PM-101

Distribution of *Xanthomonas hortorum* pv. *carotae* in Commercial Carrot Seed Lots

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Bulk samples of carrot seed are tested for *Xanthomonas hortorum* pv. *carotae* (*Xhc*) using a seed wash dilution plating assay. Testing protocols for seed-borne pathogens usually assume that infested seeds are fairly uniform with regards to bacterial populations on individual seeds and the assay will detect the average number of bacteria for infested seed present in the sample. However, previous studies have demonstrated that bacterial populations on individual seeds may vary and be non-normal in distribution. Sixteen commercial carrot seed lots were tested using a bulk seed wash assay and contained *Xhc* at populations between 10^5 and 10^9 CFU/g seed. Individual seeds from these seed lots were assayed to determine *Xhc* populations on individual seeds. The incidence of *Xhc*-infested seed varied among the seed lots, ranging from 7.7 to 94.3% infested seed. Seven of the 16 lots harbored <20% infested seed, while four lots contained infested seed at an incidence of 23 to 39%. Populations of *Xhc* ranged from 2 CFU/seed (the limit of detection of the assay) to 6.4×10^6 CFU/seed; three seed lots contained individual seeds with populations $>10^5$ CFU/seed. Most of the *Xhc* populations were not adequately described by a normal distribution and were highly and positively skewed. The incidence of *Xhc*-infested seed in carrot seed lots and the populations on individual seeds may be important factors influencing seed-borne transmission of *Xhc* and the efficacy of seed treatment, but the epidemiological implications of a relatively few, highly infested seeds in seed lots are not well-understood.

PM-102

Pythium diseases of carrots

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Cavity spot of carrots caused by *Pythium* species has been studied extensively by University of California researchers for over 30 years. In California *Pythium violae* and *P. sulcatum* are the main causes of cavity spot. However other *Pythium* species such as *P. ultimum* and *P. irregulare* have been isolated from diseased tissue. The host range of *P. violae* and *P. sulcatum* is broad with some hosts being symptomatic hosts while others are asymptomatic hosts. This host range can affect the choice of crop rotations if the desired effect is to reduce the incidence of cavity spot or *Pythium* root dieback. Many soil factors, including salinity, EC, pH, OM and soil temperature, have been studied to determine what, if any, effect they have on the development of cavity spot. Many chemical and organic fungicides have been evaluated over the course of 30 years of research. Several fungicides are now registered for use in California that have efficacy on the management of cavity spot. However, biologicals have not shown sufficient efficacy to be recommended options for the control of cavity spot. Increasing microbial activity by the addition of organic matter has resulted in the development of suppressive soils. These and other cavity spot studies conducted by various UC researchers will be presented.

PM-103

Carrots Viruses in the UK – an Agronomic Challenge

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Historically there are two carrot virus complexes which occur in the UK, Carrot Motley Dwarf Complex (CMD) and *Parsnip yellow fleck virus* (PYFV). Virus symptoms in the foliage show mottled, yellow, brown and red leaves. In roots they cause black spotting, cracking, kippering and excess hairiness. Heavy infection will significantly reduce plant stands and yields. In 2015 carrot virus accounted for around £19 million crop losses. Recently research by scientists at FERA Science Ltd, UK, discovered novel and unexpected viruses infecting carrots, one *Carrot yellow leaf virus* (CYLV) is linked to internal root browning.

These viruses are aphid transmitted, with the main vector being willow-carrot aphid (*Cavariella aegopodii*). Parsnip aphids (*Cavariella pastinacae*) and peach-potato aphid (*Myzus persicae*) may also be significant virus transmitters in carrots. CMD is transmitted relatively slowly in a persistent manner, however PYFV and CYLV are transmitted quickly in a semi-persistent manner. These aphids migrate into crops in late spring and usually numbers peak in June and July, however populations show large variations annually and regionally. Warmer winters, due to climate change, are thought to be a reason why populations are on the increase.

There are several sources of the carrot viruses in the UK. Apiaceous weeds are a source of PYFV, with cow parsley (*Anthriscus sylvestris*) the main UK weed host. Carrots are a source of CMD, which allows circular transmission from carrot to carrot in the crop. In-field storage of carrots in the UK could be creating a bridge for carrot to carrot transmission between seasons. Seed may also be an important virus source.

The distribution of carrot growing areas in the UK means that isolation of crops, or breaks in growing, are not an option to reduce exposure to virus infection. Removal of weed hosts is not possible as they are found so widespread. Therefore management of carrot viruses relies mainly on insecticide control. Timing of sprays is generally linked to regional and local aphid trapping. Seed treatment with Thiamethoxan is proving effective for the early season control. Thereafter there is a shortage of foliar aphicide sprays to cover the mid to late season period. The loss of pirimicarb in 2017 is another depletion of chemical options. Further research is required to identify the most damaging carrot viruses and understand the key periods when aphids infect them, to better target chemical applications and sowing timings.

PM-104

Understanding the ecology and epidemiology of Pythium violae causing cavity spot on carrot.

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Cavity spot is a major disease of carrot, which in the UK is caused primarily by the soilborne oomycete *Pythium violae*. Infection results in small black lesions and an unmarketable crop with high-value losses occurring every year. Disease management is challenging due to variable fungicide efficacy and difficulty in implementing long rotations. A lack of effective research tools including diagnostics for *P. violae* and the absence of a reproducible inoculation procedure for carrot has hampered research to understand the factors conducive to disease.

Initially, the identity of *Pythium* spp. associated with cavity spot was determined using a collection of 127 isolates from diseased carrots. Following ITS sequencing, 60% were identified as *P.violae*, 15% as *P.intermedium* and 14% as *P.sulcatum*. Further characterisation through sequencing of additional housekeeping genes and pathogenicity tests is being carried out to understand variation in the pathogen. Furthermore, an amplicon sequencing approach will be used to investigate *Pythium* communities and their interaction with other microbiota.

In order to quantify *P. violae* in soil and roots, a specific PCR test has been developed which, in combination with an oospore capture procedure, potentially allows testing of larger soil samples. Initial results suggest that detection of less than 10 oospores in 10 g may be possible. Testing of qPCR is currently underway.

Inoculum production and plant assay methods are also being developed for *P.violae*. Results have indicated that the pathogen can cause damping-off symptoms on seedlings while root stunting and small numbers of lesions have been observed on mature roots.

PM-105

California Carrot IPM from 1995 to 2014.

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California is the largest producer of fresh market of carrots in the United States. Carrot production, pest management, and marketing have undergone significant changes in the last 20 years. California is also the only state with 100% pesticide use reporting in agriculture. Based on the Department of Pesticide Regulation database, pesticide use in carrots has also changed over the last 20 years. Soilborne pests are the primary problems since carrot root need to be straight and free of blemishes for the fresh market. Pre-plant fumigation continues to be a major method of soilborne pest management and there has been a shift from metam-sodium to metam potassium. Foliar diseases are a concern since health tops are needed for harvest. Current fungicides applied are narrower spectrum and lower risk to human health than 20 years ago. Insects are relatively minor pests of carrots in California and current insecticides applied are less toxic than 20 years ago. Organophosphate use has declined significantly, organochlorines are no longer used; while neonicitinoid use has increased. Biological pesticide use increased significantly from 2012 to 2014 but is a relatively small proportion of pesticides applied to carrots. Changes in carrot IPM practices and pesticide use will be discussed.

PM-106

Evaluation of Flea Beetle Phenology and Damage to Carrot Production in California

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For the past few years carrot growers in the lower San Joaquin and Antelope Valleys have been reporting an unknown injury to the taproot of carrots. Superficially the damage looks like cavity spot

(*Pythium* sp.), a fungal disease that causes depressed lesions oriented across the taproot. However, upon closer inspection it became evident that damage was being caused by insect feeding, coupled with secondary infections that enhanced the injury's appearance as cavity spot. This damage is now attributed to feeding by flea beetle larvae. The principal concern with flea damage is that it can be confused with cavity spot.. This may trigger the use of fungicides for a problem caused by insects, or vice versa. The result is a lack of control, a waste of money, and continued economic damage to the crop. Currently very little is known about the best approach to flea beetle management in carrots in California. In this study we tested several different monitoring techniques to understand flea beetle phenology in California as a first step towards developing management guidelines for carrot growers.

PM-107

Managing root-knot nematodes in organic carrot production – an overview of California studies

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Carrots are grown organically on about 11,500 acres in California, which represents approximately 14% of the total California carrot acreage. In 2006, carrots surpassed tomatoes as the most sold organically grown vegetable. Although there is a price premium for organically grown carrots, there are also major challenges. One of these is the occurrence of root-knot nematodes (rkn, *Meloidogyne* spp.). The nematodes are particularly damaging on lighter sandier soils, which are the favored soil types for carrot production. Two damaging species: *M. incognita* and *M. javanica* are frequently found in California carrot fields. The nematodes cause de carrot to form galls or bumps on the surface, resulting in an unmarketable product. In a conventional production system, soil fumigants or, more recently, non-fumigant synthetic nematicides can be used to effectively control the nematodes, but these products are not available to organic growers. Promising new carrot varieties with sufficient levels of resistance against rkn are under development, but even when available they should be used judiciously to avoid the risk of rapid appearance of virulent nematode strains that can break through the resistance. Thus, few options are available in organic production systems. Since the introduction of the DiTera in 1996 as the first biological nematicide, a range of biologically-based strategies and nematicidal products have been developed and have been evaluated in California field trials by us and by others. A summary of results from various field trials on methods and products suitable for organic production systems will be presented.

PM-108

Evaluation of new nematicides for control of nematodes in carrots, in Ontario, Canada

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Carrots are particularly sensitive to nematodes especially during taproot formation. Root-knot nematode (*Meloidogyne hapla* Chitwood) and carrot cyst nematode (*Heterodera carotae* Jones) are the major nematode pests of carrots in Ontario. There is zero tolerance for root-knot nematodes in carrot production so the presence alone is enough to recommend control measures. Soil fumigation is the primary management option used by carrot growers. Fumigants PicPlus (chloropicrin 86%) and Busan/Vapam (metam sodium 42.5%) are registered on carrots for nematode control. Finding alternative nematicides is vital to provide Ontario carrot growers with the management tools they

need. Two non-fumigant nematicides have potential for nematode control: Nimitz (fluensulfone 480 g/L) and Velum Prime (fluopyram 50%). Field trials in commercial carrot fields with a history of nematode damage were conducted in 2014 – 2016 on high organic matter soils (60-80%). Various treatments were evaluated, included PicPlus, PicPlus + Vapam, PicPlus + Nimitz, Vapam, Nimitz, and Velum Prime. Carrots were harvested and assessed for nematode damage, forking, stunting and yield. Nematode damage was rated on a scale of 0-5. No significant differences in yield or percent marketable were found in 2016. In all years, PicPlus reduced nematode damage compared the check and increased yield in 2014 and 2015. In 2014, Vapam, Nimitz, and combinations of these products increased carrot yield and percent marketable carrots and reduced damage severity. Combining applications of PicPlus at seeding and pre-plant applications of Vapam or Nimitz did not significantly increase efficacy over a separate application of these products.

PM-109

New nematicides provide effective protection against root-knot nematodes

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Root-knot nematodes (rkn), particularly *Meloidogyne incognita* and *M. javanica* are the economically most important pathogens in California's fresh market carrot production. They reduce the quality of the harvested product primarily by inducing galling and forking of the main root. Galled feeder roots are also less able to supply the plant with water and nutrients which causes yield reduction. The rkn's wide host range, absence of commercially available rkn-resistant carrot cultivars, and the lack of effective non-fumigant nematicides, biocontrol products or cultural practices have resulted in reliance on pre-plant soil fumigants such as Telone II (a.i. 1,3-dichloropropene) and metam sodium or metam potassium. Often substantial parts of fields need to be excluded from fumigation because of buffer zone requirements. Other restrictions address emissions of volatile organic compounds associated with fumigant use. During the past four years we have evaluated development products with novel nematicidal ingredients in several *M. incognita*-infested field trials. At medium to high rkn population density pressure both DPX-Q8U80 (a.i. fluazaindolizine, DuPont) and Nimitz (a.i. fluensulfone, Adama) mitigated rkn disease symptoms and increased marketable yield compared to the non-treated control. With effective new modes-of action, lower mammalian toxicity, and lesser environmental impacts than previous generations of nematicides, these products are expected to considerably reduce soil fumigant use in California's carrot production.

PM-110

Variation among *Meloidogyne* spp. isolates on a panel of resistant carrot genotypes

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A collection of 49 isolates of *Meloidogyne arenaria*, *M. hapla*, *M. incognita* and *M. javanica* were compared for their infection potential on a panel of 11 diverse sources of resistant carrots (*Daucus carota*). The resistant genotypes were sources from 'Brasilia,' 'Homs,' 'Ping Ding' and 'Western Red' or combinations of these sources. They are known to contain genes for resistance to *M. incognita* and *M. javanica*. The goal was to determine the breadth of utility of resistance traits available in carrot germplasm and whether nematode virulence to the resistance is present. A susceptible carrot,

Imperator 58, was included as a control. All nematode isolates were cultured on greenhouse-grown susceptible tomato host plants. One month after seeding into sand-filled pots, each plant at the 3- to 5-leaf stage was inoculated in the root-zone with 50,000 freshly extracted eggs. Carrot root systems were assayed for root-galling (scale 0 – 8) and egg production 70 days after inoculation. Each isolate x carrot genotype combination was replicated four times and the test was conducted twice. The most resistant genotypes across isolates were derived from Brasilia 1252 and HxB, a cross between Homs and Brasilia. Ping Ding and Western Red also exhibited effective resistance across isolates. Of 29 *M. incognita* isolates, three were slightly more aggressive on Homs and Ping Ding, whereas the Brasilia sources were unaffected by those more aggressive isolates. The *M. incognita* isolates included ones known to be virulent on the tomato *Mi-1* gene or the cowpea *Rk* gene, but there was no correlation between virulence on the *Mi-1* and *Rk* genes and ability to parasitize resistant carrot genotypes. Two isolates of *M. arenaria* and seven isolates of *M. javanica* were avirulent on the carrot resistance sources, whereas variation in ability to parasitize resistant carrots was found among 11 *M. hapla* isolates.