EVALUATING POTENTIAL SOLUTIONS FOR CURRENT CODLING MOTH AND ORIENTAL FRUIT MOTH MANAGEMENT CHALLENGES.

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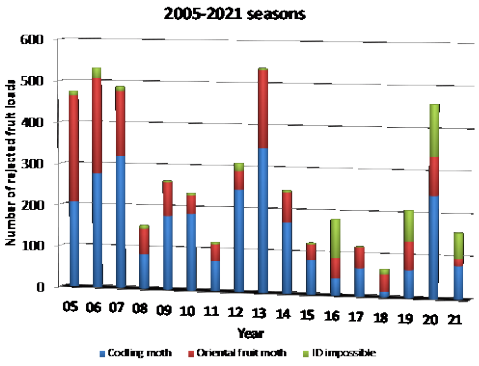
DURATION: Second year continuation of the project started during the 2021 season.

JUSTIFICATION: The Oriental fruit moth (OFM), *Grapholita molesta* (Busck) and codling moth (CM), *Cydia pomonella* (Linnaeus) are considered ones of the most important internally feeding fruit pests of apples, peaches and nectarines in the mid-Atlantic region. About 15-20 years ago, a wide-spread of insecticide resistance combined with a removal of older insecticide products from the market were responsible for explosion of CM/OFM management challenges. However recently, wider incorporation of mating disruption products and introduction of new insecticides such as Altacor and Delegate, contributed to significant reduction of the CM/OFM problems in PA commercial orchards.

Unfortunately, during last few seasons, increased numbers of apple loads destined for the processing were again rejected by USDA inspectors for the presence of live worms in the fruit.



During the 2020 harvest season, there were over 400 loads rejected for the presence of live larvae in the fruit, which placed it at a very similar level as number of rejections during the 2005-2007 seasons (see the figure below). The number of rejected fruit loads during the 2021 season was lower (see graph), however at least partially this artificial decrease may be attributed to the change in the procedures of checking for worms in delivered loads. Unfortunately, the in-field observations conducted by our lab personnel indicated the presence on wormy fruit in some commercial fruit orchards during this past season. As the season winded down, numerous orchards reported issues with live larvae in harvested fruit. The CM and /or OFM injured fruit were collected from 5 orchards and brought to laboratory for insecticide bioassays. Due to the time of collection in the fall, majority of collected larvae went into diapause and at the earliest, the full scale insecticide bioassays can be conducted no earlier than this winter.

Few fruit growing areas in the world have populations of both CM and OFM infesting apple simultaneously as it is occurring in Pennsylvania. Codling moth overwinters as full-grown larvae within loose bark scales or in other sheltered places. First generation flight starts during the bloom, and the peak flight occurs approximately 2 weeks after full bloom. First-generation eggs are laid on leaves near fruit or on the fruit and hatch in about 8 to 14 days (150-250 DD_{50} after biofix). Newly hatched larvae bore through the fruit surface, usually at the side of the fruit, feed

near the surface for few days before boring to the core of the fruit. Larvae feed on the seeds and surrounding flesh until they are fully grown in 3 to 4 weeks. CM damage to apples may be shown either by a tunnel emanating from the apple side or calyx and extending to the core, or by "stings," small shallow holes the size of pin pricks, with a little dead tissue on the cavity walls. Larvae that feed on the core characteristically leave frass exuding from the point of entry. Fully grown larvae exit the fruit and pupate outside of fruit. Two to three weeks later the second CM generation starts. Some individuals of the second generation may also pupate and produce a third generation. This generation, which usually does not survive the winter, is termed a suicide generation. Individuals can, however, inflict additional late-season fruit injury. The equally important internal fruit feeder, Oriental fruit moth also overwinters as a full-grown larvae but initiate its spring activities earlier than codling moth and have 3 to 4 complete generations per season. The feeding behavior of the OFM larvae is similar to CM, however larvae never enter the seed chamber and feed inside the fruit mostly under the skin in the stem or calyx area. Oriental fruit moth can infest both, pome and stone fruit.

It is very likely that insecticide resistance may be one of the factors influencing current OFM and CM control failures in some of PA orchards, however before we agree on this conclusion, a number of other factors should also be explored. The rate of the used products, spray coverage and timing are the most obvious ones, however other potential factors such as weather conditions during pest development, retention of the spray residue on the surface of the fruit or potential pesticide handling errors may also influence otherwise correct management practices. Due to the CM/OFM feeding behaviors, the only time the larvae can be effectively controlled by insecticide is the period between egg hatch and the moment when larvae enter fruit, which usually occurs within less than 24 hours after hatch. If an active insecticide residue is not present on the fruit surface during that period, the management will fail. And with each season having different weather conditions, the timing for insecticide application needs to be very precise and adjusted every year to occurring conditions. Despite the general perception of the 2020 season being one of the hottest years on the record, the average temperatures during the month of May were the fifth coldest on the record. And since the development of CM and OFM, similarly as for all other insects, is very closely corelated with the outside temperatures, it is possible the traditional timings for insecticide applications to control CM and OFM, might not be the most appropriate during the 2020 and 2021 seasons (please see the seasonal differences in the development of various insects as observed at the PSU FREC orchards: https://agsci.psu.edu/research/extension-centers/frec/growing-season-information/pheromone-traps .

Other potential explanation for current pest outbreaks is a gradual loss of efficacy of compounds due to the development of insecticide resistance. Continued use of insecticides with minimal rotation between different classes of insecticides (i.e., mode of action) is usually the most important and overriding factor contributing to the development of insecticide resistance problem. In case of orchard pests, the discovery and commercialization of insecticides from two IRAC groups: diamides (ryanodine receptor modulators, IRAC Group 28) and spinosyns (nicotinic acetylcholine receptor allosteric modulators, IRAC Group 5) drastically improved the effectiveness of CM/OFM management activities in PA orchards, especially after the management failures caused by organophosphates and carbamates resistance two decades ago. Recently, with high efficacies of diamides (e.g., Altacor, Exirel, Verdeprym, Voliam, Besiege) and spinosyns (e.g., Delegate), the CM/OFM management challenges become reduced mostly to

a correct timing and an choosing an effective rate while using these products. Unfortunately, after more then ten years of exclusive rotation of those two modes of action, recently some growers started to report failures with the management of the CM/OFM complex. At this point, it is not known if occurring failures are associated with a lack of proper monitoring, problems with proper timings and/or coverage, or a potential development of insecticide resistance in orchard CM/OFM populations.

During this project we will continue to re-evaluate current methods of controlling codling moth and oriental fruit moth in commercial orchards. Standard pesticides and various mating disruption programs used under optimal conditions will be evaluated for their efficacies in CM/OFM control. Field collected moths and larvae will be used for establishing baseline sensitivities to diamide and spinosyn based insecticides and compared to known sensitive CM/OFM populations reared in laboratory.

OBJECTIVE:

To monitor and evaluate the sensitivity differences in naturally occurring codling moth and Oriental fruit moth field populations to commonly used diamide and spinosyn insecticides.

METHODS: Attempts will be made to establish laboratory colonies of field collected CM and OFM populations to conduct larval bioassays and assess possible insecticide resistance and cross-resistance. If it will be impossible to collect enough injured fruit with larvae directly from affected commercial orchards, we will attempt to use CM and OFM females from laboratory reared sensitive populations and allow them mating with orchard's collected male moths. Wild males will be collected directly from orchards using not-destructive traps (e.g., glue-less, Universal traps, Uni-Trap, AlphaScent, West Linn, OR) and placed in mating chambers with freshly emerged laboratory reared females. Neonates hatched from eggs will be used in bioassays assessing susceptibility of larvae to Altacor and Delegate. Moths for this study will be collected from various commercial orchards with high enough moth populations. Universal traps baited with the codling moth or Oriental fruit moth sex pheromone will be used for collecting male moths. Traps will be placed in the orchard during evening hours and removed early the next morning. The moth collection procedures will be repeated during multiple days, at least during two periods throughout the season in each orchard - once during the 1st brood flight and once during the 2nd brood flight. An attempt will be made to establish laboratory colonies of evaluated CM populations originated from orchards.

Larval bioassays: **During the 2021 season we established laboratory populations of CM and OFM from 5 separate commercial orchards with severe CM/OFM problems during the 2021 harvest.** Larvae from these colonies will be evaluated this winter by conducting larval bioassays. The larval bioassays will be done using Heliotis Stonefly diet (Ward Science, Rochester, NY), as a larvae rearing media. Formulated diamide and spinosyn insecticides will be diluted into six to eight concentrations, and 0.5 ml of insecticide solution will be incorporated into the diet in a 28 ml cup. Five neonates will be then transferred to the treated diet, and larval mortality will be assessed at 1, 4 or 7 days day for each tested insecticide. Mortality data will be

subjected to probit analysis (POLO). The slopes of the probit regression, and LC50 and LC90 values will be estimated for each insecticide and each tested CM and OFM population.

Information on potential current levels of resistance to diamide and spinosyn insecticides throughout Pennsylvania should help to prevent or delay the development of additional resistance cases by allowing pest managers an opportunity to fashion more-assiduously-tailored spray programs as well as to test potential (and effective) anti-resistance strategies.

BUDGET – Year 2:

Wages:		
26 weeks at 24 hr/week at $19.00 per hour	*$*	*11,856*
Fringe benefit (@ 7.98 %)	*$*	*946*
Travel (4 months fleet operation vehicle lease @ $865/month, plus overnight accommodation at research sites, etc.)	*$*	*2,800*
Supplies (e.g., insect trapping and monitoring supplies, insect colonies, greenhouse fees at FREC, etc.)	*$*	*4,500*
TOTAL for the 2nd year of the project:	**$**	**20,102**

DURATION OF PROJECT: 2021 - 2023

Year 2: April 01, 2022 – March 31, 2023 $ 20,102

SUBMITTED BY:

Greg Krawczyk, Ph.D.
Principal Investigator

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