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INSECT POPULATION DYNAMICS, VARIETAL PREFERENCE AND PERFORMANCE OF ORGANIC BIO-PESTICIDES AGAINST INSECT PESTS OF ORGANIC SUMMER SQUASH IN NORTH CAROLINA

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Abstract

Organic farming prohibits use of synthetic agrochemicals and encourages use of Integrated Pest Management (IPM) methods. States in the Southeastern US generally lag behind the rest of the country in organic vegetable production partly because of high insect pressures that make it difficult to grow vegetables without pesticides. This study on summer squash (*Cucurbita pepo*), grown using organic management practices, was conducted at a research station located in Mills River, North Carolina. The objectives of the study were to assess insect population dynamics and to evaluate performance of three OMRI-approved bio-pesticides: Azadirachtin, Pyrethrin and Spinosad against major insect pests of three summer squash varieties (Gentry, Spineless Beauty, and Zephyr). The highest populations of leafhoppers and thrips were recorded in early and late July. Squash varieties significantly influenced the populations of leafhoppers, thrips, aphids, and cucumber beetles. Bio-pesticides performed similarly against the major insect pests of squash recorded in this study

Keywords: Organic Summer Squash, Insect Pests, Bio Pesticides, Organic Farming

Introduction

Organic farming according to the International Federation of Organic Agriculture Movements (IFOAM) is a certified production system based on the principle of using farming practices that are expected to enhance the ecological processes while prohibiting the use of external synthetic inputs (IFOAM, 2009). Organic agriculture is also referred to as biological or ecological agriculture that combines the traditional conservation-minded farming methods with modern farming technologies (Reganold and Watcher, 2016). Agricultural production in the last four decades has been characterized by the indiscriminate use of agrochemicals, which has resulted in loss of natural habitats, poor soil health and pollution due to run-off of fertilizers and pesticides (Reddy, 2010). The continuous use of persistent and non-biodegradable pesticides has resulted in the pollution of different components of water, air and soil ecosystems. The effects of pesticides on target and non-target organisms including earthworms, predators, pollinators, humans, fish, amphibians and birds have been reported (Gill and Garg, 2014). A recent study on health effects of pesticides reported that exposure to pesticides has been associated with several acute and chronic illnesses in humans (Mostafalou and Abdollahi, 2012). Increasing awareness of the impact of agricultural inputs on human and environmental health as well as food safety in general make organic agriculture an essential food production system in that it largely prohibits the use of synthetic pesticides (UNCTAD, 2003; Mutiara and Satoshi, 2017).

Organic food production and the interest of consumers in organic foods are both worldwide due to the belief that organic foods are healthier than conventionally produced foods (Brantsæter et al., 2017). Research studies tend to support the belief that the consumption of organic foods may have some health benefits (Axel et al., 2017). Studies conducted on the association between the consumption of organic food and health, reported a lower prevalence of allergies and/or atopic diseases in children in families that prefer organic foods (Alfven et al., 2006; Kummeling et al., 2008; Fagerstedt et al., 2016). A cohort study conducted with mothers and babies on the exclusive consumption of organic dairy products during pregnancy and infancy reported a 36% reduction in the risk of eczema in two-year-old children and a higher content of ruminant fatty acids in the breast milk of mothers. (Thijs et al., 2011). Another cohort study involving mothers and their offspring reported that frequent consumption of organic vegetables by pregnant women resulted in a reduced risk of pre-eclampsia (Torjusen et al., 2014).

The rapid increase in both the number and acreage of organic farms resulted in a fivefold increase in the market size for organic foods between 1999 and 2013. The market size for organic foods hit US $72 billion in 2013 (Willer and Lernoud, 2015) and continued its positive trajectory in 2017 with global sales reaching $97 billion (Willer and Lernoud, 2019). The Research Institute of Organic Agriculture (FiBL) in its most recent survey on certified organic food production reported that the United States ranked third worldwide with 2 million hectares under cultivation (Willer and Lernoud, 2017) and $7.6 billion in sales of certified organic commodities in 2016 (USDA-NASS, 2017). The United States remains in the pole position with its organic food market valued at $48.7 billion in 2017; it has the largest market for organic foods in the world worth $45.2 billion ((Willer and Lernoud, 2019).

Organic vegetable crops are of special importance compared to other crops because of higher economic returns to producers (Juroszek et al., 2008) and less adverse effects on the environment and human health. Demand for organic produce, especially vegetables, has increased significantly since 2006; this has resulted in premium prices for organic produce (Ashley et al., 2007). Vegetables produced using organic production practices in warmer climates are preselected to overcome significant challenges which include atypical weather patterns of high temperature, year-round presence of insect pests and diseases, heavy rainfall and periods of unpredictable drought (Lie et al., 2011; Wang et al., 2010). Agricultural production in the Southeastern States in the US is largely hampered by weather that provides favorable conditions for insect survival, and development, and increased population of various insect pests (Khaliq et al., 2014; Knox et al., 2014). The result is an increase in pesticide applications in the quest to produce marketable crops. Lack of site-specific information on the effective use of organic biopesticies is one major constraint to the adoption of organic production practices in the Southeastern United States. Organic farming excludes use of synthetic pesticides (UNCTAD, 2003) which makes pest management generally more difficult in organic relative to conventional vegetable production.

Organic farming has emerged as one of the fastest growing agricultural segments in which production of open field vegetables has increased by 26% since 2008. In 2016, United States harvested 186,178 acres (approx.74,471 ha) of vegetables grown under certified organic production systems of which open field vegetables accounted for $1.6 billion of sales (USDA-NASS, 2017). In 2016, $5.8 billion (about 77%) of certified organic sales in the US were contributed by ten states with California leading the nation. North Carolina, one of the major organic-producing states in the Southeast ranked tenth in the US, accounting for $145 million in organic sales (USDA-NASS, 2017). North Carolina is also a strong national producer of fresh and processed vegetable commodities like squash, cucumbers, tomatoes, peppers, and cabbage (Gunter, 2018). Fruit and vegetable producers in this region need pest management recommendations that consider the agroclimatic conditions.

There is however, far more pest management information available to conventional producers relative to organic producers in this region. A number of the research-based economic thresholds for various major insect pests of vegetables in the southeastern United States were developed based on the efficacy of conventional/synthetic pesticides. This fact renders such economic threshold figures unsuitable for use in organic vegetable production systems. According to Pedigo and Rice (2014), in instances where relevant economic thresholds are unavailable for specific insect pests on specific crops in a given agro-climatic zone, improvised thresholds are used based on the available information from areas that may have similar agro-climatic conditions. To date, there is very little research-based information on the population dynamics of insect pests in summer squash grown under organic management practices. The objectives of this study were to study the insect population dynamics on summer squash throughout the growing season, evaluate performance of selected commercially available OMRI-approved bio-pesticides, and determine possible differences in the suitability of three summer squash varieties as hosts for major insect pests.

Literature Review

Summer Squash (*Cucurbita pepo L*. Family: Cucurbitaceae) is a warm season and short duration crop grown throughout the United States primarily for fresh market and processing. The 2016 crop statistics reported that the United States harvested squash valued at $149 million from 14,520 hectares; per capita consumption was 5.1 pounds (Geisler, 2018). California is the lead producer of Squash in the nation followed by Florida and Georgia. In North Carolina, squash is one of the top 10 leading vegetable crops and according to 2017 statistics, the state ranked eighth in the nation in Squash production valued at $10.1 million (NCAG-STAT, 2018). Organic food production is increasing in North Carolina and summer squash is one key vegetable crop that is produced using organic practices in the state. A certified organic survey conducted by USDA in North Carolina, reported 29 certified organic open-harvested farms in the state that harvested 187 acres of squash with a sale value of $1.8 million (USDA-NASS, 2017).

Summer squash is affected by a wide range of insect pests that include the Squash bug (*Anasa tristis*), Cucumber beetles (spotted-Cucumber beetle [*Diabrotica undecimpunctata*] striped-Cucumber beetle [*Acalymma vittata*], squash vine borer (*Melittia cucurbitae*), aphids (*Aphis spp*.) and stinkbugs (*Acrosternum hilare*) (Schonbeck, 2013). Integrated Pest Management (IPM) involves the use of a number of compatible preventive and therapeutic practices against pests. IPM methods are used in both organic and conventional crop production but a major distinction is that only natural pesticides can be used in certified organic food production.

According to organic farming principles, biopesticides may be used as a curative tool for pest management (Phyllis et al., 2017). Cultural and biological methods as well as natural pesticides such as extracts from the neem plant (*Azadirachta indica)*), Pyrethrins and Spinosad are used to manage key insect pests (Cline et al., 2008; Delate et al., 2005; Seaman, 2012; Kowalska and Drożdżyński, 2009) in certified organic crop production. Azadirachtin, which is the active ingredient in Neem extracts, has multiple insecticidal properties/modes of action against target pests. The compound is an oviposition deterrent, a molting inhibitor, and a sterilant; it also has repellent, antifeedant, and growth retardant properties (Ge-Mei et al., 2003; Schmutterer, 1995; Mordue and Blackwell, 1993). Neem based products are effective against different insect pests including armyworms, cutworms, leaf miners, caterpillars, aphids, whiteflies, leafhoppers, and thrips (Dimetry et al., 2010). Studies show that neem products have low environmental impact, are non-toxic to humans, and have negligible effects on many beneficial insects (Schmutterer, 1990; Blackwell, 1997). Pyrethrum is extracted from the chrysanthemum plant and is the predominant bio-pesticide approved for organic production throughout the world. This compound kills insects by poisoning their nervous system, which results in the rapid knock down of flying insects, hyperactivity and convulsions. Pyrethrins are effective against caterpillars, aphids, leafhoppers, spider mites, bugs, cabbageworms and beetles (Nabil, 2013; Glynne-Jones, 2001).

Spinosad is a biological insecticide extracted from the soil actinomycete, *Saccharopolyspora spinosa* (Kowalska and Drozdzynski, 2009). The compound also exerts its insecticidal properties by poisoning the nervous system of target insects (Telesinski et al., 2015; Cisneros et al., 2002). Spinosad acts as both contact and stomach poisons and is effective against beetles, true flies, termites, butterflies, moths, fleas, thrips, ants, bees, and wasps. (Elzen 2001; Galvan et al., 2006; Elliot et al., 2007). Some studies have reported the toxic effects of Spinosad on some beneficial insects including plant pollinators (Galvan et al., 2005; Brunner et al., 2001; Cisneros et al., 2002; Sterk et al., 2002). This observation led to the development of a number of precautionary measures aimed at reducing the direct exposure of beneficial insects to this compound during application. However, pest management in conventional crop production systems involve the use of a number of broad-spectrum synthetic insecticides like pyrethroids, carbamates and neonicotinoids (Kemball, 2011).

Review of available pest management literature shows the availability of far more information for conventional vegetable producers relative to their organic counterparts. Only a few research studies address certain aspects of insect pest management in organic crop production in the southeastern United States. In Florida, McNeil et al. (2012) conducted a study on insect-specific population dynamics in organic squash treated with monoculture and diculture cover crops. A publication by Schonbeck (2013) on organic production of summer squash and zucchini in Virginia also provides very useful information. Some researchers focused on the effect of (different) colored plastic mulches on the production of vegetable crops. Semi et al. (1992) reported that black plastic mulch significantly reduced the number of both spotted and striped cucumber beetle eggs and larvae. Sanders (2001) reported that black plastic mulch enhanced earliness of summer squash by 7 to 14 days. The squash bug (*Anasa tristis*) and squash vine borer (*Melittia cucurbitae*) are two major insect pests that feature prominently in research publications on summer squash production. Walgenbach (2018) listed these two insects as common pests of squash in North Carolina. There have been a number of conflicting reports on the performance of specific organic pesticides against these and other insect pests of squash. Research results reveal some poor (Rogers, 2012) and decent performances of organic pesticides against a number of major insect pests of squash.

Materials and Methods

The experiment was conducted at the North Carolina State University, Mountain Organic Research and Extension Unit of the Mountain Research Station in Waynesville, NC in 2018. The experimental design was a randomized complete block design with a 3X4 factorial arrangement of three varieties and four bio-pesticide treatments including control (no pesticide applied). The bio pesticides studied included Neemix 4.5 (Active Ingredient: Azadirachtin- 4.5%), Pyganic (Active Ingredient: Pyrethrum 5.0%) and Entrust (Active Ingredient: Spinosad 22.5%), the three bio-pesticides selected are registered for use against the targeted major insect pests. The highest label rates of each bio-pesticide was applied to assigned treatment plots when major insect pests attained the relevant action thresholds. Certified organic seeds of the following Summer squash varieties/cultivars: Zephyr (Johnny's Selected Seeds, Winslow, ME), Spineless Beauty (Siegers Seeds, Holland, MI) and Gentry (Seedway, LLC Hall, NY), were direct seeded on June 11, 2018 into each treatment plot on raised beds under black plastic mulch. Two seeds were planted 0.5-inch deep in holes punched through the plastic mulch. Seedlings were thinned to one plant every 2-feet on raised beds which were 5-feet apart (center to center). Each treatment plot measured 20 ×15 feet separated by alleys that were 5-feet wide.

Insect populations were monitored with yellow sticky traps of (0.08 × 0.13 m [Bio Quip Products, Rancho Dominguez, CA] once per week. Traps were collected and replaced weekly beginning three weeks after planting. Three sticky card traps were placed in the middle row of each treatment with 2.5 m distance between two cards. The sticky traps were inserted into the coil end of reusable 11-inch galvanized wire stakes (BioQuip Products, Rancho Dominguez, CA) which were then pegged into the ground to keep the sticky cards right above the squash canopy. Sampling was done weekly, and the traps were left in the field for 24 hours; sampling was done throughout the crop season. The traps were collected and placed in clear plastic Ziploc bags of 26.8cm×27.9 cm (SC Johnson, Racine, WI) and stored in the laboratory for insect identification under a 3X magnification microscope. The total number of insects on each trap was identified and the mean number of insects per three traps was recorded for each insect pest species. Visual assessment of plants provided pest information needed to schedule treatments with biopesticides. The spray treatments and schedule were based on pest information obtained from visual assessment of plants. Plots were sprayed with designated treatments when major insect pests attained relevant economic thresholds. The economic thresholds reported by Brust et al. (1995) for various squash pests were used to improvise thresholds for this field trial. Thresholds were set at one adult or one egg mass per plant for cucumber beetles and squash bugs; the economic threshold for aphids was set at 3-5 adults per plant. A multi-treatment backpack CO_2 sprayer (Bellspray Inc. Opelousas, LA) was used for all treatments. The bio-pesticide formulations were mixed in designated 2-liter plastic bottles. Spray applications were done according to highest label application dosage for each bio pesticide.

Key insect pests in squash (leafhoppers, aphids, thrips and cucumber beetles) collected from the yellow sticky traps were analyzed using Statistical Analysis Software Ver. 9.4 (SAS Institute 2016). Data on the mean number of insect species by date were analyzed by date with (PROC GLIMMIX, SAS Institute 2016). The insect species by treatment and variety were also analyzed using SAS PROC GLIMMIX. Mean comparison tests for all analyses were conducted using Tukey's procedure.

Results

The overall abundance of the pests and beneficial insects captured on the yellow sticky traps on Summer squash indicated four key insect pests namely, leafhoppers (25%), thrips (15%), aphids (12%), and cucumber beetles (5%). Wasps constituted the highest proportion (33%) of the beneficial insects; low proportions of the other beneficial insects were recorded. (Figure 1). Overall, during the sampling season on Summer Squash, leafhoppers constituted the highest proportion among the major insect pests followed by thrips, aphids and a low proportion of cucumber beetles (Figure 1).

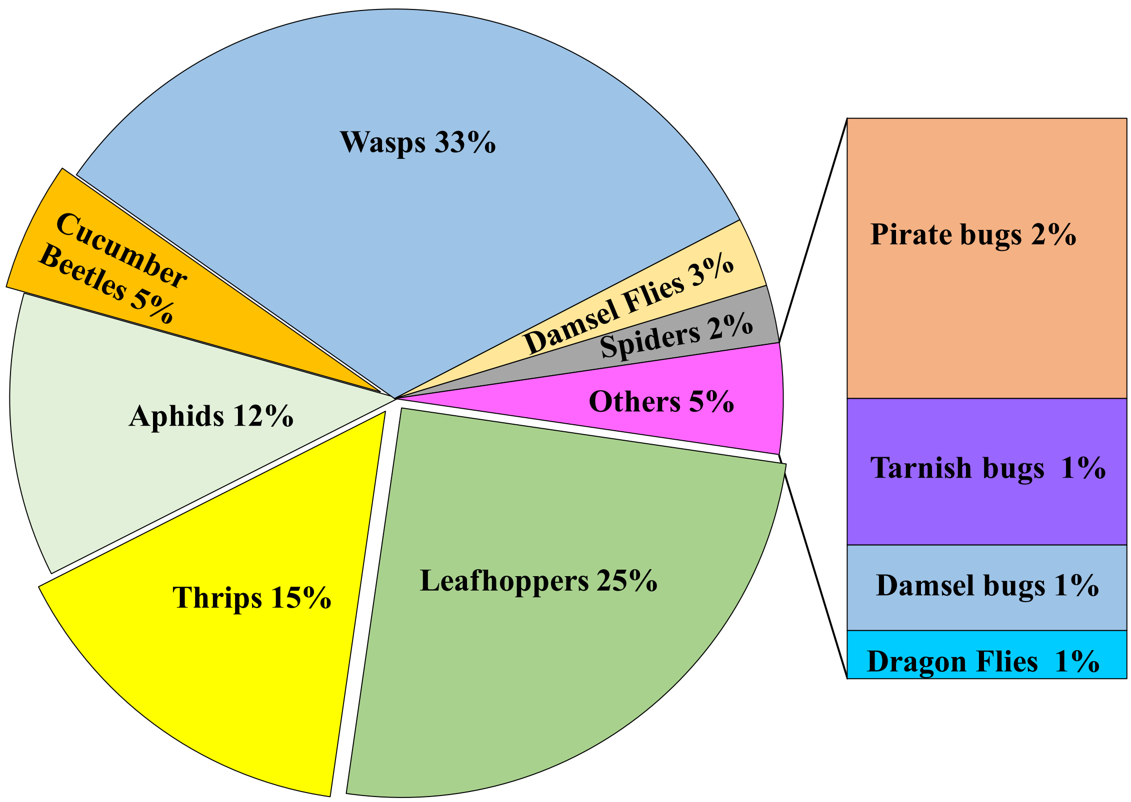

Figure 1: Major Pests and Beneficial insects captured on yellow sticky cards on Summer Squash in North Carolina, 2018.

Results from the data analyzed by date and insect numbers revealed significant differences in the number of insect pests captured on the yellow sticky cards across the sampling dates. Overall, for the population dynamics of squash pests, leafhoppers comprised majority of the insects during the sampling season with comparatively higher numbers during early July (July 5 and July 12, 2019). The peak population of leafhoppers was recorded on July 12, 2019 after which the population declined and remained low throughout the sample season. Aphids were the second most abundant insects captured during the early sampling weeks in July (i.e. July 5 and July 12, 2019) and gradually declined with time. Thrips numbers were generally low throughout the sampling period except on July 26, 2019. Cucumber beetles were captured in low numbers throughout the sampling period (Figure 2).

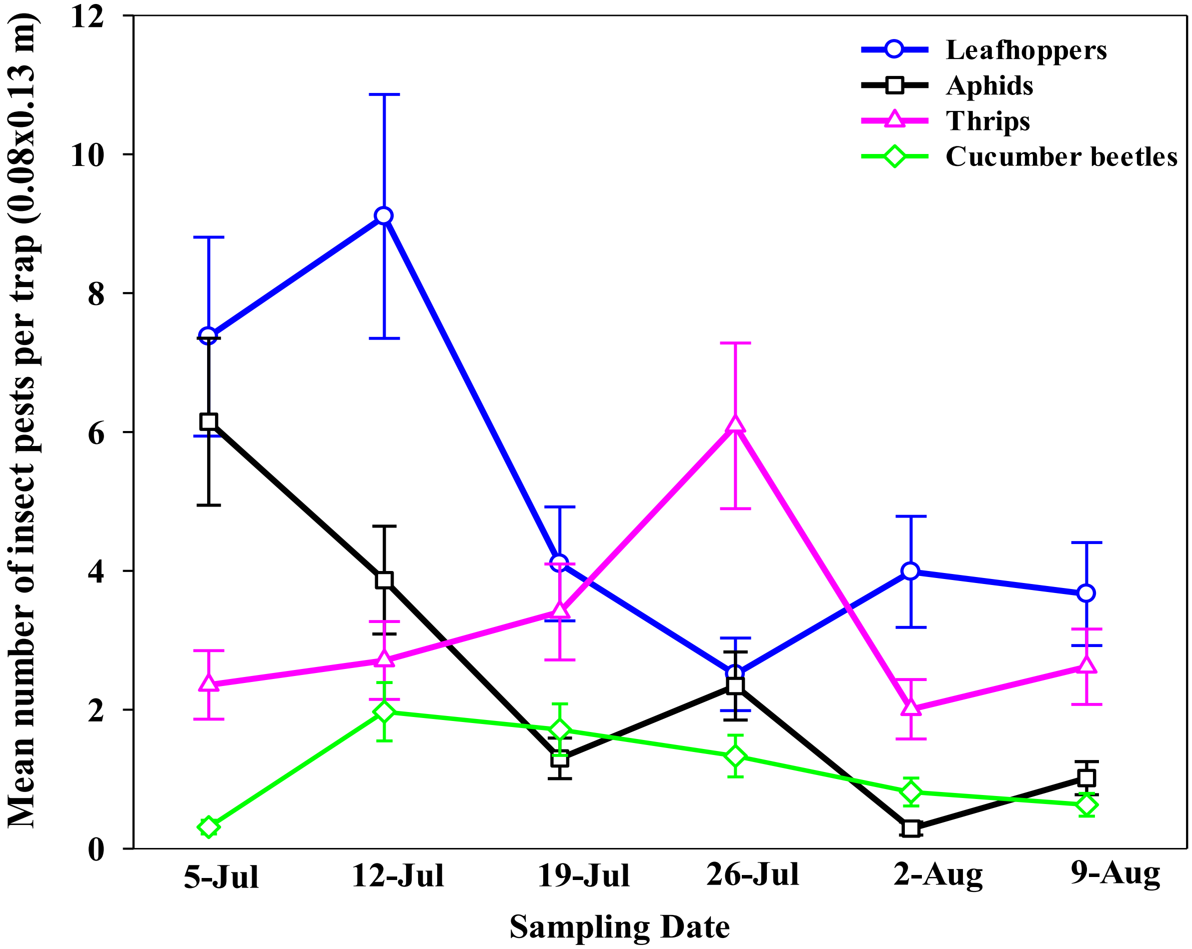

Figure 2: Mean (±SE) number insect pests captured on the yellow sticky card traps by sampling dates in North Carolina.

Insect data were analyzed to determine whether the variety/cultivar of squash exerted any influence on the populations of leafhoppers, aphids, thrips and cucumber beetles recorded on the plants. Significant differences in the preference of insect pests for squash varieties were observed (Figure 3). Zephyr recorded the lowest population of cucumber beetles. The lowest population of aphids were recorded on Gentry. The populations of thrips and leafhoppers on Spineless beauty were significantly lower than the number recorded on the other squash varieties.

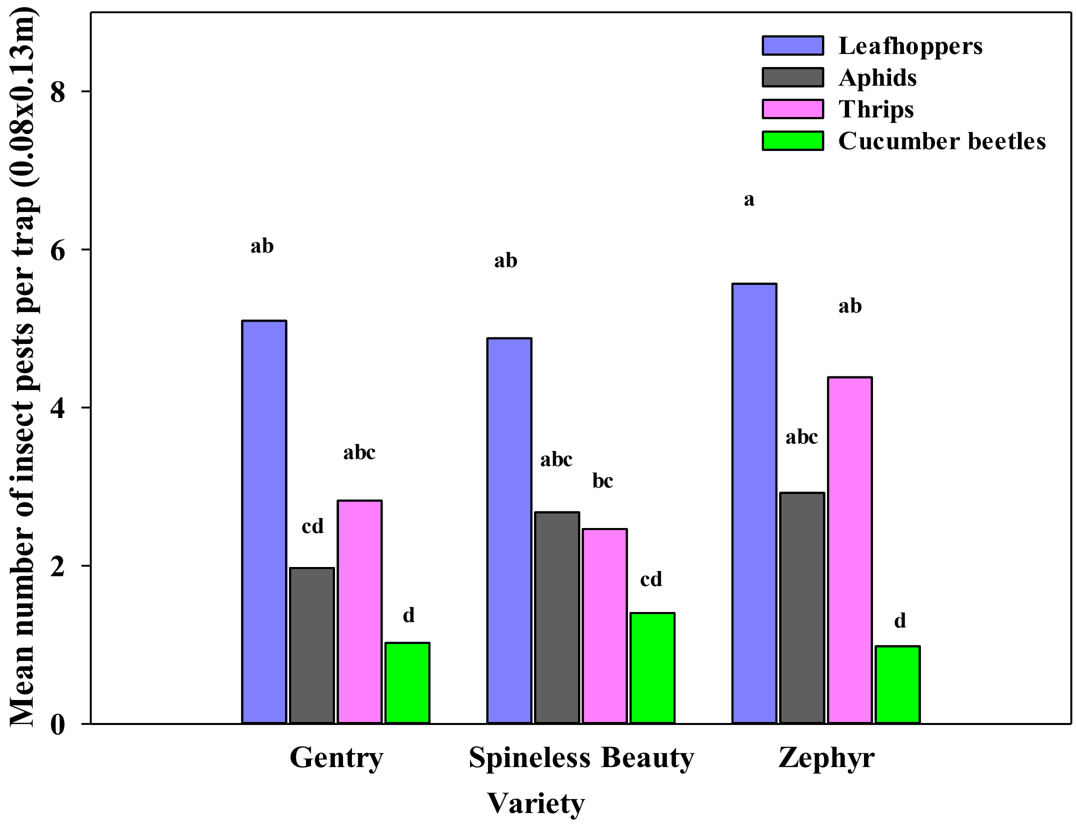

Figure 3: Mean (±SE) number insect pests captured on the yellow sticky card traps by Variety in North Carolina. Bars with the same letter are not significantly different for bio pesticide treatment.

The biopesticide performance results indicated that the treatment applications failed to control certain insect pests of summer squash. There was no significant biopesticide treatment effect observed on the populations of leafhoppers, aphids, thrips and cucumber beetles (Figure 4).

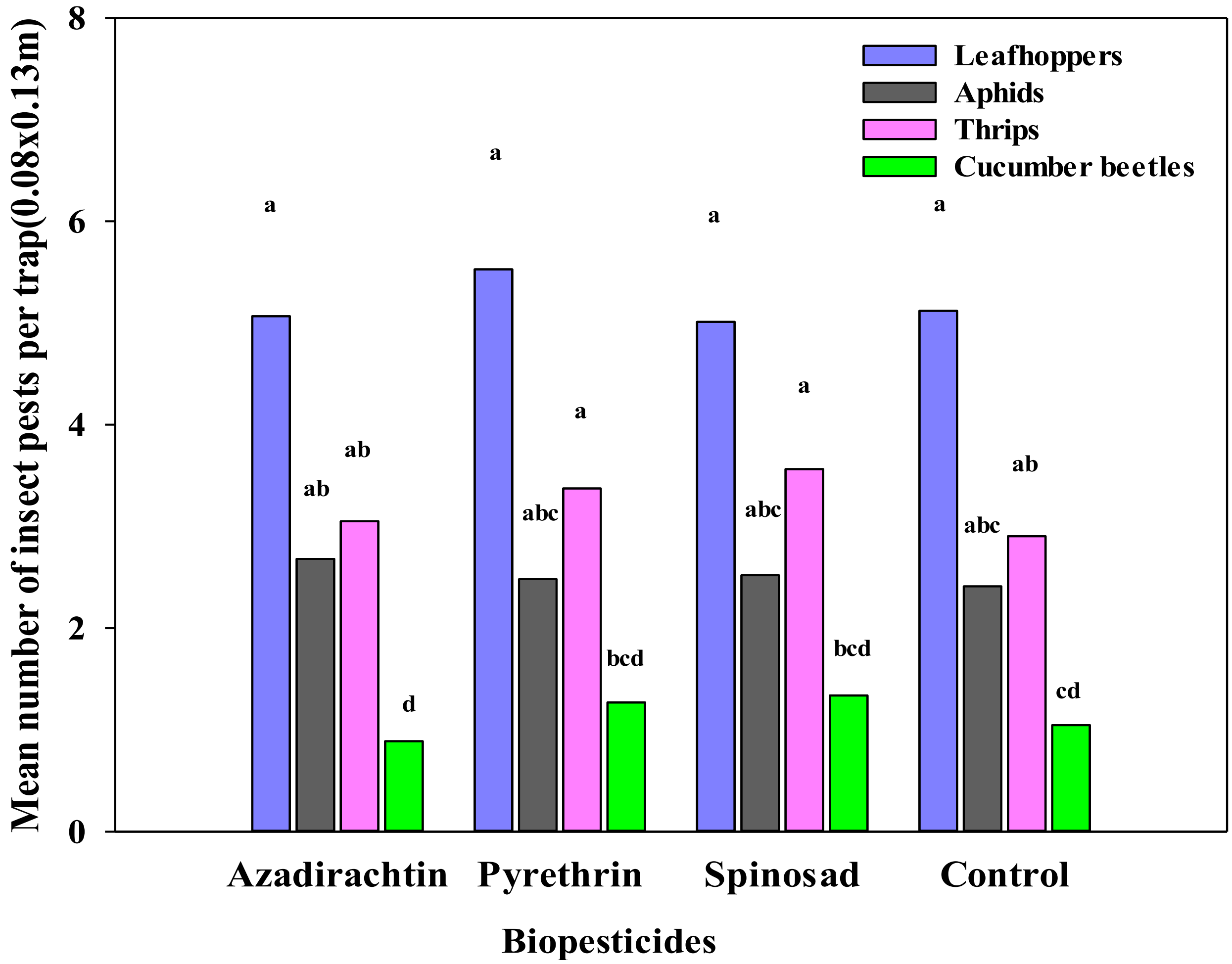

Figure 4: Mean (±SE) number insect pests captured on the yellow sticky card traps by Biopesticide treatment in North Carolina. Bars with the same letter are not significantly different for bio pesticide treatment.

Discussion

This is the first study that provides information and evidence on the dynamics of squash insect pests in organic squash in the southeastern United States. Pest population dynamics information when studied over multiple years can provide insight into periods when the populations of specific pests peak and dip. This data can inform the use of planting date as a method of eliminating/reducing synchrony between peak pest populations and the most vulnerable stages of the crop as described by Pedigo and Rice (2014). This method of pest management requires other pieces of information such as the planting window for squash and the growth stage at which squash is most vulnerable to damage by various major insect pests. The current data (Figure 3) shows that the peak populations of leafhoppers and cucumber beetles were recorded on July 12, 2019; the lowest populations of these pests were recorded on July 26, 2019 and July 5, 2019, respectively. A single year study is however not sufficient to make definitive statements on the best time to plant summer squash to avoid/reduce damage by the afore-listed insect pests.

The squash bug and squash vine borer, which are common pests of squash in North Carolina (Walgenbach, 2018) were not recorded in the field trial conducted at the Mountain Research Station in Waynesville, North Carolina. The reasons for the generally low pest pressures observed during this study are not fully understood but could be related to weather parameters associated with hurricane Florence that occurred in 2018.

It was hypothesized that the bio-pesticide treatments failed to manage the targeted key pests under the standard economic threshold indices. Even though these research findings are based on a one-year field trial, the reported failure of the biopesticide treatments is consistent with the findings of Roger (2012) who evaluated the performance of selected organic insecticides against cucumber beetles in Tennessee. There appears to be a need to alter the economic thresholds for some of the pests and/or change the pesticide application protocols in order to obtain appreciable levels of performance. The total cost of pesticide applications and the amount of crop loss prevented will continue to be important criteria for evaluating the performance of these biopesticides.

The influence of crop variety on insect host-preference is well-documented. If the current observation holds true in subsequent trials, Zephyr and Gentry will be the logical squash variety for incorporation in Integrated Pest Management (IPM) programs against cucumber beetles and aphids, respectively. Spineless beauty will be the recommended variety for farms dealing with thrips and leafhoppers.

Even though this study did not specifically evaluate the effect of plastic mulch on the incidence and severity of various major insect pests of squash, Semi et al., (1992) reported that black plastic mulch significantly reduced the number of both spotted and striped cucumber beetle eggs and larvae. A study conducted by Sanders (2001) reported that summer squash grown under black plastic mulch enhances earliness by 7 to 14 days. The effect of plastic mulch on earliness can affect the synchrony between the peak populations of certain insect pests and the most vulnerable growth stages of the crop and thereby exert significant pest management effects.

Conclusion

Overall, this study provided information on: the population dynamics of insect pests of squash during the growing season; host preference of specific insect pests of squash; and performance of selected bio-pesticides against insect pests of summer squash in organic production systems. Preliminary results from the one-year study on the host preference of squash insect pests suggest that, farmers can opt to grow the Zephyr and Spineless beauty squash cultivars which are less preferred by a number of insect pests in order to reduce management costs associated with these pests. Further studies are needed to fine-tune the economic threshold levels for the management of specific insect pests with biopesticides in North Carolina. The use of revised pesticide application protocols and more effective economic threshold levels may improve the performance of candidate biopesticides in future trials.

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References

Alfven, T., C. Braun-Fahrländer, B. Brunekreef, E. von Mutius, J. Riedler, A. Scheynius, M. van Hage, M. Wickman, M.R. Benz, J. Budde, J. Michels, K.B. Schram, D.E. Üblagger, and M. Waser. (2006). "Allergic Disease and Atopic Sensitization in Children Related to Farming and Anthroposophic Lifestyle -The PARSIFAL Study." *Allergy* 61 (4): 414-421.

Ashley R, A. Bishop and J. Dennis. (2007). "Intensive Organic Vegetable Production Integrated Development." Rural Industries Research and Development Corporation. (RIRDC) Report Publication No. 04/121 RIRDC Project No: DAT-37a..

Axel, M., R.A. Helle, G. Stefan, K. Johannes, K.G. Emmanuelle, R. Ewa, Q. Gianluca, and G. Philippe. (2017). "Human Health Implications of Organic Food and Organic Agriculture: A Comprehensive Review." *Environmental Health* 16: 111.

Blackwell A. (1997). "The Neem Tree Azadirachta indica A. Juss. and other Meliaceous Plants: Source of Unique Natural Products for Integrated Pest Management, Medicine, Industry and other Purposes." Experimental Agriculture, 33 (2), 247-252

Brantsæter A.L, T.A. Ydersbond, J.A. Hoppin, M. Haugen and H.M. Meltzer. (2017). "Organic Food in the Diet: Exposure and Health Implications." *Annual Review of Public Health* 38: 295-313.

Brunner J.F., J.E. Dunley, M.D. Doerr, and E.H. Beers. (2001). "Effects of Pesticides on *Colpoclypeus florus* (Hymenoptera: Eulophidae) and *Trichogramma platneri* (Hymenoptera: Trichogrammatidae), Parasitoids of Leafrollers in Washington." *Journal of Economic Entomology* 94: 1075-1084.

Brust G., J. Palumbo, A. York, and R. Wilson, eds. (1995). *Squash and Pumpkins: Vegetable Insect Management.* Willoughby, OH: Meister Publishing Company.

Cisneros J., D. Goulson, L.C. Derwent, D.I. Penagos, O. Hernández, and T. Williams. (2002). "Toxic Effects of Spinosad on Predatory Insects." *Biological Control* 23:156-163.

Cline, G.R., J.D. Sedlacek, S.L. Hillman, S.K. Parker, and A.F. Silvernail. (2008). "Organic Management of Cucumber Beetles in Watermelon and Muskmelon Production." *HortTechnology* 18: 436-444.

Delate K., H. Friedrich, and L. Krouse. (2002). "Evaluation of Organic Pest Management Strategies for Organic Squash Production 2001 and 2002." Iowa State Extension blog. http://extension.agron.iastate.edu/organicag/ [Retrieved February 26, 2019].

Dimetry, N.Z., A.M.E. Abd El-Salam, and F.M.A. El-Hawary. (2010). "Importance of Plant Extract Formulations in Managing Different Pests Attacking Beans in New Reclaimed Area and under Storage Conditions." *Archives of Phytopathology and Plant Protection* 43 (7): 700-711.

Elzen, G.W. (2001). "Lethal and Sublethal Effects of Insecticide Residues on *Orius insidiosus* (*Hemiptera*: *Anthocoridae*) and *Geocoris punctipes* (*Hemiptera*: *Lygaeidae*)." *Journal of Economic Entomology* 94 (1): 55-59.

Elliot R., M. Benjamin and C. Gillot. (2007). "Laboratory Studies of the Toxicity of Spinosad and Deltamethrin to *Phyllotreta cruciferae* (*Coleoptera*: *Chrysomelidae*)." *Canadian Entomologist* 139 (4): 534-544.

Fagerstedt, S., H.M. Hesla, E. Ekhager, H. Rosenlund, A. Mie, L. Benson, A. Scheynius, and J. Alm. (2016). "Anthroposophic Lifestyle is Associated with a Lower Incidence of Food Allergen Sensitization in Early Childhood." *Journal of Allergy and Clinical Immunology* 137 (4): 1253-1256.

Galvan T.L., R.L. Koch, and W.D. Hutchison. (2006). "Toxicity of Indoxacarb and Spinosad to the Multicolored Asian Lady Beetle, *Harmonia axyridis*, via Three Routes of Exposure." *Pest Management Science* 62: 797-804.

Geisler, M. (2018). "Squash." https://www.agmrc.org/commodities-products/vegetables/squash. [Retrieved February 25, 2019].

Ge-Mei L., C. Wen, and L. Tong-Xian. (2003). "Effects of Three Neem-based Insecticides on Diamondback Moth (Lepidoptera: plutellidae)." *Crop Protection* 22: 333-340.

Gill H.K. and H. Garg. (2014). "Pesticides: Environmental Impacts and Management Strategies." In M.L. Larramendy and S. Soloneski (eds.), *Pesticides - Toxic Aspects*. Intech, Rijeka, Croatia.

Glynne-Jones, A. (2001). "Pyrethrum." *Pesticide Outlook* 12 (5): 195-198.

Gunter, C. (2018). "Top Vegetables Grown in North Carolina." NC Extension blog posted on 9/19/2018. https://ipm.ces.ncsu.edu/2018/10/top-vegetablesgrown-in-north-carolina/ [Retrieved February 20, 2019].

Hole, D.G., A.J. Perkins, J.D. Wilson, I.H. Alexander, P.V. Grice, and A.D. Evans. (2005). "Does Organic Farming Benefit Biodiversity?" *Biological Conservation* 122: 113-130.

IFOAM (International Federation of Organic Agriculture Movements). (2009). The IFOAM Norms for Organic Production and Processing. https://www.ifoam.bio/sites/default/files/page/files/norms_eng_v4_20090113.pdf [Retrieved February 25, 2019].

Juroszek. P., A. T. Lumpkin, E. Warwick, and H. H. Tsai. (2008). "Organic Vegetable Production and Research Needs in the Tropics. In U. Köpke (ed.), *Organic Agriculture in the Tropics and Subtropics*. Berlin: Köster.

Kemball, J.M., F.J. Louws, K.M. Jennings, J.F. Walgenbach, eds. (2011). *Southeastern U.S. Vegetable Crop Handbook*. Lincolnshire, IL: Vance Publishing Corporation.

Khaliq A., M. Javed, M. Sohail, and S. Muhammad. (2014). "Environment Effects on Insects and Their Population Dynamics." *Journal of Entomology and Zoological Studies* 2 (2): 1-7.

Knox P., C. Fuhrmann, and C. Konrad. (2014). "Challenges and Opportunities for Southeast Agriculture in a Changing Climate: Perspectives from State Climatologists." *Southeastern Geographer* 54 (2): 118-136.

Kowalska I. and D. Drożdżyński. (2009). "Spinosad as Insecticide in Organic Farming-Possibilities of Using and Monitoring of Residues." In Proceedings of ECOpole 3: 71-75. Warszawa, Poland: Society of Ecological Chemistry and Engineering.

Kummeling, I., C. Thijs, M. Huber, L.P. van de Vijver, B.E. Snijders, J. Penders, F. Stelma, R. van Ree, P.A. van den Brandt, and P.C. Dagnelie. (2008). "Consumption of Organic Foods and Risk of Atopic Disease during the First 2 years of Life in the Netherlands." *British Journal of Nutrition* 99 (3): 598-605.

Li, W., L. Li, R. Fu, Y. Deng, and H. Wang. (2011). "Changes to North Atlantic Subtropical High and its Role in the Intensification of Summer Rainfall Variability in the Southeastern United States." *Journal of Climate* 24 (5): 1499-1506.

McNeill, C.A., L.E. Oscar, and C.A. Carlene. (2012). "Effect of Cover Crops on Aphids, Whiteflies, and Their Associated Natural Enemies in Organic Squash." *Journal of Sustainable Agriculture* 36 (4): 382-40.

Mordue, A.J., and A. Blackwell. (1993). "Azadirachtin: an Update." *Journal of Insect Physiology* 39: 903-924.

Mostafalou, S., and M. Abdollahi. (2012). "Concerns of Environmental Persistence of Pesticides and Human Chronic Diseases." *Clinical and Experimental Pharmacology* S5: e002.

Mutiara, V.I., and A. Satoshi. (2017). "The Challenges in Organic Agricultural Products Market in Southeast Asia." *Reviews in Agricultural Science* 5: 36-44.

Nabil, E. (2013). "Botanical Pesticides and Their Mode of Action." *Gesunde Pflanzen* 65: 125-149.

North Carolina Agricultural -Statistics (NCAG-STAT). (2018). Publication No. 219. North Carolina Department of Agriculture and Consumer Services.

Pedigo, L. P., and M. E. Rice. (2014). *Entomology and Pest Management,* 6th ed. Long Grove, IL: Waveland Press.

Phyllis G.W., L.M. Eitan Recht, R. Ally, B.M.D. Harari, and B. Jude (2017). "Arthropod Pest Management in Organic Vegetable Greenhouses." *Journal of Integrated Pest Management* 8 (1): 1-14.

Reganold P.J., and J.M. Wachter. (2016). "Organic Agriculture in the Twenty-first Century". *Nature Plants* 2 (2): 15221.

Reddy, S.B. (2010). "Organic farming: Status, Issues and Prospects-A Review." *Agricultural Economics Research Review* 23: 343-358.

Rogers A.M. (2012). "Efficacy of Bio-pesticides for Organic Management of Cucumber beetles." Ph.D. Dissertation, Department of Plant Sciences, University of Tennessee, Knoxville, TN.

Sanders, D. 2001. Using plastic mulches and Drip irrigation for home vegetable gardens. Horticulture information leaflet. North Carolina Extension Resources. http://content.ces.ncsu.edu/using-plastic-mulches-and-drip-irrigation-for-vegetable gardens/

SAS, Institute. (2016). User Manual Version 9.4. SAS Institute, Cary, NC.

Schonbeck, M. (2013). "Summer Squash and Zucchini: Organic Production in Virginia". Information Sheet: 031. https://vabf.org/wp-content/uploads/2013/04/squash/-info-sheet-2013-031.pdf.

Schmutterer, H. (1990). "Properties and Potential of Natural Pesticides from the Neem Tree." *Annual Review of Entomology* 35: 271-298.

Seaman, A. (2012). "Production guide for organic cucumbers and squash". NYS IPM Publication No.135. http://nysipm.cornell.edu/organic_guide/cucurbit.pdf. Accessed 02/26/19.

Sterk, G., F. Heuts, N. Merck, and J. Bock. (2002). "Sensitivity of Non-target Arthropods and Beneficial Fungal Species to Chemical and Biological Plant Protection Products: Results of Laboratory and Semi-field Trials. In Proceedings of the first International Symposium on Biological Control of Arthropods. Honolulu, Hawaii: Forest Health Technology Enterprise Team.

Semi, N., A.B. Bruce, and W.J. James. (1992). "Effects of a Black Plastic Mulch on the Soil and Plant Dispersal of Cucumber Beetles, *Aclymma vittatum* (F.) and *Diabrotica undecempunctata howardi* Barber (Coleoptera: Chrysomilidae) on Melons." *Journal of Agricultural Entomology* 9 (2): 129-135.

Telesiński A., and M. Płatkowski. (2012). "Assessment of Side-effect of Spinosad on O-diphenol Oxidase in Soil." *Zootech* 296 (23): 91–96.

Thijs, C., A. Muller, L. Rist, I. Kummeling, B.E. Snijders, M. Huber, R. van Ree, A.P. Simoes-Wust, P.C. Dagnelie, and P.A. van den Brandt. (2011). "Fatty Acids in Breast Milk and Development of Atopic Eczema and Allergic Sensitization in Infancy." *Allergy* 66 (1): 58-67.

Torjusen, H., A.L. Brantsaeter, M. Haugen, J. Alexander, L.S. Bakketeig, G. Lieblein, H. Stigum, T. Naes, J. Swartz, G. Holmboe-Ottesen, and G. Roos. (2014). "Reduced Risk of Pre-eclampsia with Organic Vegetable Consumption: Results from the Prospective Norwegian Mother and Child Cohort Study." *BMJ Open* 4 (9): e006143.

United Nations Conference on Trade and Development. (UNCTAD). (2003). "Organic Fruit and Vegetables from the Tropics." https: unctad.org/en/Docs/ditcted20034a2_en.pdf [Retrieved February 25, 2019].

United States Department of Agriculture - National Agricultural Statistics Service (USDA-NASS). (2017). "Certified Organic Survey 2016 Summary." https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Organic_Production/ [Retrieved February 25, 2019]

Walgenbach, J. (2018). "Insect Management on Cucurbit Vegetables in North Carolina." https://entomology.ces.ncsu.edu/cucurbit-insect-management-in-North-Carolina/ [Retrieved February 25, 2019].

Wang, H., R. Fu, A. Kumar, and W. Li. (2010). "Intensification of Summer Rainfall Variability in the Southeastern United States During Recent Decades." *Journal of Hydrometeorology* 11 (4): 1007-1018.

Willer, H., and J. Lernoud, eds. (2019): *The World of Organic Agriculture. Statistics and Emerging Trends*. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL).

Willer, H., and J. Lernoud, eds. (2017). *The World of Organic Agriculture Statistics and Emerging Trends*. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL).

Willer, H., and J. Lernoud, eds. (2015). *The World of Organic Agriculture Statistics and Emerging Trends*. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL).