Component II: Protection of Agricultural and Horticultural Crops

2f. Vegetables (U.S. Value 2007: $17 billion)

***Problem Statement*:** The principal commercial vegetable crops (including potato, tomato, onion, leafy greens, cucurbits, crucifer crops) do not produce maximum yields due to the following pests and gaps in knowledge:

- *Bemisia tabaci* and Whitefly Transmitted Viruses (U.S.: tomato, watermelon, squash, snap beans, and other crops)
- Onion Thrips and Iris Yellow Spot Virus
- Thrips and Tomato Spotted Wilt Virus in Tomatoes and Other Vegetable Crops (U.S.: tomato, peppers)
- Chilli Thrips (diverse vegetable crops in Florida, Georgia, Texas)
- Beet Leafhopper in Potatoes and Other Vegetable Crops
- Potato Psyllid (in potatoes and other solanaceous crops, including tomato) and Zebra Chip Disorder in Potatoes
- Wireworms in Potatoes and Other Vegetable Crops (U.S.: potato, sweet potato, sweet corn)
- Colorado Potato Beetle in Potato and Other Solanaceous Vegetables (eastern United States)
- Pale Cyst Nematode *(Globodera pallida)* and *Globodera* n. sp., a New Species of Cyst Nematode, in Potato (in Pacific Northwest)
- Diamondback Moth in Crucifers
- Striped and Spotted Cucumber Beetles in Vegetables (especially cucurbits and sweet potatoes) and Flowers, including Organic Operations (all States)
- Regional Differences in Pest Status of Insects in Vegetables and/or Effectiveness of Natural Enemies
- Improved Use and Rearing of Biological Control Agents (predators and parasitoids)
- Improved Development and Use of Insect-Specific Pathogens
- Annual and Perennial Weeds
- Other Important Pests include: Potato Tuberworm (Washington: potatoes) and Other Moths, and Viruses Transmitted by Aphids (green peach aphid, soybean aphid, etc.) (U.S.: potato, squash, snap beans)

Research Needs:

1. ***Bemisia tabaci* and Whitefly Transmitted Viruses**

Importance: First described over 100 years ago, *Bemisia tabaci* has since become one of the most devastating tropical and sub-tropical agricultural pests worldwide. *B. tabaci* has been recorded from more than 600 plant species. Crop losses can occur not only from direct feeding damage but also from feeding induced plant physiological disorders, honeydew contamination and associated fungal growth, as well as plant diseases caused by whitefly transmitted viruses. *B. tabaci* is a vector of 111 recognized plant virus species in the genera *Begomovirus* (Geminiviridae), *Crinivirus* (Closteroviridae), *Carlavirus* and *Ipomovirus* (Potyviridae). There are more than 20 biotypes of this whitefly species, with two of the most damaging to plants, the B and Q biotypes, residing in the United States. Biotype B was first discovered in the United States in 1985 and biotype Q more recently in 2004. Biotype Q was detected during routine resistance monitoring efforts when resistance values of 1000-fold were observed for buprofezin (a commonly used insect growth regulator for whitefly control). Following the introduction of biotype B, new plant pathogenic begomoviruses began to appear and threaten tomato production in many U.S. tomato growing areas. Due to the broad host range and aggressive nature of biotype B, it is likely that this whitefly will continue to be a source of introduction of new viruses into tomato and other crops. Biotype Q is also a very efficient vector of plant viruses in the Mediterranean Basin which is considered its native range and may follow the same scenario if it makes the jump from ornamentals to field grown vegetables. Currently it has been detected in 25 U.S. states, on herb and ornamental hosts.

Research Gaps: Vital solutions to the *B. tabaci* problem in tomatoes are needed. Economic losses in tomatoes related to begomoviruses are currently negated through the use of costly and intensive pesticide treatments for whitefly control. Begomovirus-tolerant tomato varieties have been developed but insecticidal control of *B. tabaci* remains the major disease-control strategy. Growers rely almost exclusively on insect growth regulators and one chemical class of insecticides (neonicotinoid), yet resistance to these insecticides in *B. tabaci* has been well documented overseas. With respect to varieties with resistance to begomoviruses, the mechanism of resistance and commercial stability of this resistance are unknown. Tomato growers will likely turn to such varieties if widespread insecticide resistance develops in *B. tabaci* stateside. If so, the reoccurrence of production problems related to disorders such as tomato irregular ripening would likely occur. Research should address vector-pathogen interactions and insect-plant interactions, role of endosymbionts, aspects of population ecology, and rapid methods of biotype detection. Research should aim at identifying the genetic basis of tomato resistance to plant viruses and transmission of these viruses by *B. tabaci* as well as novel biotechnology strategies for overcoming whitefly/virus resistance. This information would in turn be used to develop new and improved methods for reducing whitefly mediated crop losses in tomato.

Actions: ARS will:

Vector-pathogen Interactions

- Determine molecular phenomena involved in transmission.
- Insect-plant Interactions and Host Plant Resistance
- Use conventional methods to develop resistant crop hosts.
- Determine heritability of resistance in melons and watermelon.
- Develop novel host plant resistance through interdiction of important biological processes (RNAi, Bt, etc.).
- Understand causes of physiological disorders in host plants.

Endosymbionts

- Determine primary and secondary role of endosymbionts in whitefly physiology.
- Investigate role of *Wolbachia* in reproduction, fitness, and virus transmission.

Population Ecology

- Understand U.S. population dynamics in context of global phylogeny.
- Determine extent of gene flow among mixed biotype populations and influence on fecundity and insecticide resistance.

Detection

- Develop simple rapid PCR-based detection of biotypes – including field applicable protocols.

Monitoring

- Develop trapping methods using pheromones and kairomones.
- Evaluate LED-modified traps for whitefly control.

Control, Biological

- Assess the importance of biological control agents in reducing whitefly populations.
- Investigate the effect of alternative host plants on parasitoids of whiteflies.
- Determine the overwintering ability of whitefly predators in order to develop methods to conserve and augment natural populations.

2. Onion Thrips and Iris Yellow Spot Virus

Importance: Onion thrips is the vector of iris yellow spot virus (IYSV), which is an emerging threat to the United States onion industry. Iris yellow spot has been present in the Pacific Northwest for over 15 years, but has now spread to all major onion producing States. The reasons for the sudden development and dissemination of IYSV on onion

bulb and seed crops in the United States remain unclear. Projected economic impacts, if the rate of spread and damage by IYSV and thrips continue unchecked in the western United States, could reach $80 million (10 percent loss) to $120 million (15 percent loss in farmgate value), in addition to environmental and economic costs associated with additional pesticide sprays that have limited efficacy ($7.5 to 12.5 million dollars for 3 to 5 additional sprays applied to 120,000 acres per year). Onion growers in the western United States currently rely almost exclusively on insecticides for thrips management. Problems with insecticide resistance in western populations of onion thrips have been reported for over 15 years. Reliance on insecticides alone to control thrips in onions is not sustainable.

Research Gaps: The epidemiology of IYSV and its thrips vector are largely unknown, and the literature is devoid of IYSV management recommendations. Studies of the biology and epidemiology of IYSV and onion thrips are needed to establish economic injury levels for onion thrips when IYSV is a threat and develop appropriate ecologically-based IPM programs for this pest complex. There is also need to determine how these IPM programs would affect management of other pests and production practices. There is a critical need to develop onion germplasm and cultivars with improved levels of resistance or tolerance to IYSV and onion thrips. Improved diagnostics for detecting the virus in thrips and plants would facilitate monitoring and other fundamental studies of this pathosystem.

Actions: ARS will:

Host Range

- Determine reproductive hosts vs. adult feeding hosts for onion thrips.
- Determine potential sources of thrips and virus.

Population Ecology

- Characterize relationships between IYSV incidence and thrips populations on onions and weed hosts in the field.

Monitoring

- Improve sampling and monitoring methods for the vector.

3. Thrips, Tomato Spotted Wilt Virus in Tomatoes, and Other Vegetable Crops

Importance: Over the past two decades, outbreaks of tomato spotted wilt have increased greatly on a number of crops, such that tomato spotted wilt virus (TSWV) is now considered one of the most important pathogens globally, with estimated losses exceeding $1 billion dollars annually. The principal vegetable crops at risk from tomato spotted wilt are tomatoes, peppers, lettuce, eggplant, and potatoes. The primary vector of TSWV is the western flower thrips, although at least two other thrips species present in the United States are known vectors. Management of thrips and tomato spotted wilt on tomatoes has relied on high input control measures, including extensive use of conventional synthetic pesticides. Not only do these chemicals not provide satisfactory

disease control, but they also pose threats to consumers, growers, and the environment, and they can disrupt management programs for other pests, leading to secondary pest outbreaks.

Research Gaps: In order to safeguard the tomato industry and other vegetables, immediate research is required to develop efficient management programs for flower thrips and tomato spotted wilt. To the extent possible, these methods should avoid disrupting current programs that successfully control other pests. Alternative control methods that need to be addressed include improved use of naturally occurring biological control agents and methods to limit dispersal of thrips into crop fields. Efficient monitoring methods for the viruliferous thrips, and forecasting of disease severity would facilitate the targeting of control methods. Achieving these goals will require a better understanding of sources of infectious thrips and how thrips disperse into crops. Therefore, research is needed to understand season to season variation in populations of infectious thrips and their dispersal behavior. In addition, customers have identified the need for improved disease resistant varieties.

Actions: ARS will:

Population Ecology

- Conduct long-term studies of thrips population dynamics, with a focus on factors affecting the abundance of infectious thrips.
- Determine non-crop sources of infectious thrips.

Vector-pathogen interactions

- Investigate ability of thrips to acquire and transmit different virus strains from and to different host plants.

Control, Biological

- Characterize interactions between thrips and their predators, including host plant effects on interactions.
- Develop methods to conserve and augment naturally occurring populations of thrips predators.

Control, Interference with Host Plant Location

- Investigate new methods and materials to deter and/or repel thrips from entering crop fields.

4. Chili Thrips

Importance: The chili thrips (*Scirtothrips dorsalis*) is widespread across its natural range in tropical Asia and has recently been detected in the United States in Florida and Texas. The pest threatens to expand its range to most of the southern United States. Chili thrips are highly polyphagous and have been recorded from more than 100 plant species spread across 40 different families. As with other plant feeding thrips, damage is caused by sucking sap from individual epidermal cells leading to necrosis of the tissue.

Damage is most severe at growing tips, on young leaves and shoots, or on flowers and young fruits. On chilies, large numbers of thrips have been found causing young leaves to shrivel or curl badly; leaves may be shed and crop loss can reach 90 percent. Damage to roses and other ornamental hosts can be devastating with plants becoming completely defoliated, resulting in death. Chili thrips have also been reported to vector a number of plant viruses in peanut and tobacco, but it is unclear if *S. dorsalis* can transmit tomato spotted wilt virus.

Research Gaps: When invasive pests enter the United States, rapid and accurate taxonomic characterizations of the invader, as well as a determination of its genetic diversity and position in the global phylogeny of the species are crucial information. This information is a fundamental requirement to plant quarantine and biological control programs, as well as development of classical IPM control strategies. Furthermore, this information has proven useful in international trade negotiations with respect to quarantine, and plant material movement limitations. Currently, there are many taxonomic questions that need to be answered with this chili thrips species. Morphological variation has made species and subspecies determinations very difficult and many researchers believe that *S. dorsalis* may contain multiple biotypes or could be a cryptic species complex. Information regarding this invasive species is limited and research should be broad, including population genetics, general biology, host range (including crops and weeds), virus transmission potential, pesticide control and resistance monitoring, biological control, development of thresholds, and effect of cultural measures.

Actions: ARS will:

Population Genetics

- Investigate U.S. population thrips dynamics in context of global phylogeny to determine origin of U.S. thrips populations.
- Assess gene flow among thrips populations in the United States to determine complexity of genetic structure.

General Biology

- Determine thermal limitations and developmental times.
- Monitor movement between commodities.
- Identify key thrips pupation sites.
- Improve identification and taxonomy, using both classical and molecular technology.

Host Range (crops and weeds)

- Determine damage potential.
- Determine reproductive hosts vs. adult feeding hosts.

Virus Transmission

- Determine vector potential for tomato spotted wilt and other important viruses affecting vegetables.

Control, Insecticide

- Identify effective products.
- Determine residual activity.
- Determine optimal timing, frequency and method of application.
- Establish baseline data for resistance management.

Control, Biological

- Identify predators, parasitoids, pathogens and nematodes that could be effective biological control agents.
- Investigate rearing methodology to improve quantity and quality of biological control agents.
- Determine impact of pesticides on beneficial insects.
- Assess predator needs for pollen or alternate foods
- Assess host plant impacts on efficacy of biological control agents (i.e., tomato vs. ornamental hosts).
- Investigate soil controls against thrips pupae.

Develop Commodity Thresholds

- Greenhouse (herbs, vegetables, and potted plants)
- Field Vegetables

Impact of Cultural Practices

- Investigate the effect of fertility, pruning, flowering, watering, etc., on the pest and biological control agents.

5. **Beet Leafhopper in Potatoes and Other Vegetable Crops**
Importance: Potatoes and other vegetable crops are attacked by the beet leafhopper, *Circulifer tenellus*. The beet leafhopper has been identified as the vector of beet leafhopper-transmitted viresence agent (BLTVA) phytoplasma, a causal agent of the potato purple top disease, which has recently been causing serious outbreaks in the Columbia Basin of Washington and Oregon. The disease is becoming increasingly important and damaging in the Pacific Northwest, causing significant yield losses to potato fields and reduction in tuber processing quality. It is difficult to effectively manage the beet leafhopper and purple top disease in potatoes. The difficulty arises from the fact that there is very low to zero tolerance for several insect-vectored plant pathogens

in potatoes, especially for potato seed growers and the processing industry, making acceptable control strategies difficult to growers, even with conventional means. There is a need to develop an improved way for growers to accurately assess the degree and timing of the beet leafhopper threat for effective control.

Research Gaps: It is crucial to understand the source and movements of the beet leafhopper to determine if infectious leafhopper populations are local or are originating from more distant locations. In addition, since the incidence of BLTVA phytoplasma within potatoes is a function of vector dispersal from weedy habitats to potatoes, this aspect also warrants investigation. There is incomplete knowledge of the relationship between crop and non-crop habitats and abundance of beet leafhoppers in adjacent potato crops. Moreover, there is incomplete understanding of beet leafhopper movement, overwintering, and the relationship of these traits with incidence of leafhopper-vectored diseases in potatoes. Furthermore, there is a lack of action thresholds and information on how insecticides should be timed to most effectively target this insect pest.

Actions: ARS will:

Population Ecology

- Determine the relationship between weed community and abundance of the beet leafhopper.
- Determine the source and the importance of the overwintering and spring/summer beet leafhopper populations in potatoes.
- Elucidate the local spatial
- Ecology of leafhoppers in circumpolar agroecosystems.

IPM

- Develop action thresholds and information on how insecticides should be timed to most effectively target the beet leafhopper.

6. Potato Psyllid (in potatoes and other solanaceous crops, including tomato) and Zebra Chip Disorder in Potatoes

Importance: The potato psyllid is indigenous to the southwestern United States and northern Mexico and is known to migrate long distances to exploit its solanaceous host plants, including potatoes, tomatoes, and peppers. Potatoes and other vegetable crops are attacked by the potato psyllid, *Bactericera cockerelli*, which has recently been identified as associated with zebra chip, a new disease (or disorder) of potato in the southwestern United States, Mexico, Central America, and New Zealand. Zebra chip was first noted in the United States in the Lower Rio Grande Valley of Texas in 2000. In Texas, potato production was valued at $91.6 million in 2005, but the crop is at risk since all the major potato production areas in Texas and parts of Mexico have experienced outbreaks of zebra chip. Zebra chip leads to lower yields, and also to the rejection of chips processed from infected potatoes. Chips processed from infected tubers have a dark color defect and are commercially unacceptable. Tubers infected with zebra chip generally do not

sprout, or if they do, produce hair sprouts or weak plants. Mechanisms by which the potato psyllid induces zebra chip are not known. The potato psyllid is suspected to inject pathogens and/or toxins in plants when feeding. Recently, a new species of bacterium has been associated with zebra chip infected plants and potato psyllids. However, the role of this bacterium in zebra chip symptom expression is not yet clear.

Research Gaps: There is a need to increase the understanding of the role of the potato psyllid in zebra chip. In addition, little is known on the etiology and epidemiology of the disease. More studies on the ecology and population dynamics of this insect pest are needed to develop effective management strategies. Further research is needed to: investigate the role of native solanaceous plants as refuges for the pathogen; characterize the genotypes of *B. cockerelli* in Central and North America and evaluate their ability to vector zebra chip; compare the phenology of *B. cockerelli* with other pest psyllids, such as the Asian citrus psyllid. Grower difficulties in managing the potato psyllid with available tools have led to a need for research to develop effective alternative control methods that are compatible with current growing practices and IPM programs. Monitoring tools that are effective, acceptable, and used by growers are needed. This information is needed to refine the IPM program recently developed for this pest.

Actions: ARS will:

Vector Biology

- Assess the role of the potato psyllid in zebra chip by conducting transmission studies under laboratory and field conditions.

Population Ecology

- Study the phenology and population dynamics of the potato psyllid.
- Conduct additional field research to determine the potential refuges of the zebra chip pathogen.
- Assess environmental factors that influence zebra chip symptom expression, including planting time and plant growth stage.

Population Genetics

- Collect insect material for the genetic evaluation of *B. cockerelli.* ARS will conduct this research in tandem with research directed at the Asian citrus psylla.

Monitoring

- Develop effective and improved monitoring tools for the potato psyllid.

IPM

- Refine existing IPM program strategies for the potato psyllid, including chemical, biological, and cultural controls.
- Collaborate with the Texas Agrilife Extension Service to implement the IPM program developed by ARS.

7. Wireworms in Potatoes and Other Vegetable Crops

Importance: Potatoes and other vegetable crops are attacked by a complex of wireworm species. Problems caused by these soil-dwelling pests in irrigated crops appear to be increasing in severity. Current difficulties in managing these pests are due to a combination of factors: incomplete understanding of wireworm biology, the subterranean life cycle of the damaging life stage, multi-year development times, a paucity of effective insecticides, poor understanding of the relationship between wireworm numbers and damage potential, and a lack of effective monitoring tools.

Research Gaps: Grower difficulties in managing wireworms with available tools have led to a need for research to develop alternative control methods that are compatible with current growing practices and IPM programs. Monitoring tools that will be accepted and used by growers are needed. Research to develop synthetic attractants for the subterranean larval stage or the adult click beetle stage would lead to new monitoring tools and possibly to new control technologies (i.e., attract-and-kill methods). Biological studies to assess how larvae or adults are affected by putative attractants are also required. A poor understanding of how wireworm density predicts damage potential requires research to define this relationship quantitatively. Research that defines the environmental and biological factors that affect wireworm densities and distribution in fields would allow growers a means for assessing risk before planting of the crop.

Actions: ARS will:

Monitoring/Prediction of Damage

- Assess wireworm or click beetle response to putative attractants.
- Develop and improve monitoring tools.
- Determine the relationship between wireworm densities and damage potential.
- Define how field characteristics (e.g., soil type, growing history) predict wireworm infestation.

Control, Semiochemicals

- Develop methods to use synthetic attractants in control programs.

Control, Host Plant Resistance

- Identify sources of resistance.
- Determine heritability of resistance.
- Facilitate incorporation of resistance into advanced sweetpotato breeding lines and new cultivars.

8. Colorado Potato Beetle, in Potato and Other Solanaceous Vegetables

Importance: This key pest is most important east of the Rocky Mountains but is an occasional problem in the West as well. Starting around 1990, it has been controlled in many areas almost exclusively with nicotinoid insecticides, principally imidacloprid, but in the past few years, control failures have been documented as well as cross-resistance to related, more recently-registered insecticides.

Research Gaps: An integrated management system is critical to the longevity of any given pesticide class, thus a system should include cultural controls such as breeding and cultural tactics to increase crop resistance, crop rotation and timing (including trap cropping), conservation and deployment of microbial and arthropod biological controls, and application of semiochemical attractants and antifeedants. An integral component to any integrated management system is understanding the phenology of the potato beetle. Diapause is the chief physiological mechanism underlying insect phenology

Actions: ARS will:

Control, Semiochemicals

- Evaluate best strategies for use of plant volatile attractants (kairomones) and beetle pheromones, as well as antifeedants related to trapping, trap cropping, and crop timing. Strategies will likely differ by region.

Control, Biological

- Determine best practices for conservation and augmentation of natural enemies native to North America, including identification of limitations to biological control in potato and other agroecosystems.
- Identify and apply microbial (bacterial and fungal) controls that are selectively effective controls for the pest. One important component of this is to determine the role of endosymbionts and gut physiology in pathogen defense by the pest.

Control, Plant Breeding

- Enhance constitutive resistance against pest feeding and damage through conventional breeding. (Link to Madison: Vegetable Crops Research Unit)
- Pursue pest-induced expression of plant defenses as a mechanism for durable resistance.

Control, Cultural

- Determine factors responsible for cover-crop, mulch and manure effects on pest population suppression.

Biology

- Develop an understanding of diapause development and termination in the potato beetle.

9. Pale Cyst Nematode *(Globodera pallida)* and *Globodera* n. sp., a New Species of Cyst Nematode, in Potato

Importance: Two cyst nematodes new to the United States have recently been identified in the Pacific Northwest. In March, 2006, the Nematology Laboratory received and subsequently identified the pale cyst nematode *(Globodera pallida)* from soil collected at a potato processing plant in Idaho. This discovery represented the first detection of this major quarantine pest in the United States. Regulatory action was initiated, including the implementation of a survey designed to sample all U.S. potato-growing fields. Another species of cyst nematode, new to science, has been identified from a potato field in Oregon by the Nematology Laboratory. In May, 2008, the Laboratory received cysts from potato-growing acreage in Oregon and concluded that the cysts represent a new species of round cyst nematode (i.e., *Globodera* sp.). The host range of this new species and its ability to infect potato are obviously unknown. Species of *Globodera* have limited host ranges. APHIS has been notified through usual channels. If this species proves to be pathogenic on potato, significant regulatory impact will undoubtedly follow.

Research Gaps: As both of these species are new to the United States, and one is new to science, there is a need for more information on their biology, ecology, taxonomic status, host range, pathogenicity, and distribution in the United States.

Actions: ARS will:

- Conduct research on these cyst nematodes under National Program 303 – Plant Diseases.

10. Diamondback Moth in Crucifers

Importance: The diamondback moth *(Plutella xylostella)* is a major pest of crucifers (e.g., broccoli, cabbage, cauliflower, collard, mustard greens, radish and turnip). Major crucifers grown in the United States include broccoli (54,777 ha), cabbage (32,222 ha), and Brussels sprouts (1,174 ha). The diamondback moth occurs across the continental United States as well as Hawaii, and was recently detected in interior Alaska. Control failures for this pest have occurred in several states including Florida, Georgia, North Carolina, New York, South Carolina, Texas, and Wisconsin. Because of its resistance to many insecticides, the management of this insect pest is particularly problematic.

Research Gaps: Long- and short-term integrated management solutions against the diamondback moth are needed for growers of crucifer crops.

Actions: ARS will:

Ecology

- Improve the understanding of seasonality, population dynamics, and ecology of the diamondback moth, and the potential impact of natural enemies on diamondback moth populations.

Control

- Explore environmentally friendly management tools against the diamondback moth.
- Assess virulence of insect pathogens against the diamondback moth.
- Improve efficacy of biopesticides for control.

11. Striped and Spotted Cucumber Beetles in Vegetables (especially cucurbits and sweet potatoes) and Flowers, Including Organic Operations (all States)

Importance: Striped and spotted cucumber beetles, *Acalymma* (*A. vittatum* and *A. trivittatum*), and *Diabrotica* (*D. undecimpunctata* subspecies and *D. balteata*, but not including *D. virgifera* and *D. barberi*) respectively, are serious pests of many high-value crops including vegetables, peanuts, cut flowers, and diversified organic operations in the United States. Surveys of organic growers by the Organic Farming Research Foundation have found this group to be the most frequently cited group of pests for organic vegetables. *Acalymma*, the striped cucumber beetles, are cucurbit specialists which are a key threat to seedling cucumbers, squash, melons, and pumpkins, in many states. Spotted cucumber beetles, *D. undecimpunctata*, and in the South, banded cucumber beetle, *D. balteata*, are widespread polyphagous pests, which in addition to cucurbits, feed on leafy vegetables, sweet potatoes, peanuts, soybean, corn, flowers, etc. Cucumber beetles cause losses to cucurbits and other vegetables by chewing young plants, blossoms, and fruit. Root damage to sweet potatoes, peanuts, cucurbits, corn, soybeans, and other crops is caused by the larvae. Cucumber beetles also vector a serious bacterial wilt of cucurbits, which is caused by *Erwinia tracheiphila*, an incurable cucurbit pathogen. Current practices rely mainly on pesticide applications in vegetable crops.

Research Gaps: Detection and rapid, effective control methods are needed, particularly for organic plantings. Most promising is the combination of cucurbit-derived specific feeding stimulants for cucumber beetles with environmentally-friendly toxins as the basis for baits or other attract-and-kill tactics. However, the best formulations and deployments of cucurbitacins still need to be determined. Volatile attractants, including plant-derived kairomones and sex and aggregation pheromones, are known to influence cucumber beetle behavior, but specific means to apply these to pest management are not clear. Knowledge of the dynamics of bacterial wilt transmission and of effects of root feeding on various crops also is needed to place the damage in an IPM perspective. Adult parasitoids (braconid wasps and tachinid flies) are poorly known, as is the guild of predators and other mortality factors for larvae in the soil.

Actions: ARS will:

Control, Semiochemicals

- Develop knowledge of chemistry of cucurbitacins from plant sources, and how to quickly and economically measure and concentrate these feeding stimulants for field use in baits or other controls for cucumber beetles.
- Develop knowledge of emission dynamics of cucurbitacins and other attractant semiochemicals.
- Develop effective traps to determine pest abundance in the field.
- Compare and optimize field deployment of best formulations for attract-and-kill methods in vegetable crops.
- Develop a synthetic method for vittatalactone, the known aggregation pheromone for *Acalymma vittata* (eastern striped cucumber beetle). Currently, the active enantiomer is not available in pure form, and various racemic mixtures need to be tested in combination with novel chemical syntheses, to determine the best approach for an economic production of the attractant.

Control, Biological

- Evaluate larval (root) feeding and mortality, using molecular predation detection techniques and possibly plant biochemistry to look at larvae using phytochemicals to defend against natural enemies.
- Evaluate parasitoids of adults as a source of mortality for striped and spotted cucumber beetles.
- Examine non-target effects on natural enemies and pollinators, of novel baits and controls discussed above.
- Test novel microbial controls and toxins for larval and adult suppression.

Control, Cultural

- Evaluate trap cropping, barriers and row covers, possibly in combination with cucurbitacin-containing baits, to mitigate effects on affected crops, particularly susceptible cucurbits.

Control, Host Plant Resistance

- Identify sources of resistance.
- Determine heritability of resistance.
- Facilitate incorporation of resistance into advanced sweetpotato breeding lines and new cultivars.

12. Regional Differences in Pest Status of Insects in Vegetables and/or Effectiveness of Natural Enemies

Importance: The occurrence and pest status of some insect pests varies among regions or changes with passage of time. Management methods that work well in some areas or for certain periods of time, including biological control, may be unsatisfactory in others.

As a result, management techniques must often be tailored or modified according to these regional differences. In some cases, reasons for the differences may be known but often the underlying reasons are not well understood, making it difficult to improve management tools.

Research Gaps: Changes in regional pest distribution and status require greater understanding of pest biology, ecology and movement, as well as the development or modification of scouting and control methods. Research is needed to more fully understand the factors that determine such regional differences. There are many potential causal factors in need of further study, such as genetic differences among regional populations, development of insecticide resistance, climate or weather-related factors, and basic biological and other biotic factors such as competition and differences in natural enemy complexes.

Actions: ARS will:

Monitoring

- Improve sampling and monitoring methods to account for regional differences in pest status and distribution, including the appearance of insecticide resistance.

Ecological Research

- Conduct comparative ecological studies of pests in different regions, including invasive pests in their native range.

Control, Host Plant Resistance

- Develop and evaluate new and improved varieties tailored for better pest resistance in specific regions.

Control, Cultural

- Develop and evaluate cultural management tactics appropriate for specific regions.

Control, Biological

- Develop improved methods of foreign exploration for more efficacious populations of natural enemies of invasive pests.
- Develop methods to improve natural enemy conservation of resident natural enemy populations.

13. Availability of Pesticides for Minor Crops

Importance: There is low availability of herbicides, insecticides, and miticides that are registered for use on minor acreage crops such as most vegetable crops, which are affected by a wide range of arthropod and weed pests. Pesticides registered for use on the major crops such as cotton, corn, soybeans, and small grains are not generally available to growers of minor crops because of the economic disincentives for pesticide registrants. Croplife America industry analysts, in 2000, estimated the development of a

new crop protection chemical costs in excess of $180 million and takes over 9 years. First registrations are for major crops such as: corn (76 million acres), soybean (75 million acres), wheat (47 million acres), and cotton (13 million acres). The acreage of vegetable crops is generally too small for manufactures to add the cost of vegetable use to the labels.

Research Gaps: Short term integrated pest management solutions are needed for growers of minor crops because few or no options are available when needed. Reduced risk and biopesticides options are especially needed. The EPA crop grouping scheme provides a mechanism to obtain food use tolerances by the use of a few representative crops on an entire crop group. However, pesticide registrants are reluctant to add the crops to the label in many instances because of a lack of performance and safety data on the crops where data were not obtained for the tolerance. The IR-4 program functions as a public sector registrant and is the only publicly funded program which conducts research and petitions EPA for the registration of suitable control compounds.

14. Improved Rearing Systems for More Robust Biological Control Agents (predators and parasitoids)

Importance: Concerns about the impact of agricultural practices on environmental quality are continuing to increase. Also, the effectiveness of traditional chemically-based insect and weed control measures has decreased due to resistance. These two major problems have increased the need for biologically-based IPM strategies that include the use of beneficial insects for the control of pest insects and invasive plants. However, there are substantial obstacles to the successful implementation of biological control programs. One is the difficulty and expense of rearing beneficial insects in sufficient numbers for release at the appropriate times. Most beneficial insects are reared on their natural host, which is an inefficient approach. Consequently, artificial rearing and storage methods are needed for economical production of consistent populations of natural enemies. However, formulations of artificial diets have problems associated with the nutritional quality and other parameters that affect the quality of beneficial insects.

Research Gaps: To make augmentative biological control a more viable option for vegetable crops, improved mass rearing systems for the cost-effective production of high quality predators and parasitoids must be developed. Development of rapid, sensitive and accurate detection methods for the measurement of the quality of mass produced beneficial insects will help ensure that mass produced beneficials consistently meet high quality standards. Information is lacking on the impact of plant and environmental factors on the effectiveness of beneficial insects in the field.

Actions: ARS will:

Control, Biological

- Invent new or improved diet formulations and rearing technologies for production and storage of insects to enhance the use of beneficial insects and to improve and preserve their natural qualities.

- Identify and develop attractants for key predators and parasitoids, and protocols to utilize semiochemicals for detecting beneficial insects and promoting predation and parasitism in agroecosystems.
- Develop molecular methods (PCR and/or immunoassays) for use in detection of predation and parasitism in agroecosystems, including released strains.
- Identify genetic and biochemical factors involved in health, fitness and production of insects and develop those factors as accurate, high-speed biomarkers of those traits.
- Conduct foreign and domestic exploration for predators and parasitoids that may be candidate biological control agents.
- Improve non-target safety and effectiveness of biological control agents.

15. Improved Development and Use of Insect-Specific Pathogens

Importance: Control of insect pests in vegetables has relied predominately on synthetic insecticide sprays. Many of these pesticides are under increasing regulatory pressure, and are of concern in relation to pesticide residues in food and water, environmental concerns for pesticides in air and water, and worker safety. Research is needed to develop non-insecticidal means for controlling these pests and to reduce the need for pesticides in vegetables.

Research Gaps: Although insect pathologists have identified numerous pathogenic microbial agents that show good potential for use as biopesticides, there is a need to continue exploration for new species and strains of insect-specific pathogens including entomopathogenic nematodes, viruses, fungi and bacteria. Few of the currently known microbial agents have been commercially developed as biopesticides. A significant constraint to the commercial use of microbial agents in agriculture is the lack of low-cost, large-scale methods for producing and formulating stable, effective microbial products. Additional research is needed to develop quantitative assay methods for quantification of virulence of insect-specific pathogens. The commercial use of microbial control agents will be facilitated through improved application and formulation of pathogens to better target pest insects and improve persistence of pathogens in the environment. The ongoing concerns regarding environmental effects of biological control demand that quantitative assessments of the environmental impact of insect specific pathogens be improved, especially their effects on non-target organisms and other biological control agents.

Actions: ARS will:

Control, Biological

- Conduct foreign and domestic exploration for new and more virulent insect-specific pathogens. Foreign exploration would be in cooperation with ARS overseas laboratories (in France, Argentina, Australia, China).

- Improve production methods of pathogens including improved fermentation and development of new in-vivo methods.
- Invent new and improve existing methods of bioassay of pathogens against pest and non-target insects.
- Develop formulation additives for improved application, attractiveness (to pest insects), and persistence of insect-specific pathogens.
- In combination with other control methods, develop an integrated approach to insect control that maximizes the efficacy of insect pathogens and minimizes their effects on other components of integrated control including other biological control agents.

16. See IS4 Program for Minor Crops and Host Plant Resistant Section

17. Annual and Perennial Weeds

Importance: Annual and perennial weeds lower the quantity and quality of vegetable crops through direct competition for resources (light, water, nutrients), harboring other insect and nematode pests and plant pathogens, and by impeding harvest. Perennial weeds, including yellow and purple nutsedge, are extremely difficult to manage in certain vegetable cropping systems. Methyl bromide is effective on several weeds and has been utilized in some vegetable production systems, but is no longer available for use in most cases. Most vegetable crops have a limited number of herbicides registered for use, some of which are older herbicide chemistries with user concerns such as herbicide resistance in weeds and/or less favorable environmental profiles. Weed management systems, including the use of non-chemical approaches, must buffer against the failure of an individual tactic. Handweeding or hand-hoeing is frequently used; however, high labor costs can be prohibitive. Moreover, demand for organically produced vegetables is increasing and weed control costs in organic vegetable production can exceed $1,500/acre.

Research Gaps: Factors controlling seed/tuber dormancy, regulation of dormancy, and germination are unknown. Why specific weeds are a pest in certain regions and crops is largely unknown. There is a need for new herbicides to kill weeds, vegetable crops with greater tolerance to herbicides, and pest management alternatives to methyl bromide. Weed hosts of important vegetable root crop pests need to be identified and the impact of these weeds on insect, disease, and nematode pests needs to be determined. The effect of weed host presence in the landscape on disease and insect dynamics is largely unknown. Also, an understanding of multitrophic interactions among weeds, insects (beneficial and pest), pathogens, the crop, and how various crop production practices influence these interactions is needed. Integrated systems to control weeds need to be improved. Cropping systems that target not only seedling control, but also seed rain, seed bank, and emergence, are needed. In addition, systems that utilize multiple control tactics, such as

crop rotation, weed suppressive cultivars, cover crops, soil amendments, and cultivation should be developed to reduce the risk of weeds in vegetable production.

Actions: ARS will:

Control

- Provide safe and effective pest management solutions for vegetables through the IR-4 program.
- Explore the feasibility of enhancing herbicide tolerance in specific vegetable crops.
- Identify new opportunities to improve weed management by a greater understanding of vegetable crop/weed ecology.
- Determine biotic and abiotic factors that contribute to weed seedbank fate.
- Develop methods to manage specific problem weeds in vegetable crops.
- Identify successful elements of cropping systems utilizing cultural, mechanical, and chemical weed suppression tactics for meeting weed management objectives.

Anticipated Products:

- Increased knowledge of pest biology, ecology, behavior, genetics, interactions with host plants, and geographic variation.
- Increased knowledge of invasion biology of insect pests.
- Increased knowledge of the ecology of insect vectors of plant pathogens, including knowledge of vector and pathogen sources and dispersal into crops, and disease epidemiology.
- Information on endosymbionts associated with vegetable pests, and their effect on pest physiology.
- Characterization of insect semiochemicals (attractants, repellents and confusants).
- Behavioral manipulation of pest and beneficial insects through the use of semiochemicals.
- Improved pest sampling and detection methods.
- Development of economic threshold and injury levels based on quantitative relationships between pest populations and crop damage.
- Facilitation of registration of pesticides for insect, mite and weed pests on minor crops.
- Discovery of new biological control agents.
- Increased knowledge of the genetics, basic biology, and ecology of biological control agents.

- Improved production and application of mass reared biological control agents.
- Improved methods for conservation and augmentation of biological control agents.
- Novel methods of incorporating pest resistance into vegetable crops.
- Development of crop varieties resistant to major pests.
- Increased knowledge of the effect of horticultural practices on pest and beneficial populations.
- Increased knowledge of weed biology and ecology that leads to enhanced control.
- Identification of weed hosts of insect, nematode, and plant pathogens of vegetables.
- Novel methods of reducing the impact of weeds on vegetable crops.

***Potential Benefits (Outcomes)*:**

- Sustainable, biologically-based IPM practices to manage pests of vegetable crops more effectively.
- Reduced economic losses from insect pests of vegetables and the plant diseases that they transmit, as well as weed pests of vegetables.
- Reduced reliance on synthetic pesticides.
- Reductions in expenditures to manage insect and weed pests.
- Weed management tactics that are ecologically and economically sound.

***USDA ARS Resources*:**

- Applications Technology Research, Wooster, Ohio
- Beneficial Insects Research Unit, Weslaco, Texas
- Biological Control of Pests Research Unit, Stoneville, Mississippi
- Crop Protection and Management, Tifton, Georgia
- Fruit and Vegetable Insect Research, Wapato, Washington
- Insect Behavior and Biological Control Research Unit, Gainesville, Florida
- Invasive Weed Management, Urbana, Illinois
- Insect Behavior and Biological Control Research Unit, Gainesville, Florida
- Pest Management and Biological Control Research Unit, Maricopa, Arizona
- Subtropical Insect Research Unit, Fort Pierce, Florida
- Sustainable Agricultural Systems, Beltsville, Maryland
- Vegetable and Forage Crops Research, Prosser, Washington
- Vegetable Research Unit, Charleston, South Carolina