Order Number 9108253

Utilization of starch matrices for development of corn rootworm-specific semiochemical/insecticide delivery systems: Potential for adult suppression

Weissling, Thomas John, Ph.D.

The University of Nebraska - Lincoln, 1990

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

NOTE TO USERS

THE ORIGINAL DOCUMENT RECEIVED BY U.M.I. CONTAINED PAGES WITH POOR PRINT. PAGES WERE FILMED AS RECEIVED.

THIS REPRODUCTION IS THE BEST AVAILABLE COPY.

UTILIZATION OF STARCH MATRICES FOR DEVELOPMENT OF CORN ROOTWORM SPECIFIC SEMIOCHEMICAL/INSECTICIDE DELIVERY SYSTEMS: POTENTIAL FOR ADULT SUPPRESSION

By

Thomas J. Weissling

A DISSERTATION

Presented to the Faculty of
The Graduate College in the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Doctor of Philosophy

Major: Entomology

Under the Supervision of Professors Lance J. Meinke and Z B Mayo

Lincoln, Nebraska

August, 1990

DISSERTATION TITLE

Utilization of Starch Matrices for Development of Corn Rootworm Specific

Semiochemical/Insecticide Delivery Systems: Potential for Adult Suppression

BY

Thomas J. Weissling

SUPERVISORY COMMITTEE:

APPROVED	DATE
Signature	26 July 90
Lance J. Meinke Typed Name	
Signature	26 July 90
Z B Mayo Typed Name	
Signature	26 July 90
George Manglitz Typed Name	
Signature	26 July 90
Kenneth Pruess Typed Name	
Signature	26 July 90
Lowell Moser Typed Name	
Signature	
Typed Name	

GRADUATE COLLEGE
UNIVERSITY OF NEBRASKA

UTILIZATION OF STARCH MATRICES FOR DEVELOPMENT OF CORN ROOTWORM SPECIFIC SEMIOCHEMICAL/INSECTICIDE DELIVERY SYSTEMS: POTENTIAL FOR ADULT SUPPRESSION

By

Thomas John Weissling, Ph.D.
University of Nebraska, 1990

Advisors: Lance J. Meinke and Z B Mayo

Starch matrix technologies were utilized to create controlled release semiochemical/insecticide formulations that selectively attract and kill corn rootworm (CRW) adults over time in field corn. Semiochemicals and insecticides were incorporated into starch borate (SBM) and pregelatinized starch (PGM) matrices. Chemical analyses of SBM granules indicated that variable pH environments created during formulation may have degraded some volatile attractants and carbaryl. The PGM is inert and could be used to encapsulate all compounds tested. Semiochemicals successfully encapsulated in the SBM were released at rates attractive to CRW beetles for varying lengths of time in field corn. Western CRW adults were concentrated in field plots following application of SBM granules formulated with semiochemicals and carbaryl, but mortality was low despite observed beetle feeding. Laboratory bioassays indicated that carbaryl, methomyl, or carbofuran formulated in the PGM, and carbofuran formulated in the SBM, will effectively kill CRW beetles (> 90% mortality/24 h). When placed in traps in the field, PGM granules formulated with semiochemicals and carbaryl attracted and killed CRW beetles.

Mortality of western and southern CRW beetles following application of starch encapsulated semiochemical/insecticide granules was comparable to mortality following a broadcast application of Sevin XLR Plus while utilizing 90% less insecticide.

Season-long studies indicated that CRW attraction to starch encapsulated semiochemicals decreased during corn flowering. Starch encapsulated semiochemical/insecticide formulations are more effective when placed at or above corn ear height than at ground level.

Starch granules broadcast-applied in the field had variable impact on adult stages of the non-target species Coleomegilla maculata lengi, and Harpalus pennsylvanicus. Impact of starch formulations on both species was decreased by coating granules with cucurbitacin.

Results suggest that the SBM and PGM can be used to create species specific semiochemical/insecticide delivery systems that are palatable to CRW adults. These delivery systems may have potential in future corn rootworm management programs.

ACKNOWLEDGMENT

I wish to thank my advisor, Lance Meinke for his encouragement, guidance, and critical input throughout my Ph.D. program. I am also grateful for the input and guidance offered by my supervisory committee: Dr.'s George Manglitz, Z B Mayo (co-advisor), Lowell Moser, and Ken Pruess. Many thanks are due to the Department of Entomology, especially Matt Byers, Larry Godfrey, Wes Watson, and Robert Wright, for their valuable input.

I am indebted to the following people who have provided laboratory and/or field assistance at one time or another: Mike Barnhart (Barney), Jim Brown, Matt Byers, Todd Frazier, Krista Golden, Greg Grundmayer, Rod Hansen, Kandy Lytle, Lance Meinke, Troy Urban, Wes Watson, and Kris Weissling.

Funding was provided by the Nebraska Corn Development, Utilization, and Marketing Board, and the University of Nebraska Agricultural Experiment Station Project 17-043. Corn starch was provided by the Lauhoff Grain and National Starch and Chemical Companies.

TABLE OF CONTENTS

INTRODUCTION AND LITERATURE REVIEW

Corn rootworm biology, injury, and impact

The genus Diabrotica Chevrolat is largely neotropical and includes 338 valid species (Krysan & Smith 1987). The systematics of the virgifera group were reviewed by Krysan & Smith (1987). Within the virgifera group are several economic pests, including the western corn rootworm (WCR), D. virgifera virgifera LeConte, and the northern corn rootworm (NCR), D. barberi Smith & Lawrence, which are widely distributed pests of field corn in the midwestern United States (Chiang 1973). The WCR has recently become established in Virginia, North Carolina, and Texas. The southern corn rootworm (SCR), D. undecimpunctata howardi Barber, is a member of the fucata group and is an economic pest of peanut, sweet potato, and corn in the southeastern U.S. (Hunt & Baker 1982).

A recent review of Diabrotica biology by Krysan (1986) provides a key to adult identification, and descriptions of the larvae and eggs. As indicated by Krysan (1986), the geographical distribution of Diabrotica in North America is limited by climate. In North America, species of the virgifera group are univoltine and overwinter as eggs in the northern temperate regions while species in the fucata group are multivoltine and overwinter as adults in southern regions although some (i.e. SCR) will migrate north in the summer.

Western and northern corn rootworm beetles oviposit between 200 and 1000 eggs per female (Krysan 1986, Luckmann 1982). Eggs are deposited in soil in late summer and early fall primarily in the top 15

cm of the soil profile (Pruess et al. 1968, Chiang 1973, Weiss et al. 1983) and remain in diapause through the winter. However, eggs of the NCR are capable of extended diapause (Chiang 1965, Krysan et al. 1986a). Larvae eclose in late spring through early summer and migrate short distances to host roots (Short & Luedtke 1970) where they feed until reaching the pupal stage after three instars...about 13 days at 25°C (Krysan 1986). Adults emerge from pupae in the soil after about 10 days, locate food and mates, and females begin ovipositing after approximately 14 days (Krysan 1986). A review by Chiang (1973) details several physical factors such as temperature, light, and moisture acting on all life stages of corn rootworms, and Krysan & Smith (1987) provide an index of plants utilized by Diabrotica species in the virgifera group as larval and adult hosts.

Upon eclosion, neonate WCR and NCR larvae locate corn roots, in part, by orienting to carbon dioxide (Branson 1982, Strnad & Bergman 1986) and other volatiles (Hibbard & Bjostad 1988) emitted by corn seedlings. Larvae are capable of infesting most corn roots they locate (Strnad & Bergman 1987a), at which time they bore into the root (Chiang 1973) and tunnel towards the root tip (Strnad & Bergman 1987b). As the larvae mature, they concentrate around the base of the plant and attack the later developing root whorls (Strnad & Bergman 1987b). The feeding behavior of corn rootworm larvae has been reviewed by Branson (1986). Decay of roots often follows larval injury and is occasionally mistakenly identified as "root rot" (Tate & Bare 1946).

Corn yield loss due to rootworm larval feeding can occur directly through decreased plant vigor and indirectly through difficulty in

harvesting lodged plants (Foster et al. 1986). Apple (1971) reported that a 93% reduction in NCR larval population resulted in an 18.8% increase in corn yield and a 97.4% reduction in plant lodging. Chiang (1973) reported this same data as an average yield reduction of 0.86% per NCR larvae. In a later study, Apple et al. (1977) reported that subsequent larval attack from fields that averaged 5 corn rootworm eggs per 473 ml of soil would decrease corn yield by 3%. Utilizing known artificial WCR egg infestation levels, Branson et al. (1980) and Chiang et al. (1980) determined that reduction in yield, for the most part, increases with higher infestation levels. Fisher (1985), also utilizing artificial infestation of WCR and NCR eggs, determined that subsequent WCR larval attack causes more injury to corn roots than NCR at the same egg density. Decreased yield following injury may be due to delayed silking possibly caused by reduced plant turgor (Spike & Tollefson 1989). In addition, injury may be compounded by drought stress at the time of peak larval feeding (Chiang et al. 1980, Spike & Tollefson 1989).

Adult corn rootworm injury to corn is primarily attributed to their consumption of green silks which can reduce pollination and subsequent ear fill. However, adults are not considered a serious threat unless densities are high (Keith et al. 1982). During the green silk stage, five to seven beetles per plant has been suggested as a level where pollination would be significantly impeded (Mock et al. 1981), although Capinera et al. (1986) reported no significant yield loss with as many as 20 WCR beetles per ear.

Losses from corn rootworm injury can be high. In Kansas, loss of corn due to rootworm larval damage in 1953 and 1960 exceeded $2.5 million, and $18 million, respectively (Burkhardt & Peters 1961). More recently, Turpin et al. (1972) placed Iowa's rootworm losses at $60 million annually and Metcalf (1986a) estimated that crop losses and control costs due to Diabrotica spp. approaches $1 billion annually.

Corn rootworm management

Larval control. In 1948, Hill et al. tested soil applied (preplant and side-dressed) benzene hexachloride for control of corn rootworm larvae and found that yields increased 15.4 to 27.4% over the check following treatment. Cox & Lilly (1953), Lilly (1954) and Burkhardt (1954) reported significant decreases in corn rootworm larval populations following preplant broadcast and banding, or planting time applications of aldrin, heptachlor, and benzene hexachloride. Burkhardt (1955) found that aldrin and heptachlor applied over the row at planting time was most effective for control of rootworm larvae. The low cost and successful control of corn rootworm larvae achieved with insecticides led to their extensive use in the midwest. Planting-time or first cultivation applications of soil insecticides (Mayo & Peters 1978) are still commonly used for corn rootworm control.

Sampling. Insecticides are often applied prophylactically to protect corn roots from larval damage. Much of the insecticide that is applied for corn rootworm control is not needed since the economic damage threshold is exceeded in only about 11-19% of the total corn acreage (Luckmann 1978). To reduce insecticide use and associated costs, efforts have been taken to determine when implementation of

rootworm management practices are required to prevent economic loss.

Because corn rootworm eggs and first-instar larvae are difficult to detect in soil, and sampling for both stages can be time and labor intensive (Weiss & Mayo 1983, Bergman et al. 1981, Foster et al. 1979), they are generally not considered practical indicators of corn rootworm damage potential. However, various workers have determined that corn rootworm beetle population estimates can be useful indicators of rootworm damage the following year (Roselle 1977, Stamm et al. 1985, Tollefson 1990). Research has lead to the recommendation of larval treatment the following season (Turpin 1974) or adult suppression the current season (Pruess et al. 1974) if population levels exceed the adult threshold. In Nebraska, the current threshold is 0.75 beetles per plant, based on a population of 59,303 plants per hectare (Wright et al. 1990). Corn rootworm beetles can be sampled by a variety of techniques which were reviewed by Tollefson (1986).

A threshold of one beetle per plant was evaluated for WCR control in a Nebraska integrated pest management project from 1974-1976 (Roselle 1977). Roselle (1977) determined that this adult threshold was accurate more than 80% of the time and most fields that were not recommended for soil insecticide treatment did not develop economic infestations (based on root damage ratings of <2.75 on a 1-6 scale) the following year. Stamm et al. (1985) determined that by lowering the treatment threshold to 0.75 beetles per plant, prediction accuracy increased to more than 90%. This resulted in a 62% decrease in corn fields in Lincoln Co. Nebraska receiving larval insecticide treatment.

Although determination of adult population levels can provide an estimate of potential damage, studies by Hein & Tollefson (1985) and Foster et al. (1986) suggest that these estimates are not always accurate for optimal management.

Insecticide resistance. Following several years of continuous corn and annual widespread use of cyclodiene and chlorinated hydrocarbon insecticides, reports of management failures became common in central Nebraska. Weekman (1961) postulated that larvae were resistant to these insecticides and was proven to be correct by Ball (1962). Subsequently, Ball & Weekman (1963) demonstrated WCR and NCR resistance to aldrin and heptachlor in Nebraska and in neighboring states. Organophosphates and carbamates successfully replaced the chlorinated hydrocarbons, but heavy use of these chemicals also lead to several cases of reported failures (Mayo 1976a) and suspected corn rootworm resistance to diazinon (Ball 1968) and phorate (Patel & Apple 1966). The history and development of corn rootworm resistance to insecticides was reviewed by Ball (1981).

Enhanced insecticide biodegradation. Although several organophosphate and carbamate soil insecticides applied at planting time and at first cultivation still provide adequate corn rootworm control (Mayo & Peters 1978, Sutter et al. 1989), an increasing number of carbamate insecticide failures have been reported across the cornbelt (Newton 1978, Felsot et al. 1981) that are not attributed to larval resistance. A major cause of localized failures of carbofuran as a corn rootworm insecticide has been its enhanced biodegradation in "aggressive" soils by microorganisms (Newton 1978, Felsot et al. 1981,

1982, 1985, Gorder et al. 1982, Read 1983). Since insecticide breakdown in aggressive soils often occurs prior to contact by the target pest, efficacy of insecticides can be greatly reduced (Felsot et al. 1982).

Adult control. An alternative to corn rootworm larval control is suppression of adult populations. Theoretically, by reducing adult populations during peak periods, oviposition will be reduced to a level that prevents significant larval damage the following year. Hill et al. (1948) were the first to test this management technique with aerially applied DDT. They determined that lodged corn during the season following adult suppression was significantly reduced. Area wide aerial application of ULV malathion provided similar suppression of WCR beetles and reduction in larval damage the following season (Pruess et al. 1974). An important factor in adult control is the duration of insecticide residue activity on corn foliage. Mayo (1984) determined that moisture (rainfall and irrigation) is responsible for reducing the residual activity of several insecticides used for beetle suppression.

The possible advantages and disadvantages of adult corn rootworm suppression were discussed by Mayo (1976b). Advantages include: 1) Application of insecticide only when a potentially damaging corn rootworm population is present, 2) Reduced control costs (if only one application is required), 3) Increased grower safety, 4) Reduced chance of improper insecticide application, and 5) May aid in controlling other insects present at the time of application. Disadvantages

include: 1) Increased potential to harm non-target species, and 2) Because adult populations within a field during a given season may be affected by factors such as plant density (Weiss & Mayo 1985), corn planting date (Musick et al. 1980, Bergman & Turpin 1984), corn phenology (Matin & Yule 1984), and adult movement between fields (VanWoerkom et al. 1983, Godfrey & Turpin 1983, Cinereski & Chiang 1968, Hill & Mayo 1980, Naranjo & Sawyer 1988), timing of insecticide application is critical. In addition, the wide-spread use of insecticides on adult rootworms could result in selection of resistant populations.

Several management options have been explored to complement insecticides or to be used as alternatives to insecticides for reducing corn rootworm injury to corn. These include cultural practices, biological control, plant resistance, and exploitation of Diabrotica chemical ecology.

Cultural practices. Because the WCR and NCR are univoltine, and larvae are not capable of long distance movement (i.e. <30 cm, Strnad & Bergman 1987b), control can be achieved by rotation to a non-host crop (Forbes 1882, Gillette 1912). However, Bigger (1932) observed that rotation to corn every other year failed to control NCR larvae. This possibly could have been attributed to NCR oviposition in fields rotated out of corn (Hill & Mayo 1980), but current studies suggest that rotation has selected for extended diapause in a portion of the NCR population (Krysan et al. 1986a). Crop rotation still provides an effective means of controlling rootworm damage but rotations may have to be adapted to a three or more year cycle in local areas where

extended diapause is a problem (Krysan et al. 1986a). A review by Ostlie (1987) examines the extended diapause situation in detail.

The addition of a late planted or "trap" strip of corn to a corn field for corn rootworm management was investigated by Hill & Mayo (1974). They determined that by attracting ovipositing female WCR and NCR beetles to the trap crop, populations in the non-trap field during the current season were reduced 21%. In the following season root ratings decreased 47%, lodging decreased 64%, and yield increased 64 bushels per hectare in non-trap areas. Hill & Mayo (1974) concluded that the second years crop was "protected" by the first years trap crop. However, results obtained in a similar study by Witkowski & Owens (1979) were not as pronounced as those observed by Hill & Mayo (1974).

Biological control. Brust (1989) reported heavy predation of first- and second-instar SCR larvae by larvae of Cantharidae, Staphylinidae, and Carabidae. Chiang (1970) determined that mite predation on WCR and NCR under natural field conditions accounted for 19.7% control which was increased to 63% when manure was applied to the field. However, these studies appear to document the best control of corn rootworms achieved with predators, reported in the literature. Ballard & Mayo (1979) determined that ant predation of WCR eggs in Nebraska was negligible, and Kirk (1982) provides an account of the minimal impact that carabids have on WCR and NCR. The potential impact of entomophagous nematodes on rootworm larvae was evaluated in 1968 (Munson & Helms 1970) but minimal success was observed. Poinar et al.

(1983) tested a different strain of the nematode utilized by Munson & Helms (1970) in their studies and achieved variable levels of suppression. Jackson & Brooks (1989) determined that third-instar WCR larvae were most sensitive to the 'Mexican' strain of the nematode Steinernema feltiae but determined that larvae were capable of encapsulating all strains tested. An entomopathogenic fungus infecting NCR beetles was observed in the laboratory following their collection in the field (Naranjo & Steinkraus 1988) but the effectiveness of the pathogen as a NCR mortality agent in the field is unknown.

Plant resistance. Host plant resistance to corn rootworm larval injury has been under investigation for several years and was recently reviewed by Branson (1986). Branson et al. (1982) evaluated rootworm larvae susceptible and resistant inbred corn lines under uniform WCR egg infestation levels for yield response. They determined that the resistant line yielded higher than the susceptible line under high rootworm populations and that resistance was due to tolerance expressed through the development of larger root systems. Branson et al. (1983) determined that three experimental hybrids yielded higher than a commercial hybrid under uniform WCR egg infestation levels and thought that resistance in these hybrids could be due to compensatory root growth. Finally, Branson et al. (1986) evaluated 400 maize populations resistant to the Mexican corn rootworm (D. v. zeae) in Mexico, and chose 25 of the best populations to test for resistance to WCR in South Dakota. Twelve of these populations suffered less larval injury than the control, and appear to have some potential for use in the development of corn rootworm resistant lines.