 20%, water - 80%	3.3
	Maltose - 20%, water - 80%	2.5
	Root beer syrup - 75%, water - 25%	2.1
	Sucrose - 20%, water - 80%	0.9
	Brewer's yeast - 10%, water - 90%	0.7
	Dextrose - 20%, water - 80%	0.3
	P. molasses - 10%, water - 90%	0.3

Table 31. Individual test results with liquid baits using B. germanica.

Test no.	Baits	Mean consumption in millimeters
1.	Sucrose - 5%, water - 95%	3.6
	Invert sugar - 20%, water - 80%	3.0
	Maltose - 20%, water - 80%	2.9
	Sucrose - 20%, water - 80%	2.5
	Fructose - 20%, water - 80%	2.3
	Coca Cola syrup - 50%, water 50%	2.1
	Dextrose - 20%, water - 80%	2.0
	Root beer syrup - 50%, water - 50%	1.9
	Potato water	1.3
	Water	1.1
	Blackstrap molasses - 75%, water - 25%	0.6
2.	Sucrose - 20%, water - 80%	2.6
	Sucrose - 5%, potato water - 95%	2.4
	Papst beer - 85%, water - 15%	2.2
	Sucrose - 5%, L-glutamic acid - 0.1%, water 94.9%	1.9
	Prune juice	1.6
	Root beer syrup - 50%, water - 50%	1.6
	Maltose - 20%, water - 80%	1.5
	Sucrose - 20%, potato water - 80%	1.3
	Water	0.6
	Karo syrup	0.2
	Honey	0.0

VITA

Michael Donovan Miesch Jr.

Candidate for the Degree of

Doctor of Philosophy

Thesis: ECOLOGICAL AND PHYSIOLOGICAL MECHANISMS INFLUENCING FOOD FINDING IN BLATTARIA

Major Field: Entomology

Biographical:

Personal Data: Born in Clarksville, Texas, March 6, 1934, the son of Michael Donovan and Alma Louise Miesch.

Education: Attended grade and high school in Clarksville, Texas; received an Associate of Art degree from Paris Junior College, Paris, Texas; completed the requirements for Bachelor of Science in Entomology at Texas A & M University, College Station, Texas in January, 1956; received Master of Science in Entomology from Purdue University, West Lafayette, Indiana in May, 1959; completed requirements for the Doctor of Philosophy degree at Oklahoma State University, Stillwater, Oklahoma in August of 1964.

Experience: Cotton checking, Texas Agricultural Experiment Station, College Station, Texas, summer of 1954; cotton checking and commercial pest control, Stroope Pest Control, Waxahachie, Texas, summers of 1955 and 1956; cotton checking and commercial pest control, self employed, Clarksville, Texas, summers of 1957 and 1958; employed part time by Reliable Exterminators, Lafayette, Indiana during the school terms of 1956, 1957, and 1958; part time research assistant, Purdue University Agricultural Experiment Station during the school terms of 1956, 1957, 1958, and 1959; employed as an Entomologist by Thuron Industries, Inc., Dallas, Texas from November, 1959 through August, 1963; Research Grant, National Pest Control Association, September, 1963 through August, 1964, Oklahoma State University, Stillwater, Oklahoma.

Organizations: Entomological Society of America, Indiana Archaeological Society, Sanborn Entomology Club, Sigma Xi.