FACTSHEET 07/16
Field Vegetables

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Virus diseases of carrots

Historically, there were two virus complexes known to occur in the UK: Carrot Motley Dwarf complex (CMD) and *Parsnip yellow fleck virus* (PYFV). Recent research has shown that previously unknown viruses are commonly infecting UK carrot crops and one of these, *Carrot yellow leaf virus* (CYLV), has been linked to carrot root necrosis. The viruses are all aphid transmitted but can vary in their incidence and epidemiology. This factsheet describes current knowledge and the latest developments in the area as well as looking at what is still unknown.

Figure 1. Reddening of leaves caused by infection with CMD complex

Figure 2. Symptoms of viral infection in carrot – Seedling death (necrosis) caused by PYFV

Figure 3. Yellowing of leaves caused by infection with CYLV

Introduction

Leaf symptoms from virus infections of carrot are still poorly understood. This variability could be due to several factors, eg age of the crop at infection, variety, environmental conditions as well as confusion from plants being infected with multiple viruses. However, for some of the viruses there are indicative of leaf symptoms as the names suggest, such as CtRLV and CYLV. Root symptoms are also difficult to associate with virus infections but a range of symptoms such as misshapen roots, stunting, and root browning (necrosis) have been linked to virus infections. Ultimately, any virus infection that changes leaf colour will affect photosynthesis and have the potential to lower yield. The following are broad descriptions of the types of symptoms associated with each virus or complex.

Diseases and symptoms

Carrot Motley Dwarf Complex (CMD)

In some cases the virus name can be used to determine what leaf symptom will be seen, CtRLV is associated with leaf reddening (Figure 1) and CMoV with mottling, which is a dappled yellowing of the leaf. However, in experimental studies, single infections by either of these viruses resulted in mild symptoms. The two viruses in coinfection have a greater effect on the plant and the result is called CMD disease. The third virus in the complex, CtRLVaRNA, is not known to have any noticeable effect on disease symptoms.

While foliar symptoms may be obvious, there is little data on root symptoms or crop loss due to these viruses. Anecdotally, infections with CMD have been linked to root symptoms such as excessive lateral root hairs (bearding) and root cracks and splits (splitting or kippering).

Visual identification of this virus complex is not helped by leaf reddening etc. being a general response to stress or physical damage, and there are also similar symptoms caused by infections with other pathogens such as phytoplasmas.

Parsnip yellow fleck virus (PYFV)

PYFV is important as an early season disease where it is associated with seedling death (Figure 2). However, in many seasons PYFV does not commonly occur. The reasons for this sporadic occurrence are still unknown, but it is possibly due to its complicated epidemiology involving AYV, which limits onward spread in carrot crops. In mature crops, the virus can sometimes be associated with misshapen roots, stunting and death of plants. Work conducted at Warwick Crop Centre (Project IF0188) suggested a close relationship between observed symptom, root weight and the proportion of plants infected with PYFV suggesting that this virus can cause stunting in mature carrot crops.

Carrot yellow leaf virus (CYLV), Carrot closterovirus-1 (CtCV-1) and Carrot torrado virus (CaTV)

The most obvious symptom of infection with CYLV is the strong yellow colour (chlorosis) and often upright habit of leaves of infected plants (Figure 3). Recent AHDB Horticulture-funded work at Fera (FV 382a) showed a statistical link between the presence of CYLV and internal root necrosis (Figure 4). This problem had been recognised in the carrot industry for many years but with a limited range of diagnostic tools, the cause could not be identified. Using advanced diagnostic technology several previously unknown viruses, as well as CYLV, were found in an infected crop. CYLV was strongly associated with the presence of root necrosis symptoms.

As the novel viruses were only discovered through this recent study, there is very little known about their symptoms. It is possible that symptoms of CtCV-1 may be similar to CYLV, but there has not been enough evidence to show a link to either leaf or root symptoms. Early indications from project FV 382b are that single virus infection with Carrot torrado virus (CaTV) may be symptomless in the foliage of the plant. The combined effect of this virus in coinfections with other viruses has not yet been studied.

In practice, a wide range of symptoms such as leaf reddening, yellowing, stiffening, stunting, distortion and curling of leaves can be seen in fields, and the association of these with different viruses and combinations of viruses is being clarified as research progresses. During the course of projects FV 382a and b, testing of field carrots has revealed that most carrot fields suffer from a moderate to high level of virus infection with a combination of the viruses described here.

Figure 4. Internal necrosis in carrot roots associated with infection by CYLV

Transmission

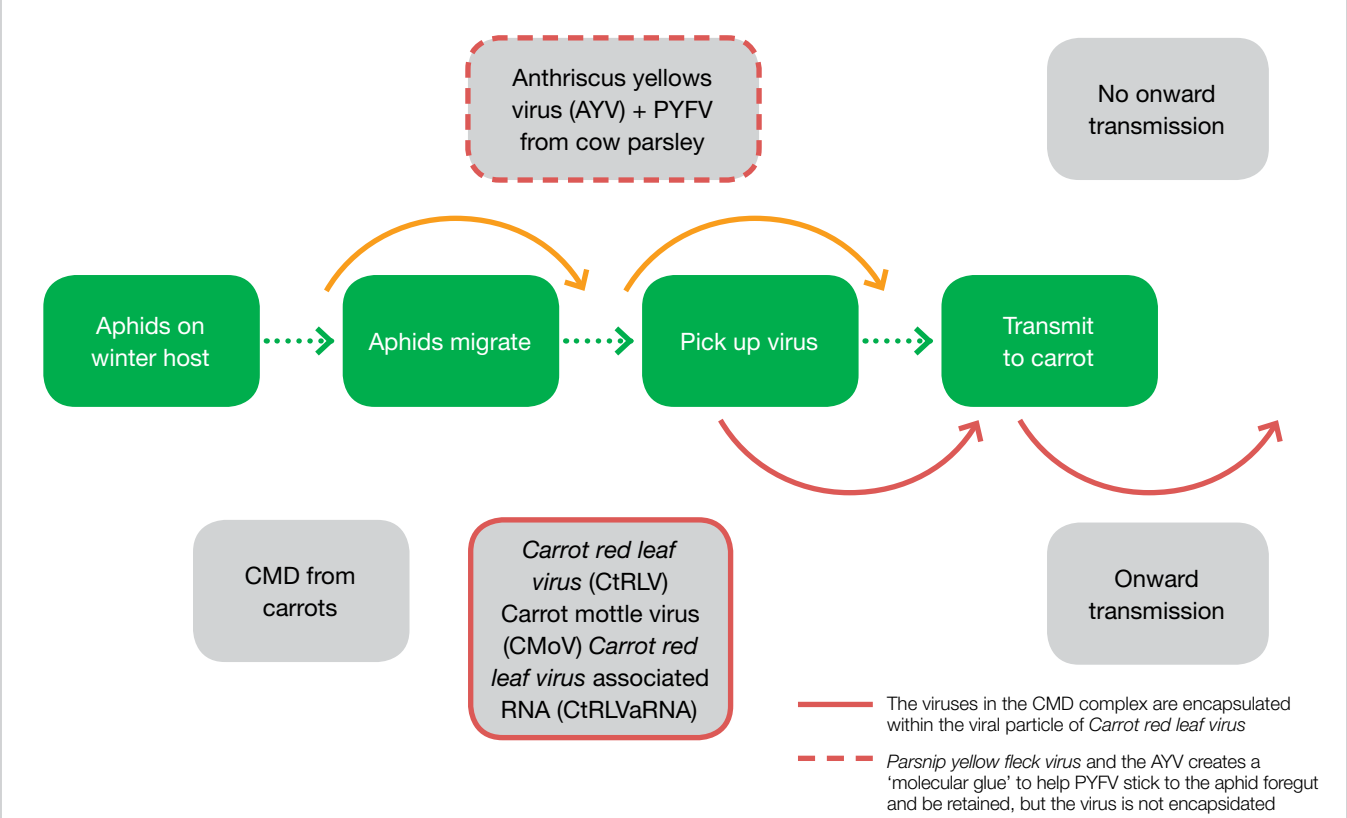

Figure 5. Overview of transmission pathways for known carrot viruses: PYFV cannot be transmitted without the presence of AYV. The infection is most likely to originate from cow parsley. As carrot is not a host of AYV, infection in carrot is a 'dead-end' for PYFV. For transmission of CMD complex, CtRLV enables the transmission of CMoV and CtRLVaRNA. The origins of CMD are most likely to be from other carrots and onward transmission can occur

The viruses commonly occurring in UK carrot crops are all known to be aphid transmitted. There are two virus complexes where transmission of one or more viruses is dependent on the presence of another virus, the CMD and the PYFV complex. Recent AHDB-funded projects (FV 382a and b) have detected a number of other viruses infecting UK carrots, such as CYLV, which has been associated with the presence of root necrosis in affected crops. Other viruses, CaTV and Carrot closterovirus-1 (CtCV-1), which were previously unknown to science, have been found to be present in some crops at higher levels than the known viruses.

The main vector in carrots is thought to be the willow-carrot aphid (*Cavariella aegopodii*) but in parsnips this may be *Cavariella pastinacae*. CYLV and CaTV are also known to be transmitted by the peach-potato aphid (*Myzus persicae*) which brings additional challenges for management of virus epidemics. The various types of viruses all have different biological characteristics, which will mean they also have different life cycles.

Carrot Motley Dwarf complex (CMD)

CMD is a complex of CtRLV, CMoV and CtRLVaRNA. The essential component of the complex, CtRLV is transmitted in a 'persistent' circulative manner. After being taken up by an aphid, the virus passes through the gut wall and into the salivary gland. Having acquired the virus, the aphid injects it into a fresh plant when it settles to feed.

Persistent virus transmission is a relatively slow process, whilst exact times are variable this mechanism means it will take several hours for an aphid to take up the virus, recirculate the virus and be able to transmit the virus to the host crop.

The other components of this complex, CMoV and CtRLVaRNA, cannot produce a coat protein that is needed for transmission and so they need another virus present to be passed on by aphids. In coinfections with CtRLV, some of the CtRLV virus particles carry the CMoV and CtRLVaRNA genetic material allowing all three viruses to be transmitted simultaneously, or occasionally by chance just one or two viruses may be passed on.

Parsnip yellow fleck virus (PYFV)

PYFV is transmitted via the aphid's mouthparts and is stored in the foregut. When it is feeding on an infected plant and is then injected into a subsequent plant, acting a bit like a syringe, potentially leading to infection. Occasionally, transmission can be to more than one plant if the aphid moves on rapidly. Transmission by this 'semi-persistent' syringe-like manner is relatively quick, needing only 10–15 minutes to take up the virus and only two minutes feeding to infect a healthy plant. To stick to the aphid's mouthparts the virus needs a molecular glue (helper component). An unusual characteristic is that PYFV cannot produce its own glue and so is dependent for transmission on the presence of a second virus – AYV.

If a plant is infected by both viruses, feeding aphids can pick up both or either and transmit them. However, if AYV is not present onward transmission will not occur. The interesting quirk of this complex is that PYFV can infect carrots but AYV cannot (see section 'Sources of carrot virus epidemics'). For this reason PYFV is not serially transmitted in carrot crops and PYFV infections have come from another plant host susceptible to both viruses.

Carrot yellow leaf virus (CYLV), Carrot closterovirus-1 (CtCV-1) and Carrot torrado virus (CaTV)

Until recently the viruses of greatest concern to UK growers were PYFV and the CMD complex. An AHDB Horticulture-funded investigation into the cause of carrot root necrosis (Project FV 382a), detected the presence of these viruses in carrot crops. CYLV has been known about in the UK for more than 30 years, but had been previously only found in weeds and was not considered a major threat to carrots. CYLV is transmitted by aphids in a semi-persistent manner, although this virus does not require a helper virus and can be transmitted on its own.

The other viruses, CtCV-1 and CaTV, were completely new to science and consequently little is known about these viruses. CtCV-1 is from the same virus group as CYLV and we assume that it will be transmitted in a similar manner. CaTV belongs to a recently discovered group of viruses (the torradoviruses) and is the first of this group to be found in the UK. It is also the first member of this group to be found affecting root crops. Other torradoviruses are known to be whitefly transmitted and affect glasshouse crops. As part of an ongoing Defra-funded project, CaTV has been recently shown to be aphid transmitted. The manner of transmission is not yet known, but the virus can be transmitted on its own and does not require a helper virus.

Transmission and sources of virus

Aphid vectors

Viruses cannot move from plant to plant without a means of transmission, ie a vector. The main vector of carrot viruses has traditionally been thought to be the willow-carrot aphid (*Cavariella aegopodii*). This aphid primarily overwinters as eggs on willow trees (*Salix* sp.). In the spring, wingless aphids multiply on the willow and in late spring winged aphids are formed and these disperse onto apiaceous hosts (the carrot family), to give more wingless generations. Throughout the growing season different apiaceous (unbelliferous) plants then become unsuitable as hosts, usually due to senescence following setting seed or overcrowding, more winged aphids form and disperse to further hosts. Finally, in autumn, winged sexual forms are produced that mate and lay eggs on willow. This pattern means that, while some winged aphids may be trapped throughout the summer, the largest numbers generally occur in a major spring flight, which may spread over eight weeks or more. The exact timing of migration will vary with latitude and prevailing environmental conditions making aphid monitoring a key part of targeted spray programmes.

Willow is not a known host of either PYFV or CMD complex and for infection of carrot to occur aphids must first feed on an infected apiaceous host. Particularly in mild conditions, some aphids will overwinter as adults on apiaceous hosts, bypassing the sexual stage and giving birth to live young. This then gives the potential for these new generations of aphids to pick up virus infections from their first feed.

Through AHDB Horticulture project FV 382b and work by a Defra-funded PhD student there have been transmission experiments carried out to investigate the vectors of CYLV and the novel virus CaTV. In these studies other aphid species including the parsnip aphid (*C. pastinaceae*) and the willow-parsnip aphid (*C. theobaldi*) were shown to be able to transmit these viruses. Of greatest concern was the demonstration that the peach-potato aphid (*M. persicae*) was also shown to be an efficient vector of these viruses. Peach-potato aphid is recognised to be resistant to multiple insecticidal chemistries, including organophosphates, carbamates and pyrethroids, and managing transmission by this species will present challenges for the carrot industry.

Figure 6. *Cavariella aegopodii* is thought to be the major vector of carrot viruses, but recent work suggests *Myzus persicae* should also be considered in virus control programmes

Sources of carrot virus epidemics

The role of wild hosts in virus epidemiology is often overlooked. Between 2010 and 2012 a Defra-funded project (IF0188), used molecular testing (PCR) to look at the distribution and frequency of CtRLV and PYFV in the wild apiaceae commonly found surrounding carrot fields. The findings of CtRLV and PYFV from this work were studied at the genetic level to identify where carrot infections originated. This built on earlier work, particularly a HortLINK project (HL0149). During AHDB Horticulture project FV 382b the samples collected during the previous Defra project (years 2011 and 2012) were re-tested for the presence of the new carrot viruses CYLV, CtCV-1 and CaTV (Figure 7).

Parsnip yellow fleck virus/Anthriscus yellows virus

As PYFV is dependent for transmission on AYV, which does not infect carrots, PYFV infections in carrots must come from outside the crop. In theory, this could include non-carrot crops such as parsnip but, in practice, is probably almost entirely from wild apiaceae. In both survey projects (Defra IF0188 and HortLINK HL0149) the vast majority of PYFV findings were in cow parsley (*Anthriscus sylvestris*) a very common hedgerow plant in much of the UK, it was also found occasionally in hogweed (*Heracleum sphondylium*). AYV was found in several wild hosts, but again most commonly in cow parsley. During project HL0149 genetic analysis of PYFV isolates showed that there was a close relationship between virus findings in cow parsley and carrot and a link between hogweed and parsnip sourced virus. In project IF0188 genetic sequences of virus isolates were again compared, PYFV isolates from hogweed were distinct from those found in carrot and cow parsley. These results strongly suggest that most PYFV infections found in carrot crops originate from cow parsley.

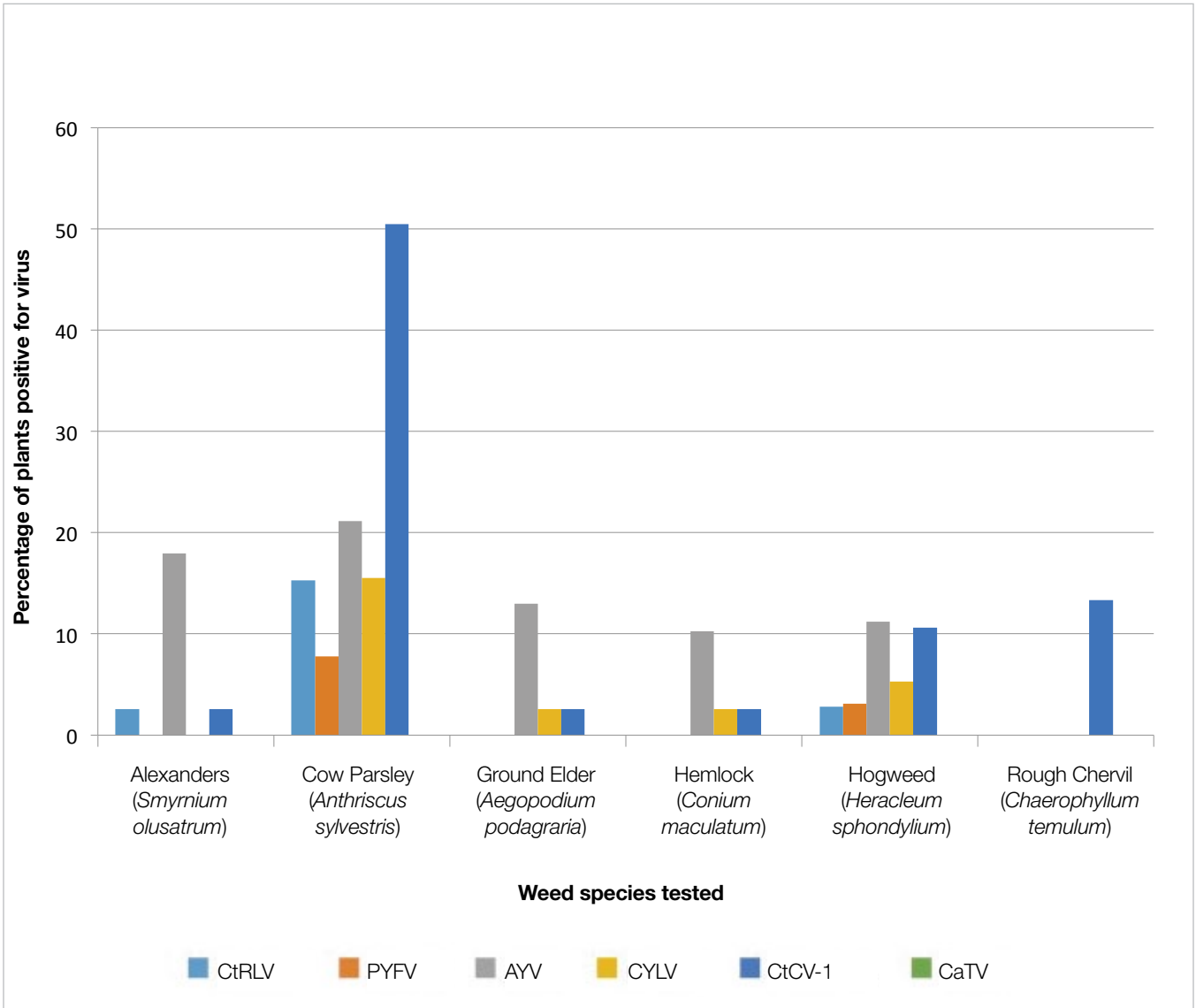

Figure 7. Percentage of weeds found to be positive with viruses

Carrot red leaf virus (CtRLV)

During Defra project IF0188, CtRLV was detected in all species of apiaceae tested. However, with very few exceptions isolates detected in carrot were clearly distinct from those in all other hosts. This means that there is a carrot type of CtRLV quite distinct from the type of virus found in several other host types and the majority of infections in carrot crops are thought to be coming from other carrots, either cultivated or wild.

Carrot yellow leaf virus (CYLV), Carrot closterovirus-1 (CtCV-1) and Carrot torrado virus (CaTV)

As part of AHDB Horticulture project FV 382b the same samples of wild apiaceous hosts collected during IF0188 were tested for the presence of the newly described carrot viruses. Cow parsley was again the host most commonly found to be infected with these viruses. CtCV-1 was found in every species tested. Broadly speaking, where found, these new viruses were at least as common as CtRLV and PYFV. These viruses were also present in every region where samples were taken ranging from Scotland to the south-west of England showing that these viruses have probably been around in the UK undetected for many years. Despite testing over 1,000 samples there was no evidence of the presence of CaTV in wild apiaceous hosts. This indicates that this virus probably has a source of virus in carrots either from previous crops overwintered in the field or from seed sources. In recent testing of carrot seed lots at Fera, two out of 10 seed lots tested contained CaTV. Although the infection rate was at a very low level, and seed transmission has not yet been demonstrated, there is clearly the potential for seed to be a source of virus infections.

Management of carrot viruses

Once a host becomes infected with a virus there is no means of treating the plant. In most cases an infected plant will then act as a reservoir for onward spread of that virus. Because there is no direct means of treating virus diseases it is better to think in terms of managing viruses through indirect measures. There are key principles that can be applied to any crop system for virus management, such as controlling vectors and virus reservoirs. These principles are discussed below in context with the latest findings on carrot virus management.

Grow in absence of vectors

While it is generally thought that the willow-carrot aphid is the main virus vector in carrot crops, there is still no firm understanding of precisely when the different viruses are spread. It is assumed that, as a mainly early season problem, PYFV is brought into crops during the spring migration but it is not known if all early migrants are equally likely to be carrying the virus, which could partly explain the sporadic nature of PYFV epidemics. The need for AYV to help transit PYFV means there will then be no onward spread in carrot crops. The relatively quick mechanism of transmission of PYFV means that this initial flush of transmission will be difficult to control even if aphicides have a rapid knockdown effect.

CtRLV and the other CMD viruses seem to be spread throughout the season, but some of this spread may be onward transmission from plants infected early to young plants, especially if aphid control is poor. The relatively protracted amount of time taken for the aphid to take up CtRLV, recirculate and then pass on the virus means that chemical control should be achievable.

The mechanism of transmission of CYLV, CtCV-1 and CaTV means that the virus is likely to come in from weeds or other carrots and then have the potential to spread rapidly within the crop. Given the relatively rapid transmission of these viruses aphicides will have a limited effect upon the initial infections, but may limit onward transmission in crops. As peach-potato aphids must now be considered a vector of these carrot viruses, as well as willow-carrot aphid and other aphids feeding on apiaceous plants, aphicide resistance must also be considered when planning spray programmes.

Although early season transmission may be reduced through delayed planting, so that young vulnerable crops are not emerging during peak aphid flight periods, this may not be practical in the field; barrier methods may also offer an approach for limiting exposure to early season virus transmission, however, the applicability of both of these approaches require further investigation.

Grow in absence of virus reservoirs and isolate from similar crops

Both common weed hosts and carrot crops may act as sources of virus infections into uninfected crops. There is strong evidence that PYFV infections originate from cow parsley in hedgerows and field margins, whereas the CMD viruses, and possibly CaTV appear to be coming from other carrots (whether wild or crops). A physical separation from these sources of infection will reduce the risk of virus carrying aphids entering a crop. Ensuring maximum distance between crops in practice will be challenging given the limited availability of suitable growing land. Geographic isolation from a ubiquitous field weed is also likely to prove a practical impossibility. However, separation of crops in this respect could be isolation from other carrot crops ‘in time’ such as the suggestion of ‘date-smart’ planting, or physical separation such as the use of barriers.

Use resistant (or tolerant) varieties

The approach of using either resistant varieties that do not become infected by the viruses, or tolerant varieties, which become infected but show no discernible symptoms, is a valid principle. However, data on the susceptibility of a range of varieties to the viruses or symptoms is very limited and currently based upon casual observations. To date, the majority of work carried out on carrot viruses has been carried out on cv. Nairobi as this is the variety most commonly grown in the UK and the variety in which root necrosis was first identified.

Future understanding and prospects for control methods

Recent work at Warwick Crop Centre (FV 445) has shown that carrots from aphicide treated plots had a higher yield than carrots from the untreated control plot, the first time that the impact of viruses on carrots has been quantified (Figure 8). However, the spectre of aphicide resistance as seen with peach-potato aphid complicates the possible chemical control strategies, and resistance management should also be taken into account when developing spray programmes. Given the limited control options available with the current insecticidal chemistries, alternative control measures need to be developed. Development of novel insecticidal active ingredients should focus on speed of knockdown to give any hope of controlling the transmission of semi-persistent viruses such as PYFV and CYLV. To date, little work has been carried out on the aphicide resistance status of willow-carrot aphid, and this information could help to explain why there appears to be poor virus management even where chemical control should be achievable.

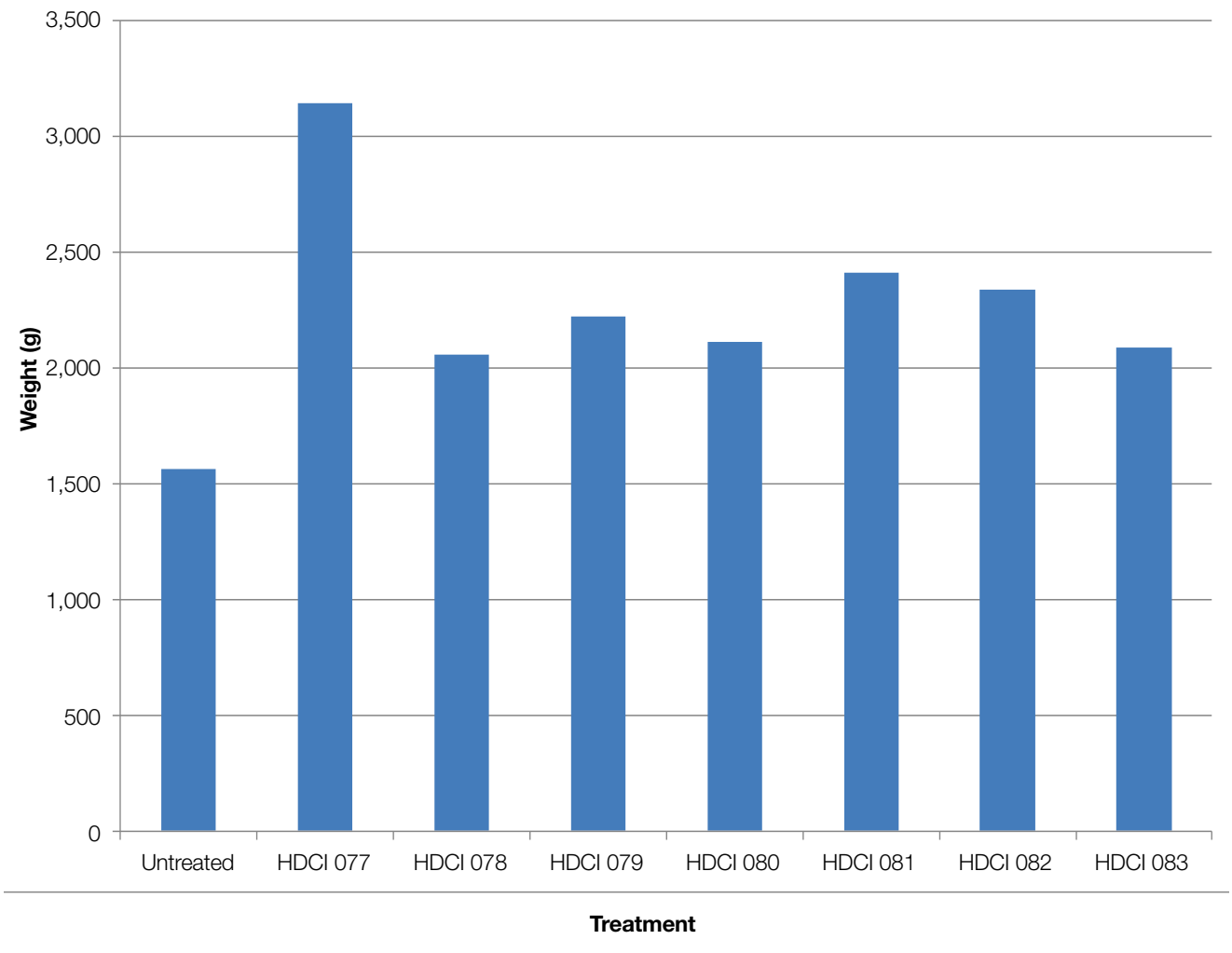

Figure 8. Preliminary experimental data from project FV 445 showing carrot root yield from insecticide treated plots as compared to untreated plots

Acknowledgements

The content of this factsheet expands upon the content of the previous AHDB factsheet written by the late Dez Barbara. AHDB Horticulture would also like to thank Larissa Collins, Fera and Howard Hinds, Howard Hinds Crop Consultancy, for useful comments.

Further information

AHDB Horticulture Project Reports

AHDB Horticulture project FV 445: Optimising control of willow-carrot aphid and carrot fly.

AHDB Horticulture project FV 382a: Internal browning of carrot: investigating a link with the viral diseases PYFV and CMD.

AHDB Horticulture project FV 382b: Carrots: The Epidemiology of Carrot yellow leaf virus (CYLV) – the development of a decision support system for the management of carrot viruses in the UK.

AHDB Horticulture project FV 228a: Parsnip Yellow Fleck Virus: Development of a disease management strategy.

Other useful publications

Carrot and Parsnip Crop Walkers' Guide (2015) horticulture.ahdb.org.uk/publication/carrot-and-parsnip-crop-walkers-guide-revised-2015 or for hard copies please email hort.info@ahdb.org.uk

Defra project IF0188 (2013): Plant pathogen populations in wild and agricultural hosts and interactions with plant genotype.

AHDB Horticulture project FV 228a (2004): Parsnip Yellow Fleck Virus: development of a disease management strategy (HortLINK HL 0149).

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