Project Title: Development and Implementation of Novel Trapping Systems for Monitoring Cranberry Fruitworm and Cranberry Weevil Populations

(i) Project Type: Research

(ii) Summary Statement. The proposed research will investigate the role of host-plant volatiles as attractants for the cranberry weevil (CBW) and cranberry fruitworm (CBFW), two major pests in cranberries and blueberries in the Northeast US; with the goal to develop traps that can be integrated into a reduced-risk pest management plan. Most current control methods for CBW and CBFW involve applications of broad-spectrum organophosphates and carbamates. Since more rigorous restrictions for the use of broad-spectrum insecticides were implemented in cranberries and blueberries, the need for effective methods to detect, attract, and monitor these two insect pests has attained great importance. New selective, reduced-risk insecticides will require a more precise method for monitoring these pests to better assess application timing. Monitoring adult CBFW populations has relied on the use of pheromones to attract adult males. These pheromone traps, however, have failed to predict fruit damage in cranberry and blueberry fields. A trapping system for monitoring female fruitworm populations is desperately needed. No pheromones have been identified for CBW. We will investigate the behavioral and antennal electrophysiological responses of CBW and CBFW to host-plant volatiles to identify attractants for the development of new traps. After laboratory evaluations, we will conduct on-farm demonstrations to: a) identify "optimal" host-plant volatile blends to attract CBW and CBFW and b) implement traps baited with these blends into reduced-risk IPM programs, and deliver an educational program on the appropriate use of the new technologies in New Jersey, Massachusetts, and Michigan (states involved in this proposal).
PROBLEM, BACKGROUND, AND JUSTIFICATION:

Economic Importance of Crops. Highbush blueberries (*Vaccinium corymbosum* L.) and cranberries (*Vaccinium macrocarpon* Aiton) are both native to North America, and have been under commercial cultivation for many years. Blueberries and cranberries are two of the most important crops in the northeast United States: cranberries are grown in over 39,000 acres, primarily in Wisconsin, Massachusetts, and New Jersey (USDA-NASS 2006a). Two states involved in this proposal, Massachusetts and New Jersey, account for more than 40% of the total US cranberry acreage and for more than 30% of the total US production, valued at $65.3 million. Blueberries in the United States are grown on close to 48,000 acres (USDA-NASS 2006b). Most highbush blueberries are grown in Michigan and New Jersey, two of the states in this proposal. Michigan and New Jersey account for approximately 50% of the total US blueberry acreage and for more than 45% of the total utilized production, valued at $139 million.

Importance of Pests. The two insect pests in this study, cranberry weevil (CBW), *Anthonomus musculus* Say, and the cranberry fruitworm (CBFW), *Acrobasis vaccinii* Riley, can cause major economic losses in the northeast US (Marucci 1966; Averill and Sylvia 1998; Long and Averill 2003). Both insects feed on the plant’s reproductive organs (flower buds, flowers, and fruit), which makes them major direct pests in blueberries and cranberries in the growing areas where they occur. As a consequence, even a low population may cause a substantial loss to growers, particularly if CBFW larvae are detected by a customer after processing. Current monitoring techniques for CBW and CBFW populations are very limited, and therefore limit the scope of current management practices. For example, pheromone trapping in blueberries monitors only male moth CBFW populations; this makes it difficult to accurately time control measures because females are responsible for egg laying. In cranberries, pheromone traps cannot even be used because there is no relationship between male flight and onset of oviposition (Ginnetty and Edgar 1996). No pheromones have been identified for CBW.

Cranberry weevil (also known as blossom weevil) is regularly found across the northeastern US. This insect feeds as an adult on developing anthers, pistils, and leaf buds of blueberries and cranberries. Females lay their eggs into the unopened flower and the larvae complete their development within the flower buds in which they were deposited as eggs. Weevil-infested flower buds become purple in color, fail to open, and eventually fall to the ground. Currently, CBW is a major pest of cranberries in Massachusetts. Outbreak populations were observed throughout the state in 2002-2004 owing to the appearance of organophosphate-resistant populations and the absence of effective management alternatives. This was rectified through EPA approval of a Crisis Exemption petition for indoxacarb. Cranberry weevil is currently considered a secondary pest of blueberries in New Jersey and Michigan, where populations have been kept under economic threshold with applications of broad-spectrum insecticides. However, proposed regulatory restrictions on the use of organophosphates (OPs) and carbamates create a potential for this insect to become a major pest in New Jersey, Michigan, and other growing regions. In 2006, New Jersey blueberry growers reported several outbreaks of this insect requiring immediate chemical control.

In New Jersey blueberries, adults of CBW are monitored using beating trays (action threshold has been an average of 5 weevils per bush or 20% of blossom clusters with reported injury). In cranberries, adults CBW are monitored using sweeping (action threshold has been an average of 4.5
weevils per 25 sweeps). These monitoring methods are labor-intensive. Furthermore, populations are exceedingly patchy and CBW adults are very small and will, when disturbed, fall to the ground; taken together these traits make sweep-net sampling variable and often unreliable among scouts. A cost-effective and reliable method for monitoring CBW adults is critical to accurately time insecticide applications. Traps using volatiles from host plants may provide growers with a cost-effective, low-disturbance, and reliable method to monitor CBW populations.

Volatile from host plants (leaf and flower buds and flowers) may inform foraging females about suitable oviposition sites. Several species related to CBW, e.g. *Anthonomis pomorum*, *A. grandis*, and *A. rubi*, have shown electrophysiological responses to host plant volatiles (Dickens 1990; Kalinova et al. 2000; Bichao et al. 2005) and several species of weevils, such as the pine weevil, banana weevil, and vine weevil (Budenberg et al. 1993; Wibe et al. 1997; van Tol and Visser 2002) responded to host-plant volatiles in behavioral bioassays.

**Evidence for Response of CBW to Host-Plant Volatiles.** Mechaber (1992), in Y-tube olfactometer assays, found that adults CBW are more attracted to CBW-damaged cranberry vines compared to intact, healthy vines. Adults CBW were also attracted to intact and CBW-damaged flower buds compared to clean air (Mechaber 1992). There were no differences in response between male and female CBW (Mechaber 1992). Similarly, we found that 73% of adult CBW were attracted to blueberry terminals containing flower buds (at pre-bloom stage) and flowers compared to clean air ($G = 4.71; P = 0.03$) (Fig. 1). Our results and those from Mechaber (1992) demonstrate that adult CBW utilize volatiles from vegetative and flowering parts in host finding.

In 2006, we conducted gas chromatography (GC-FID) and GC-mass spectrometry (GC-MS) studies to identify attractants used by adult CBW in host and mate finding. CBW adults deposit eggs in flower buds and feed on buds, flowers, and leaves (Averill and Sylvia 1998). Therefore, we collected and identified volatiles emitted from flower buds, flowers, and leaves of highbush blueberry, *V. corymbosum* cv. Duke (Appendix A). Flowers emitted higher amounts of volatiles compared to flower buds and leaves. Several compounds were emitted from all plant tissues; however, most esters were emitted only from flowering plants.
In EAG detection analyses, we found that adult CBW antennae strongly responded to blueberry flower extracts compared to clean air or solvent (methylene chloride) alone (Fig. 2; Bars, mean ± SE, with different letters are significantly different, $P < 0.05$). At 1 µg, adult CBW antennae strongly and consistently responded to hexyl acetate and methyl salicylate (Fig. 3). These two volatiles are major components of the blueberry flower and leaf blends, respectively (Appendix A).

Fig. 2. Antennal (EAG) responses of adults of the cranberry weevil, A. musculus, to blueberry flower extracts.

Fig. 3. Antennal (EAG) responses of adults of the cranberry weevil, A. musculus, to volatile compounds from blueberries.
Cranberry fruitworm. Because of its direct pest status and lack of effective monitoring techniques, studies on CBFW are a top research priority for berries in the northeastern US (http://northeastipm.org/work_fruipriority.cfm). Cranberry fruitworm is a fruit-eating pyralid infesting cranberries and blueberries and is common throughout the eastern US and Canada. As expected for a direct pest, there is low threshold for damage, especially for the percent of fruit that is marketed as fresh. In Massachusetts’ cranberry, infestation levels may exceed thresholds throughout July and August, requiring a series of sprays. Still, damaged fruit may contain larvae at harvest, which is unacceptable to all handlers. Tolerance among blueberry and cranberry growers for CBFW contamination is extremely low, making CBFW one of the most important pests of cranberries in Massachusetts and of blueberries in Michigan and New Jersey. Although CBFW has not been considered a major pest in New Jersey cranberries, populations of this insect have increased in recent years causing alarm among growers.

In blueberries, monitoring techniques for CBFW involve the use of sex-pheromone baited traps for capturing male moths, combined with berry inspections (Mallampalli and Isaacs 2002). In cranberries, IPM programs do not rely on monitoring for determining the timing of the initial sprays and instead, recommend two prophylactic sprays based upon crop phenology; these are followed by collection and visual examination of fruit for presence of visible eggs. Berry inspection is labor-intensive. Further, due to the narrow window of opportunity for fruitworm control, insecticide applications need to be made before fruitworm larvae enter the fruit. If larvae escape treatments and enter into the fruit, control is not possible. CBFW populations are variable between years, between and within farms, and in the timing of their damage. Therefore, a reliable sampling method will provide growers with a better tool for determining when and where intervention is required and reduce unnecessary insecticide applications at sites where populations of CBFW are low. Thus, a low-cost, easy-to-use, and reliable monitoring technique is desperately needed to eliminate or precisely time applications.

Timing based on the first captures of female moths is expected to improve control effectiveness compared to monitoring male moths. Because its univoltine life cycle focuses on Vaccinium spp., females of CBFW are expected to utilize volatile cues from host plants to find oviposition sites, much like the attraction of female codling moth to apple volatiles (Bengtsson et al. 2001; Backman et al. 2001; Ansebo et al. 2004; Hern and Dorn 2004) and female grapevine moth to grape volatiles (Tasin et al. 2006).

Evidence for Response of CBFW to Host-Plant Volatiles. Because female CBFW become active during cranberry and blueberry bloom and prefer to oviposit on young fruit (Averill and Sylvia 1998), we focused our attention on volatiles from plant tissues dominant at time of activity: flowers, leaves, and fruit. Appendix A shows a list of volatiles that were collected from blueberry flowers and leaves. In addition, we tested 7 fruit volatiles: 1-hexanal, trans-2-hexenal, 1-hexanol, trans-2-hexenol, cis-2-hexenol, linalool, and limonene (Parliament and Kolor 1975; Hirvi and Honkanen 1983)

Commercially available synthetic compounds were tested for electro-antennographic (EAG) responses of field-collected female and male CBFW. We found that female antennae were more
responsive to host-plant volatiles than male antennae (Fig. 4). Thus far, four compounds strongly and consistently elicited a response from female antennae compared to clean air or solvent alone. Female antennae responded strongly to 1 µg of hexanol, 2-hexenol, hexyl acetate, linalool, methyl salicylate, and caryophyllene ($P < 0.05$) (Fig. 4). Male antennae responded only to hexanol and methyl salicylate ($P < 0.05$) (Fig. 4). In addition, dose-dependent EAG responses were conducted to determine a range of active concentrations for further laboratory and field studies. Methyl salicylate elicited a dose-dependent response from both male and female CBFW antennae (Fig. 5&6). Female antennae also responded in a dose-dependent manner to linalool (Fig. 6).
Justification for the study. The proposed research will address a top research priority stated by the Fruit IPM Working Group, which is to develop and implement “Effective monitoring strategies for key pests in which technologies currently do not exist” [http://northeastipm.org/work_fruipriority.cfm](http://northeastipm.org/work_fruipriority.cfm). If successful, this study will develop cost-effective and reliable monitoring techniques for CBFW and CBW based on host-plant attractants, which can be implemented into a reduced-risk IPM program in cranberries and blueberries across multiple states in the northeast and other US regions. The new monitoring technologies described in this study will replace the current practices that are labor-intensive and ineffective for monitoring CBW and CBFW populations. These new monitoring techniques may help improve the timing of insecticide applications to control CBW and CBFW in two crops (blueberries and cranberries) and three states (New Jersey, Michigan, and Massachusetts).

Host-plant volatiles may provide a natural source for the development of attractants for monitoring insect pests that are safe to humans, wildlife, and the environment. Volatiles from plants are important cues for many phytophagous insects (Bernays and Chapman 1994), and aid foraging insects in finding hosts, mates, and oviposition sites (Miller and Strickler 1984; Visser 1986). The use of attractant traps has been tested for insects belonging to the various Orders, including Diptera, Coleoptera, and Lepidoptera. One of the best known success cases is the use of attractant traps to monitor and control fruit flies (e.g., Prokopy et al. 1973; Reissig 1974; Carle et al. 1986; Averill et al. 1988; Prokopy and Vargas 1996; Prokopy et al. 1996; Linn et al. 2003). Attractants (baits) for fruit flies are now commercially available (e.g., Nu Lure, GF-120, Naturalure). Examples of attractants from plants under development for monitoring and management of insect pests include: apple volatiles for codling moth *Cydia pomonella* (L.) (Yan et al. 1999; Hern and Dorn 2004), grape volatiles for grapevine moth, *Lobesia botrana* Denis & Schiffermüller (Tasin et al. 2006), and potato volatiles for Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Dickens 2000; Martel et al. 2005).

Population variation in sex pheromone blends has been well documented for different phytophagous insects (e.g. Wu et al. 1996; Hansson et al. 1990; McElfresh and Millar 2002), but...
geographic variation in the attraction of phytophagous insects to host-plant volatiles has rarely been studied. Populations of the Colorado potato beetle, *Leptinotarsa decemlineata*, from Alberta, Arizona, and Maryland varied in their level of acceptance for four different solanaceous host-plant species (Harrison 1987). Electroantennogram (EAG) studies with *L. decemlineata* showed variability in antennal responses among populations (Visser 1983). More recently, Bernays and Funk (1999) showed geographic variation among eastern and western US populations of the aphid, *Uroleucon ambrosiae*, in their host finding and acceptance. This geographic variation was explained by differences in the number of olfactory sensillae among populations (Bernays et al. 2000). Thus, efficiency of traps to attract insects may vary across a large geographic area, depending on behavioral and antennal electrophysiological differences among insect populations and their association to a particular host-plant. We will compare the behavioral and antennal electrophysiological responses of CBW and CBFW populations from major centers of fruit production across their geographic range to cranberry and blueberry volatiles. Populations will be sampled from Michigan, Massachusetts, and New Jersey. Michigan is a major center of blueberry production with minimal cranberry production and Massachusetts is a major producer of cranberries with little blueberry production, whereas New Jersey grows blueberries and cranberries at large geographic scale.

After further identification and field evaluation of volatile attractants for CBFW and CBW, we propose to implement these new monitoring techniques in coordination with the new reduced-risk insecticides that are selective and less toxic to the environment. This proposed research will address another top priority for northeastern IPM in berries by conducting studies towards the “Development and testing of softer materials and non-pesticide options” (http://northeastipm.org/work_fruipriority.cfm). These complementary IPM strategies for monitoring and management will be used to provide recommendations to growers on when, where, and what insecticide to apply for the management of CBW and CBFW populations. This is critical due to the fact that OP and carbamate insecticides are currently undergoing tolerance reassessment by the US Environmental Protection Agency in response to *The Food Quality Protection Act* (FQPA). Although blueberry and cranberry growers have already adopted target-specific reduced-risk compounds for other pests, CBW and CBFW are two of the few pests that still need applications of broad-spectrum insecticides, and thus, are major disrupters of the system. For instance, treatments directed against CBFW account for the majority of OP use in Massachusetts cranberry (diazinon and chlorpyrifos are the most often used). In New Jersey, Asana (esfenvalerate), a pyrethroid, is the only option to control CBW in blueberries. Therefore, there is the immediate need to provide growers with new reduced-risk strategies against CBW and CBFW.

To determine the efficiency of traps, on-farm evaluations will be conducted in blueberries and cranberries at different locations and in three different states. Traps will be implemented into reduced-risk IPM programs in cranberries and blueberries. These programs involve the collaboration of local farmers and Land Grant University extension personnel across the three states in this study. Growers will provide their land to compare the efficiency of traps under reduced-risk strategies vs conventional growers’ practices at real-world large-scale settings. These on-farm demonstrations and recommendations on what to apply, when needed, will facilitate growers’ adoption of new monitoring technologies and reduced-risk options. We expect the results from this study to provide the basis for the development of commercial traps for CBW and CBFW that can be easily used by cranberry and blueberry growers in Michigan, Massachusetts, New Jersey, and other production regions.
Manufacturers of insect traps will be approached to help in the commercialization of cost-effective trapping systems.

There are several environmental, health, and economic benefits that can be anticipated from this study. By monitoring and better timing of applications of insecticides to control CBW and CBFW, we expect to see a reduction in insecticide use in cranberry and blueberry fields. This reduction of insecticide use coupled with an increase in use of selective reduced-risk practices will have a positive impact on the environment. Unnecessary insecticide applications will reduce pesticide residues in fruit and maximize farm-worker protection. Furthermore, use of traps will reduce the need for scout visits that are costly and labor-intensive, and thus minimize exposure of scouts to pesticide residues.

OBJECTIVES AND ANTICIPATED IMPACTS:

Objectives:

1. Assess the behavioral responses of adult cranberry fruitworm and cranberry weevil to host-plant volatiles;
2. Identify volatiles important in attraction of the cranberry fruitworm and cranberry weevil to plants;
3. Evaluate potential compounds and techniques to attract and trap adults in the field;
4. Implement traps into a reduced-risk IPM program;
5. Distribute information on monitoring and control of cranberry fruitworm and cranberry weevil populations to growers.

Anticipated Impacts:

Implementation of IPM. This study’s ultimate goal is to provide cranberry and blueberry growers with: a) new tools for monitoring CBFW and CBW populations, and b) monitoring techniques that can be implemented into a reduced-risk IPM program, and to educate growers about the use of these new practices. This work will have a strong likelihood to contribute towards our ongoing efforts to implement better monitoring techniques and new reduced-risk strategies into pest management programs in cranberries and blueberries.

Economic and environmental benefits. This study will develop and implement novel traps that are economically feasible, easy-to-use, and reliable for cranberry and blueberry growers. ISCA technologies (http://www.iscatech.com/exec/index.htm), a company dedicated in the production and commercialization of insect traps, will be approached to develop a product for the growers.

This will result in several short- and long-term benefits to growers and the environment that include:
a) More effective pest monitoring techniques;  
b) Reduced monitoring costs;  
c) Implementation of selective pest management tactics;  
d) Reduced insecticide use;  
e) Lower likelihood for the development of resistant populations;  
g) Greater preservation of beneficial insects; and  
h) Better protection to workers.

APPROACH AND PROCEDURES:

Objective 1. Assess the behavioral responses of adult CBFW and CBW to host-plant volatiles.  
(Rodriguez-Saona, Averill, Isaacs, Stelinski)

*Insects.* Populations of CBW and CBFW from Michigan, Massachusetts, and New Jersey will be 
tested for their behavioral and EAG responses to blueberry and cranberry volatiles. In 2007-2008, 
adults of the CBW will be collected from infested cranberry fields in June-July only from 
Massachusetts because populations in New Jersey cranberries are low (Rodriguez-Saona, personal 
observations). In blueberries, CBW adults will be collected only from New Jersey in late March to 
early April because CBW populations in Michigan are low (Stelinski and Isaacs, personal 
observations). Although CBW populations in Michigan occur at very low densities, efforts will 
continue for the development of a trapping system to prevent it from becoming a major pest and to 
learn more about its abundance and phenology in Michigan. Cranberry weevil adults will be collected 
from blueberry fields by shaking the foliage onto a white ground cloth and by sweep net from 
cranberries. Adults from Massachusetts will be sent to New Jersey.

CBFW will be collected from infested blueberry fields in Michigan and New Jersey, and 
cranberry fields from Massachusetts and New Jersey in 2007 and 2008. Berries infested with CBFW 
will be collected in late June from blueberry fields and in late August from cranberry fields. Berries 
will be placed in 60 x 28 x 4 cm wooden boxes with the bottoms containing a layer of newspaper and 
fine moist sand. Larvae emerging from the berries will drop to the sand and form hibernaculae 
(overwintering stage). These will be sifted from the sand and placed in moist leaf litter inside a plastic 
container with mesh top. Then placed in cold storage (6 °C for two weeks, then 3 °C), with a super-
saturated salt solution to maintain humidity, and removed as needed. CBFW hibernaculae from 
Michigan and Massachusetts will be sent to New Jersey for use in behavioral and EAG assays. Adults 
will emerge after transfer to 22 °C, will be separated by sex, and provided water and sucrose food 
source.

*Chemical stimuli.* We propose to collect volatiles from cranberries for comparison to blueberry 
volatiles (Appendix A). In the present study, we will collect and identify volatiles from cranberry 
flower buds, flowers, leaves, and fruit, and from blueberry fruit.

*Behavioral assays.* From our recent findings, flower and leaf volatiles appear to play a critical role in 
host finding for CBW and CBFW. The behavioral response of different populations of these insects to 
blueberry and cranberry volatiles will be studied in the laboratory using olfactometers. A Y-tube 
olfactometer will be used to study the behavioral response of CBW, while an 8-arm olfactometer
described by Gokce et al. (2005) will be used to study the behavioral response of CBFW. Males and virgin and gravid females of CBFW will be tested separately.

**Objective 2. Identification of volatiles important in attraction of the CBFW and CBW to plants. (Rodriguez-Saona, Stelinski)**

Further studies will be conducted to identify additional active compounds from blueberries and cranberries using gas chromatography and coupled gas chromatography-electroantennographic detection (GC-EAD).

**Volatile collections.** Terminal stems supporting flower buds, flower clusters, and leaves will be excised from blueberry and cranberry fields. Excised plant material will be sealed in plastic bags and placed on ice immediately for transportation to the laboratory for volatile collection. The excised end of the stems will be wrapped in wet cotton balls. Volatiles from excised flower buds, flowers, and leaves will be collected using a push-pull system (Rodriguez-Saona et al. 2001; Rodriguez-Saona et al. 2002). Volatiles from at least four different plants will be collected for 6 h.

In addition, volatiles from cranberry and blueberry fruit will be collected for tests with CBFW. Fruit (20 g) will be enclosed inside 20 x 20 cm non-absorbent Vac-Pak bags (Richmond Products, Norwalk, CA). Volatiles will be collected in Super-Q adsorbent traps (Alltech, Deerfield, IL) by pulling air from inside bags at a rate of 1.5 mL/min with the aid of a 12-volt vacuum pump (Sensidyne, Clearwater, FL). Volatiles from at least four plants per treatment will be collected for 6 h. Empty bags will be sampled concurrently to test for contamination.

**Identification of active compounds.** So far, we have isolated and identified volatiles from blueberry flower buds, flowers, and leaves. We will collect and identify volatiles from blueberry and cranberry fruit and cranberry flower buds, flowers, and leaves. Volatiles from the Super-Q traps will be extracted by rinsing with 150 µL of methylene chloride. An internal standard (400 ng of n-octane [Sigma-Aldrich] in 5 µl methylene chloride) will be added to each extract. A 1-µL aliquot of each extract will be injected onto a Hewlett-Packard (HP) 6890 Series GC, equipped with a flame ionization detector (FID) and a 10 m x 0.53 mm i.d., 2.65 µm film HP1 column.

Samples will be analyzed by coupled gas chromatography-mass spectrometry (GC-MS). Compounds will be identified by comparing spectral data with those from commercially available standards and spectra from MS libraries, and confirmed by retention times of authentic standards, if available. Quantifications of individual components will be based on comparison of peak areas from GC-FID with that of the n-octane internal standard (Rodriguez-Saona et al. 2001).

**Gas chromatography-electroantennographic detection (GC-EAD).** Plant samples will be analyzed by coupled GC-EAD to identify compounds from blueberry and cranberry flower buds, flowers, and fruit that elicit an electrophysiological response from adult male and female CBW and CBFW. An antenna will be excised from the head and the distal tip cut off with a scalpel. The cut ends of the antenna will be inserted into small droplets of electrode gel on a plexiglas platform. Glass electrodes filled with 0.9% NaCl₂ will be inserted into the gel. Gold wires inside each glass electrode will be connected to a Syntech (Hilversum, The Netherlands) portable INR-2 amplifier connected to a personal computer containing a Syntech data acquisition interface board and Syntech GC-EAD software.
Two-uL samples from plants will be injected into the GC (HP 5890 Series). One half of the column effluent will be delivered to the flame ionization detector (FID) of the GC and the other half will go to a Syntech heated (215 °C) transfer line emptying into a humidified airstream (about 300 mL/min) directed at the excised antenna.

Electroantennogram (EAG) dose response. EAG dose-response profiles for the responses of antennae from adult CBW and CBFW of both sexes to individual volatile compounds from cranberry and blueberry will be developed following the protocol of Stelinski et al. (2003). Only active GC-EAD compounds will be tested for dose responses.

Objective 3. Evaluate potential compounds and techniques to attract and trap adults in the field. (Rodriguez-Saona, Averill, Isaacs)

New Jersey. In New Jersey, we will evaluate the potential of individual, and blends of, compounds attractive to CBW or CBFW. Thus far, we have identified hexyl acetate and methyl salicylate as potential attractants for adult CBW. In addition, we have identified hexanol, 2-hexenol, hexyl acetate, linalool, methyl salicylate, and caryophyllene as antennally-active compounds to females of CBFW. In 2007, we will conduct field experiments to test the attractiveness of these compounds.

To test the attraction of adult CBW to hexyl acetate and methyl salicylate, sticky board traps (7 x 20cm) will be placed in blueberry fields. Standard polyethylene caps containing the active compound(s) will be placed directly above each trap. Treatments will consist of traps baited with hexyl acetate, methyl salicylate, hexyl acetate plus methyl salicylate, and unbaited traps as controls. Treatments will be replicated four times in four different sites (n = 16 traps per site, total = 64 traps). The experiment will be conducted from late March through mid May (beginning of flower bud formation until bloom).

For tests with CBFW, ISCA delta traps (http://www.iscatech.com/exec/traps.htm) containing a standard cap with the antennally-active compound(s) will be tested in blueberry and cranberry fields. Treatments will consist of traps baited with either: A) a single compound (hexanol, 2-hexenol, hexyl acetate, linalool, methyl salicylate, or caryophyllene); B) a blend of compounds: hexanol + 2-hexenol + hexyl acetate + linalool + methyl salicylate + caryophyllene (complete blend) or hexanol + hexyl acetate + linalool + methyl salicylate (most active blend); or C) unbaited controls. Traps in blueberry fields will be hung 15 to 60 cm below the uppermost branch of the bush canopy. This height has been found to be the best location for trapping CBFW (Sarzynski and Liburd 2004). Traps in the cranberry fields will be suspended 1 m above the canopy (Averill, personal observation). Treatments will be replicated four times in four different blueberry and cranberry sites (n = 36 traps per site, total = 288 traps). Experiment will be conducted from bloom until fruit set.

Traps will be checked once a week, and replaced as needed. Caps containing synthetic volatiles will be replaced every two weeks. Adults caught in traps will be counted and sexed. All traps will be placed at least 10 m apart at each site; sites will be separated at least 100 m. Traps with volatile attractant treatments and controls will be deployed in randomized complete block design, with site as blocks. Trap catches, after transformation if needed, will be analyzed by ANOVA.
In 2008, we will conduct similar field studies as described above, except that we will incorporate or eliminate treatments based on laboratory and field results obtained in 2007. Field studies will determine an “optimal” volatile blend for trapping CBW and CBFW.

Massachusetts. Since both CBW and CBFW are abundant in cranberry 3-5 weeks after peak activity in New Jersey, the six treatments (two for CBW and four for CBFW) determined to be most attractive in New Jersey’s 2007 field trials will be tested in Massachusetts in 2007. Methods from the New Jersey trials will be duplicated (see above).

New Jersey, Michigan, and Massachusetts. Field studies will be conducted during 2008 and 2009 in New Jersey, Michigan, and Massachusetts, to evaluate the “optimal” synthetic volatile blend to attract CBW and CBFW. Sticky board and delta traps baited with the “optimal” synthetic blend for trapping CBW and CBFW, respectively, will be tested in New Jersey and Michigan blueberry fields, and in New Jersey and Massachusetts cranberry fields. Treatments will consist of traps baited with either the synthetic volatile blend, female pheromone (CBFW only), or unbaited controls. Two traps per treatment will be placed within 1-acre plots and each replicated four times within each farm (n= 8 traps per treatment per farm). Traps will be placed in three blueberry farms in Michigan, three cranberry farms in Massachusetts, and three blueberry and three cranberry farms in New Jersey (N = 288 traps for CBFW and 192 traps for CBW across all states). Within each farm, traps will be placed at least 10 m apart within plots, and at least 100 m will separate the replicates. Adult CBW and CBFW caught in traps will be counted and sexed. Experiments will be conducted from the beginning of flower bud formation until flowering for adult CBW captures; and from early bloom until fruit set for adult CBFW. Traps will be checked once a week, and replaced as needed.

Traps with different treatments will be deployed in randomized complete block design with farms as blocks. Counts from 2 traps for each treatment within each plot will be summed prior to analysis. Data will be analyzed separately for each state (New Jersey, Massachusetts, and Michigan), and crop (blueberries and cranberries). Moth catches, after transformation if needed, will be analyzed by ANOVA.

Objective 4. Implement traps into a reduced-risk IPM program. (Rodriguez-Saona, Averill)

In 2009, the most effective trap (“optimal” synthetic blend from Objective 3) for monitoring CBW and CBFW will be incorporated into on-farm blueberry and cranberry reduced-risk IPM programs. In New Jersey, two monitoring programs will be compared: a grower standard program based on monitoring techniques currently used by growers (GS program) and a program based on the use of the new attractant-based traps (AT program) (Appendix B). Each program will be compared using 5-acre paired plots of blueberries and 3-acre paired cranberry bogs. Both programs will be conducted at three commercial farms.

For CBW, conventional monitoring practices will be compared with the use of traps based on host-plant volatiles under reduced-risk controls in blueberry fields (Appendix B). GS plots will be monitored by beating 5 canes (5 beats per cane) per bush (N = 10 bushes per plot) using a beating tray. Samples will be taken weekly from late March through mid-May. AT plots will be monitored by placing 4 traps baited with the “optimal” volatile blend (Objective 3). In addition, 4 unbaited traps will
be placed in the GS plots. Traps will be placed from late March through mid-May, checked once a week, and replaced as needed.

To estimate time of insecticide applications based on trap catches of adult CBW, trap catches will be correlated with larval CBW injury to blossoms. Blossoms ($N = 150$) will be inspected weekly for CBW larval feeding damage at each AT site. Chemical application (Asana) will be recommended if blossom injury equals or exceeds 20% of clusters. In GS plots, chemical control treatment will be recommended if average number of weevils per bush is equal to or greater than 5.

Similarly, we will compare conventional monitoring practices versus the use of traps based on host-plant volatiles under reduced-risk controls for CBFW in blueberries and cranberries (Appendix B). GS plots will be monitored with the use of pheromone traps. Four pheromone traps will be placed in each farm. AT plots will be monitored by placing four traps based on an “optimal” volatile blend (Objective 3). Four additional traps will be placed in AT plots containing a combination of the “optimal” volatile blend and CBFW pheromone. Traps will be checked from May-July.

Chemical control (Intrepid or Confirm) will be recommended at the peak of male captures in the GS plots or at time of first female captures in the AT plots. In addition, the number of CBFW in traps will be correlated with the beginning of oviposition. From each plot, we will count weekly the number of eggs in 5 blueberry clusters per bush ($N = 10$ bushes per plot) and 100 cranberries. To assess CBFW fruit damage, fruit clusters ($N = 150$) will be inspected at each site (GS and AT plots) for larval feeding damage. CBFW fruit damage will be assessed at the end of July.

Distance between traps within plots will be same as described above. Data from trap counts and insect damage will be analyzed in a randomized complete block design, with four replicates per program (GS vs AT), and farms as blocks. In addition, trap counts within the AT plots containing the “optimal” host plant volatile blend will be compared with those containing host-plant volatile blend plus CBFW pheromone. Trap catches, after transformation if needed, will be analyzed by ANOVA. Information on number of insects/trap, insect damage, and control recommendation will be provided to growers.

In Massachusetts, methods will mimic those of New Jersey with these exceptions. Work on both pest species will be on cranberry only. For GS plots, both spring and summer populations of CBW will be sampled by sweep-net, and if the action threshold is exceeded (4.5 adults/25 sweeps), chemical application will be recommended. Chemical control in both GS and AT plots will be Avaunt (spring) or Actara (summer) (Appendix C). For CBFW, GS plots will receive two prophylactic treatments (10 days between applications of Diazinon, Lorsban, or Sevin) based on crop phenology (sex pheromone traps cannot be used reliably in MA cranberry); subsequent applications will be triggered by egg counts (1% infestation). AT plots will be treated with Intrepid, based on the onset of captures in “optimal” blend traps. CBFW damage will be assessed at the end of August.

Objective 5. Distribute information on monitoring and control of CBFW and CBW populations. (Rodriguez-Saona, Averill, Isaacs)

Several methods will be used to transfer the data from this study to growers:
1. The results from this study will be presented at New Jersey, Michigan, and Massachusetts Small Fruit Grower meetings.
2. The information will be transferred to IPM coordinators in each state.
3. Fact sheets and newsletters will be written on the use of traps.
4. Scientific articles will be written on the development and efficacy of traps.
5. Information will be provided to a major pheromone supplier (ISCA Technologies, etc.) on the most effective trap to commercialize the volatile blend.
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¹ CBFW= cranberry fruitworm; CBW= cranberry weevil; MI= Michigan; MA= Massachusetts; NJ= New Jersey
EVALUATION PLANS

The proposed research will address several of the top entomological research priorities set by the northeastern IPM working group for Fruit (Berries), which are:

1. To conduct studies on cranberry fruitworm (CBFW), one of the subject pests in this proposal;
2. To develop effective monitoring strategies for key pests in which techniques currently do not exist; and
3. To develop and test softer materials and non-pesticide options.

This project will optimize the management of cranberry weevil (CBW) and CBFW, by providing cranberry and blueberry growers with new monitoring techniques that may improve the timing of insecticide applications and reduce unnecessary applications where significant populations do not exist.

In 2006, Rutgers University (Dr. Rodriguez-Saona, principal investigator) received a one-year funding from the Regional IPM Competitive Grants Program to identify host-plant attractants for CBW and CBFW. The results from this study (presented in this proposal) are very encouraging and several host-plant volatiles were identified as potential attractants for CBW and CBFW. In the present proposal, we will continue our efforts to identify and evaluate host-plant attractants for CBW and CBFW to develop new trapping systems for these pests. We will evaluate the behavioral and antennal responses of individuals from different populations across three states. This proposal will also allow us to conduct on-farm demonstrations of traps baited with the identified active plant volatiles and to determine the efficacy of these traps for monitoring CFW and CBW populations when implemented into reduced-risk pest management programs in cranberries and blueberries.

We expect a trend towards an increase in the use of the new monitoring techniques under this proposal in coordination with the use of reduced-risk strategies. The success of the project will be measured by the number of growers, IPM specialists, consultants, etc., who use the new traps and follow our recommendations from trap counts. Given that three of the main states involved in cranberry and blueberry production are represented in this proposal, the educational and economic impacts of the research will be maximized. This will help in the adoption of the proposed IPM practices. The outreach program described in this proposal will highlight the use, cost, and benefits of using the new technologies. Workshops, meetings, fact sheets, and newsletters will be used to present the results from this study to cranberry and blueberry growers. All these avenues will be used to help promote, implement, and increase the adoption of the proposed novel technologies among growers across the northeastern US and other regions of cranberry and blueberry production.
REFERENCES


KEY PERSONNEL

• Dr. Cesar Rodriguez-Saona (PD), Assistant Professor and Extension Specialist (Project Director)
  Blueberry and Cranberry Entomology
  Rutgers, The State University of New Jersey
  Phillip Marucci Blueberry and Cranberry Research and Extension Center
  Chatsworth, NJ 08019
  Ph. (609) 726-1590 ext. 4412; e-mail: crodriguez@aesop.rutgers.edu

  Responsibilities: Overall management of the project. Participate in all objectives: conduct behavioral assays, volatile collections (GC, GC-MS), EAG and GC-EAD analyses, field evaluations of traps and reduced-risk practices. CV follows.

• Dr. Rufus Isaacs (CO-PD), Associate Professor, Department of Entomology, Michigan State University
  East Lansing, MI 48824

  Responsibilities: Evaluation of traps in Michigan. Conduct educational program. Participate in Objectives 1, 3, and 5. CV follows.

• Dr. Anne Averill (CO-PD), Associate Professor, University of Massachusetts
  Amherst, MA 01003

  Responsibilities: Evaluation of traps in Massachusetts. Conduct educational program. Participate in Objectives 1, 3, 4, and 5. CV follows.

• Dr. Lukasz Stelinski (CO-PD), Research Associate, Department of Entomology, Michigan State University
  East Lansing, MI 48824

  Responsibilities: Participate in laboratory and greenhouse experiments (EAG, GC-EAD, behavioral assays) (Objectives 1 and 2). CV follows.
RELEVANCE STATEMENT

(1) Names and institutions of PD and major cooperators (CO-PDs):
Cesar Rodriguez-Saona (PD), Rutgers, The State University of New Jersey
Rufus Isaacs (CO-PD), Michigan State University
Anne Averill (CO-PD), University of Massachusetts
Lukasz Stelinski (CO-PD), Michigan State University

(2) Project title: Development and Implementation of Novel Trapping Systems for Monitoring Cranberry Fruitworm and Cranberry Weevil Populations

(3) Project type: Research

(4) Project summary: The proposed research will investigate the role of host-plant volatiles as attractants for the cranberry weevil (CBW) and cranberry fruitworm (CBFW), two major pests in cranberries and blueberries in the Northeast US; with the goal to develop traps that can be integrated into a reduced-risk pest management plan. Most current control methods for CBW and CBFW involve applications of broad-spectrum organophosphates and carbamates. Since more rigorous restrictions for the use of broad-spectrum insecticides were implemented in cranberries and blueberries, the need for effective methods to detect, attract, and monitor these two insect pests has attained great importance. New selective, reduced-risk insecticides will require a more precise method for monitoring these pests to better assess application timing. Monitoring adult CBFW populations has relied on the use of pheromones to attract adult males. These pheromone traps, however, have failed to predict fruit damage in cranberry and blueberry fields. A trapping system for monitoring female fruitworm populations is desperately needed. No pheromones have been identified for CBW. We will investigate the behavioral and antennal electrophysiological responses of CBW and CBFW to host-plant volatiles to identify attractants for the development of new traps. After laboratory evaluations, we will conduct on-farm demonstrations to: a) identify "optimal" host-plant volatile blends to attract CBW and CBFW and b) implement traps baited with these blends into reduced-risk IPM programs, and deliver an educational program on the appropriate use of the new technologies in New Jersey, Massachusetts, and Michigan (states involved in this proposal).

(5) Description of the problem, background, and justification: This study’s ultimate goal is to provide cranberry and blueberry growers with: a) new tools for monitoring cranberry fruitworm (CBFW) and cranberry weevil (CBW) populations and b) monitoring techniques that can be implemented into a reduced-risk IPM program, and to educate growers about the use of these new practices. This work will have a strong likelihood to contribute towards our ongoing efforts to implement better monitoring techniques and reduced-risk strategies into pest management programs in cranberries and blueberries. Blueberries and cranberries are two top crops in New Jersey, Massachusetts, and Michigan.

This proposal addresses several of the top entomological research priorities set by the northeastern IPM working group for Fruit (Berries), which are to conduct studies on cranberry fruitworm (CBFW), one of the pest species in this study; to develop effective monitoring
strategies for key pests in which techniques currently do not exist; and to develop and test softer materials and non-pesticide options (http://northeastipm.org/work_fruipriority.cfm).

We will develop cost-effective and reliable monitoring techniques (traps) for CBFW and CBW based on host-plant volatiles. Host-plant volatiles provide a novel natural source for the development of insect attractants that are safe to the environment. The new monitoring technologies described in this study will replace the current practices that are costly and ineffective for monitoring CBFW and CBW populations and will help improve the timing of insecticide applications across the two crops (blueberries and cranberries) and three states (New Jersey, Michigan, and Massachusetts).

After development of monitoring techniques for CBFW and CBW, we propose to implement the new traps into reduced-risk IPM programs. These complementary IPM strategies for monitoring and management will be used to provide recommendations to growers on when, where, and what insecticide to apply for the management of CBFW and CBW populations. This is critical due to the fact that broad-spectrum (organophosphates and carbamates) insecticides used to control these pests are undergoing tolerance reassessment by the US Environmental Protection Agency in response to The Food Quality Protection Act (FQPA). Although blueberry and cranberry growers have already adopted target-specific reduced-risk compounds for other pests, CBFW and CBW are two of the few pests that still need applications of broad-spectrum insecticides, and thus, are major disrupters of the system.

On-farm evaluations of the new traps will be conducted in blueberries and cranberries at different locations in New Jersey, Michigan, and Massachusetts. In addition, traps will be implemented into reduced-risk IPM programs in cranberries and blueberries. These programs involve the collaboration of local farmers and Land Grant University extension personnel. Growers will provide their land to compare the efficiency of traps vs conventional growers’ monitoring practices under reduced-risk strategies at real-world large-scale settings. These on-farm demonstrations and recommendations on what to apply, when needed, will facilitate growers’ adoption of new selective reduced-risk practices. Without better monitoring techniques, new reduced-risk pest management strategies are unlikely to be adopted by growers because of the perceived risk and difficulties associated with the growers’ transition away from broad-spectrum insecticides. Most reduced-risk insecticides are selective and require precise timing of application. We expect the results from this study to provide the basis for the development of commercial traps for CBFW and CBW that can be easily used by cranberry and blueberry growers in Michigan, Massachusetts, New Jersey, and other production regions. Manufacturers of insect traps will be approached to help in the commercialization of cost-effective trapping systems.

There are several environmental, health, and economic benefits that can be anticipated from this study. By monitoring and better timing the applications of insecticides to control CBFW and CBW, we expect to see a reduction in insecticide use in cranberry and blueberry fields. This reduction of insecticide use coupled with an increase in use of selective reduced-risk practices will have a positive impact on the environment. Reduced-risk strategies are expected to have fewer negative effects on several classes of non-target, beneficial insects such as predators, parasitoids, and pollinators. Selective chemicals are also safer to humans and aquatic
life, and will reduce environmental hazards. Unnecessary insecticide applications will reduce pesticide residues in fruit and maximize farm worker protection. The use of traps will reduce the need for scout visits that are costly and labor-intensive, and thus minimize exposure of scouts to pesticide residues.

In summary, this study will result in several benefits to growers and the environment that include: a) more effective pest monitoring techniques; b) reduced monitoring costs; c) more selective pest control tactics; d) reduced insecticide use; e) lower likelihood for the development of resistant populations; f) greater preservation of beneficial insects; and g) better protection to workers.

(6) Project Objectives and Anticipated Outcomes: The objectives of the proposed research project are to:

1. Assess the behavioral responses of adult cranberry fruitworm and cranberry weevil to host-plant volatiles;
2. Identify volatiles important in attraction of the cranberry fruitworm and cranberry weevil to plants;
3. Evaluate potential compounds and techniques to attract and trap adults in the field;
4. Implement traps into a reduced-risk IPM program;
5. Distribute information on monitoring and control of cranberry fruitworm and cranberry weevil populations to growers.

Anticipated Outcome: This project will optimize the management of CBFW and CBW by providing cranberry and blueberry growers with new monitoring techniques that may improve the timing of insecticide applications and reduce unnecessary applications where significant populations do not exist. To do so, growers’ on-farm demonstrations will be conducted in three states (New Jersey, Michigan, and Massachusetts). Field studies on how to monitor and control CFBW and CBW populations will be conducted for the future implementation of these technologies into reduced-risk pest management programs in cranberries and blueberries.

The success of the project will be measured by the number of growers, IPM specialists, consultants, etc., who use the new traps and follow our recommendations from trap counts. We expect a trend towards an increase in the use of the new monitoring techniques under this proposal in coordination with the use of reduced-risk strategies.

Given that three of the main states involved in cranberry and blueberry production are represented in this proposal, the educational and economic impacts of the research will be maximized. This will help in the adoption of the proposed IPM practices. The outreach program described in this proposal will highlight the use, cost, and benefits of using the new technologies. Workshops, meetings, fact sheets, and newsletters will be used to present the results from this study to cranberry and blueberry growers. All these avenues will be used to help promote, implement, and increase the adoption of these novel technologies under this proposal among growers across the northeastern US and other regions of cranberry and blueberry production.