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INTRODUCTION TO SYMPOSIUM ON ATTRACTANTS FOR MOSQUITO SURVEILLANCE AND CONTROL[1]

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INTRODUCTION

Over the past few decades public concern about potential health and environmental hazards that result from the use of broad-spectrum insecticides for controlling insect pests, including mosquitoes, has increased and become more vocal. In addition to the general public's concern, many environmental groups are demanding a pesticide-free environment. In response to these concerns and demands, environmental protection agencies have had legislation enacted or proposed that bans or places rigid use restrictions on an increasing number of pesticides. The overall impact of this environmental legislation on mosquito control is that there are now fewer adulticides available than at any other time during the past 20 years (Rathburn 1990). Rathburn (1990) further states that manufacturers and formulators have withdrawn several existing insecticides and formulations for 2 primary reasons. First, there is the high cost of reregistration due to additional research required by the Environmental Protection Agency (EPA) to determine the environmental impact of these pesticides on humans or nontarget organisms. Second, there is the increased cost of production for a limited market, as compared with the more extensive agricultural market. Industry is reluctant to make the investments necessary to discover, develop, and demonstrate safety of new pesticides because of the time, risks, and high costs involved. Meanwhile mosquitoes continue to produce offspring that may become resistant to currently approved insecticides. Development of resistance will further limit the availability of suitable insecticides. For these reasons, operational mosquito control personnel are becoming concerned about the possibility that satisfactory insecticides may not be available in the near future. Thus, the need to perfect alternate mosquito control strategies is becoming increasingly urgent.

This increased concern has provided the impetus to evaluate the potential of attractant traps/targets. Much of the optimism for this approach is based on the success that tsetse workers have had with attractant-baited, insecticide-impregnated targets in Zimbabwe (Vale 1993). Until the mid-1980s tsetse control in Zimbabwe was achieved by the broadcast of endosulfan or deltamethrin from the air or the application of DDT from the ground (Allsopp 1984). Since then, steadily increased use of targets led to the complete replacement of spraying in 1991 (Vale 1993).

There is a nucleus of researchers worldwide that have a renewed interest in exploring the use of attractants as alternatives to currently used technology for surveillance and control of mosquitoes. This group was invited to participate in the First International Symposium on Hematophagous Insect Attractants, sponsored by the Metropolitan Mosquito Control District, Minneapolis, MN, in November 1989. Twenty-five scientists from the United States, Canada, the United Kingdom, and the Netherlands participated in this symposium. The consensus of this group of scientists was that attractants could play a significant role in the control and surveillance of hematophagous insects. The extent of that role was the subject of much discussion. The major outcome of this meeting was the agreement that an informal working group should be formed to organize workshops and symposia for the exchange of ideas and information. It was proposed that these meetings be held on an annual or biennial basis in association with major entomological meetings throughout the world. Four symposia and 3 workshops have been held since 1989. In 1991 this working group became closely affiliated with the AMCA through the establishment of the AMCA Ad Hoc Attractants Committee.

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This symposium was organized in response to a request from AMCA President Cyrus Lesser (1992–93) to the Attractants Committee to advise the organization on the current potential of attractants for mosquito control and surveillance and to determine the research needs for the further development of attractants for vector control. Therefore, the first objective of this symposium was to review the current state of knowledge of attractants utilized by mosquitoes as well as what is known about endogenous factors that regulate behavior when the attractants are present. The 2nd objective was to determine future research needs.

REVIEW OF CURRENT KNOWLEDGE

To accomplish the first objective, 16 scientists with diverse backgrounds were invited to make presentations in their field of expertise. Eleven of these speakers have submitted manuscripts of their presentations for publication in these proceedings. The keynote speaker was Stephen Torr (IPMI, Tsetse Project, Harare, Zimbabwe), who reviewed the development of the successful attractant-based tsetse control project in Zimbabwe. In his presentation Torr stressed that success was achieved through the development of new research tools and the close interdisciplinary collaboration among entomologists, chemists, and electrophysiologists. He suggested that the same approach to analyzing the responses of mosquitoes to their hosts will produce improved baits for mosquitoes.

Sandra Allan (U.S. Department of Agriculture, Agricultural Research Service, Medical and Veterinary Entomology Research Laboratory, Gainesville, FL, USA) and Bill Bidlingmayer (Florida Medical Entomology Laboratory, IFAS, University of Florida, Vero Beach, FL, USA) presented talks on the importance of vision and visual cues for mosquitoes to find their hosts. Allan's talk emphasized the physics of mosquito vision. Important information for the location by mosquitoes of a wide range of resources is provided by the visual perception of objects and the environment. Allan concluded that examination of visually oriented mosquito behavior requires an understanding of the constraints of visual perception as a result of eye morphology and physiology as well as the conditions under which the behavior occurs (e.g., natural light vs. artificial light). Such studies aid in our understanding of the visual ecology of mosquitoes and also provide the basis for development and refinement of monitoring and trapping systems for mosquitoes. Bidlingmayer reviewed what is known about the visual responses of female mosquitoes during appetitive and attraction flights to conspicuous features of their environment. He presented data from many of his field studies and discussed the influence of visual targets upon mosquito flight behavior and the effect of this behavior upon trap catches.

The importance of various olfactory attractants was presented by several presenters. The role of 1-octen-3-ol (octenol) and carbon dioxide (CO_2) in host finding was reviewed by D. L. Kline (the written review that follows discusses only the role of octenol). Several reviews on the role that CO_2 plays in host finding by mosquitoes have already been published (Gillies 1980, Takken 1991). Carbon dioxide has long been used as an effective attractant to survey mosquito populations. A common belief is that although CO_2 is effective for surveillance, it has limitations from an operational control point of view. Use of CO_2 as an attractant entails use of either bottled gas or dry ice. Although both sources of CO_2 are relatively inexpensive, their use and availability in remote locations can be cumbersome. Despite these limitations, current studies on the use of CO_2 for the control of selected mosquito species are in progress. Octenol has shown some promise as an attractant for several species of mosquitoes.

The topic of olfactory attractants for oviposition was reviewed in the symposium by Paul Reiter (San Juan Laboratories, Division of Vector-Borne Infectious Diseases, National Center for Infectious Diseases, Centers for Disease Control and Prevention, San Juan, Puerto Rico). Although no formal paper on oviposition attractants by Reiter or others appears in these published proceedings, this topic was reviewed during each of our workshops and symposia. The essence of these discussions is that oviposition attractants show great promise for surveillance and control of certain mosquito species. Gravid females of many species of mosquitoes show a high degree of preference in selecting specific oviposition sites in the general area of their breeding sources. This preference may be due to the presence of oviposition pheromones or oviposition attractants and repellents in natural habitats. The oviposition-modifying chemicals regulate ovipositional behavior of mosquitoes and, in general, determine the population distribution of adult mosquitoes. Oviposition pheromones may occur in nature as intraspecific messengers to inform conspecifics of suitable oviposition sites in natural systems by microbial fermentation of organic matter, and these transpecific messengers serve as kairomones or allomones to provide cues for gravid mosquitoes to detect suitable or unsuitable oviposition sites. If these oviposition-modifying substances become known and available to us, perhaps mosquito populations can be sampled and manipulated through regulation of mosquito oviposition. Thus, these substances offer an excellent potential for developing population-management techniques that could supplement other chemical and biological control strategies developed for vector and pest mosquitoes.

Woodbridge Foster and Robert Hancock (Department of Entomology, The Ohio State University, Columbus, OH, USA) summarized the available knowledge of nectar-related olfactory and visual attractants for mosquitoes. This summary of current information indicates that nectar sources are not as attractive as blood sources at specific times in a mosquito's life, but that sugar feeding is usually necessary and more frequent than blood feeding. Plant attractants used in traps would have the advantage of being effective for both sexes, starting soon after emergence, and for blood-digesting, gravid, and gonoinactive females. Efforts to identify the specific volatile chemicals associated with flowering plants that attract mosquitoes has only just begun.

Alan Cork (Natural Resources Institute, Central Avenue, Chatham Maritime, Chatham, Kent, United Kingdom) presented the progress that his research group has made with release technology of olfactory attractants. Improved means of dispensing attractants have been developed where the odors are released by diffusion through sealed polyethylene sachets. Various tsetse chemical attractants are now dispensed from sachets made of various thicknesses of low-density polyethylene. One operationally used sachet is 150 μm thick, with a surface area (both sides combined) of about 50 cm^2. Each sachet is charged with 4 ml of a 1:4:8 mixture of 3-n-propyl phenol : octenol : 4-methyl phenol, and then heat-sealed. The sachet is placed in a cloth cover to protect it from direct sunlight; it will remain effective for about 4 months. Recently, sachets have been developed that give a slow and controlled release of attractants for more than a year (Hall et al. 1992).

An overview of the role played by acoustical cues was provided by Peter Belton (Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada). Several field tests of the technique of attracting male mosquitoes with sound have been promising but the procedure has not led to practical large scale application. Besides the possibility of attracting and destroying males, however, there are advantages to attracting, sterilizing, and releasing them. Perhaps the least expensive technique would be to omit the traps and use sound to disrupt mating. Despite the apparent success of some field tests, it still seems impractical to use sound to control species that occur in the millions on the tundra or prairies and in forest or woodland. Nevertheless, it might be worth reconsidering the use of the technique for species occurring in ecological islands, for example, rice paddies, other irrigated areas, or, perhaps most appropriately, used tire dumps. A 2nd paper on acoustics was presented by Richard Mankin (Insect Attractants, Behavior and Basic Biology Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Gainesville, FL, USA), which summarized his recent research on the use of sound in surveillance programs for the black salt-marsh mosquito, *Aedes taeniorhynchus* (Wiedemann). Mankin concluded that it is technologically feasible to construct an acoustical device for remote surveillance of large swarms or emergence exoduses of *Ae. taeniorhynchus.* This device could also detect nearby individuals attracted to a bait. Such a device can distinguish males from females by their wingbeat frequencies.

Several papers were presented that summarized our current knowledge of the morphological and physiological basis of attractancy. James Sutcliffe (Department of Biology, Trent University, Peterborough, Ontario, Canada) reviewed current knowledge of the morphology of the cuticular sensory receptors used by mosquitoes to detect and orient to odor-type stimuli (including heat and humidity). Sutcliffe concluded that no new information has been published on the morphology of mosquito olfactory sensilla since McIver's (1982) major review, with the exception of a study of palpal pegs of *Toxorhynchites brevipalpis* Theobald by McIver and Siemicki (1984). Ed Davis and M. F. Bowen (SRI International, Life Sciences Division, Menlo Park, CA, USA) reviewed the current knowledge of the sensory physiological basis for attraction in mosquitoes. Their Insect Neurobiology Group at SRI has been studying the chemosensory mechanisms that underlie odor-mediated behavior in disease-transmitting arthropods. The ultimate goal of their research is to provide a foundation of basic information necessary for the rational development of new materials and strategies for the control of blood-sucking arthropods and other pest organisms. Their basic approach has been to utilize electrophysiological studies to investigate the biological mechanisms that control certain key behaviors in an attempt to identify aspects of the insect system that can be manipulated to our advantage in the development of new control schemes employing attractants, repellents, and other behavior-modifying substances. Over the years this group has developed a library of information about the peripheral sensory system of the mosquito and how this system mediates behavior.

The expressions of many mosquito behaviors are governed by an endogenous circadian clock. Marc Klowden (Division of Entomology, University of Idaho, Moscow, ID, USA) presented a summary of his research on the role of endogenous regulation of mosquito attraction using *Aedes aegypti* (Linn.) as his model mosquito. He also presented a modification of the traditional view of the gonotrophic cycle. This modified view takes into account factors that can cause host-seeking behavior to return after an initial blood meal.

Papers were given that presented 3 different theories of host-seeking behavior. The first was a video presentation by Bernard Roitberg (Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada). In his presentation, Roitberg suggested that the simple ethologically based approach of describing insect behavior by means of stimulus–response patterns is not broad enough to help us predict how expressions of behavior will change under varying exogenous and endogenous states. He developed the theme that the stimulus–response approach can be particularly detrimental to our understanding of mosquito attractants. In their manuscript published within these proceedings, he and his colleagues present a theory-driven model to predict mosquito responses in the presence of changing internal and external conditions. The second paper on host-seeking behavior was a video presentation by Philip Callahan (retired, Gainesville, FL, USA). He explained host-seeking behavior on the basis of electromagnetic radiation, especially in the infrared region. The last theory was presented by Paul Choate (Department of Entomology, University of Florida, Gainesville, FL, USA). Choate suggested that reported mosquito blood meals clearly demonstrate that species of mosquitoes show little preference for specific species of animals. Instead, accepted hosts are determined by size, which may be explained on the basis of the amounts of expired respiratory by-products. He further stated that a seemingly diverse list of hosts fall into well-segregated groupings based on the volume of respired gases, especially CO_2. The ability to detect various hosts is proposed to be a function of the number of CO_2 receptors on the palpi, the surface area of maxillary palpi, and the volume of air between the palpi that may be sampled at any given moment by female mosquitoes. Because this paper stimulated quite a bit of discussion, it is unfortunate that a final manuscript was not available for inclusion in these proceedings.

The last formal presentation of the symposium was made by Dan Dobbert and Nancy Read (Metropolitan Mosquito Control District, St. Paul, MN, USA). They presented a brief overview of their InterNet-based attractants bibliography project. This bibliographic database contains thousands of references to published and unpublished documents related to biting insect attractants research and development. The database is available on InterNet using Gopher. The bibliography can be found at the University of Minnesota Gophers, in the College of Natural Resources Gopher and on the Forestry Library Gopher. This database has already proven to be an invaluable resource to researchers in the field of attractants. Comments and questions are requested. Send responses to Dan Dobbert, MMCD, 2099 University Avenue West, St. Paul, MN 55104-3431; (612) 645-9149, FAX 3246.

After conclusion of the formal presentations, a group of approximately 20 interested workers met for several hours to discuss research needs, which was the 2nd objective of this symposium. A brief summary of that discussion follows.

RESEARCH NEEDS

During the course of this symposium and the symposia and workshops that preceded it, many problems and research needs were identified. Nearly everyone agreed that the greatest priority is that more efficient and economical traps/targets and attractants need to be developed. How best to accomplish this was the center of most of the discussion. In the end most participants agreed that the most critical need is a better understanding of the basic behavioral responses of the target mosquitoes at all stages of their life cycle with emphasis placed on host-seeking and bloodfeeding behaviors. Torr recommended that our attention should be directed away from studying the effects of known odors on trap catches and toward the responses of mosquitoes to their natural hosts. This is what led to success with the tsetse fly. Other research needs were identified that included: 1) more research on the effect(s) of chemical and physical factors on the physiological behavior of pest species; 2) sound production and reception in insects; 3) electrophysiology studies of mechanical, thermal, and chemical sensory organs of vector and nuisance species; 4) detailed studies on distance orientation of mosquitoes to their hosts; 5) studies on the effect of site on trap and target performance and in optimizing the deployment pattern; 6) improved means of dispensing attractants; and, 7) development of methods to sample populations with and without attractants, to establish relationships with absolute natural populations in order to understand what trapping results mean. Finally, all agreed that there is a need for frequent feedback between field and laboratory research to better understand species responses to the various types of attractants.

CONCLUSIONS

The science of mosquito control is currently entering a period of change. Economic and environmental factors have combined to shift emphasis away from merely researching and conventionally applying new chemical pesticides, toward more efficient methods of applying existing compounds, the development of alternative techniques such as biological control, and increasingly (recently), the combination of all available methods into effective integrated pest management programs. This includes the prospect for the use of attractants, which seemed unrealistic for mosquito control until the remarkable methods developed by our colleagues working on tsetse in Africa became known. Today there are realistic possibilities for the use of pheromones and kairomones for mosquito surveillance and control, as well as better opportunities for the use of visual and auditory cues.

All the symposium participants agreed that the development of odor baits to control tsetse in Zimbabwe is the best example of the use of kairomones to control a medical and veterinary pest. Therefore, as we consider the use of kairomones and other attractants in mosquito management strategies, it is important to realize that tsetse control by means of attractant technology was not an overnight success story. This success was the result of a long, dynamic process over many decades achieved by the collaboration of many dedicated scientists from a variety of disciplines. Indeed, the technique is still being improved. As Torr (1994) states in his symposium presentation, the development of bait technology for mosquito control will not be achieved overnight either, but will also require close interdisciplinary collaboration among entomologists (with ecological and/or behavioral backgrounds), chemists, and electrophysiologists.

If recent changes are any indication, it appears that as environmental concerns become more prominent, there will be many additional forced changes in the choice of mosquito insecticides and the way they are used to control mosquitoes (Rathburn 1990). Therefore, alternative strategies such as the use of attractants need to be fairly evaluated. In the final analysis, however, no matter how promising the basic technology for controlling a given pest species might be, it will be necessary to demonstrate to mosquito control operational personnel, administrators, regulatory agencies, environmentalists, and others that it will be effective, practical, and safe.

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