

# Field Vegetable Review 2019





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## Foreword

### Welcome to the 2019 Field Vegetable Annual Review.

It has been another challenging year for many in terms of the weather. In particular, the heavy rainfall in June caused significant challenges for brassica growers in Lincolnshire, and while there is not much AHDB can do to control the weather, our research and knowledge exchange programmes continue to deliver new tools and information to help us stay resilient to the challenges we face.

The SCEPTREplus programme continues to deliver new EAMUs to help plug gaps in our crop protection armoury. This year's trials have been looking at high-priority pests, including bean seed fly, aphids and asparagus beetle, diseases such as downy mildew, and Pythium. We also have weed control trials on nine different target crops: you can read about the results from page 6.

This year we also announced a new three-year research programme to revolutionise the understanding and improve control of downy mildew and late blight in horticultural crops; more detail can be found on page 12.

Excitingly, AHDB has just launched Strategic Centres for Field Vegetable crops. They will showcase the latest ideas, science and technology on integrated pest management strategies. Placed around the UK, they will specifically focus on carrots, peas, onions and brassicas. They will build on the success of our programme of variety trials and are a great opportunity for more grower-to-grower learning. I hope to see you at an event soon.

Labour continues to be the biggest concern for many growers. Earlier this year, we had the SmartHort

Conference in Stratford-upon-Avon, looking at the latest technology, robotics and automation in horticulture. The presentations are available online for those who missed it. We also launched three Strategic SmartHort Centres in Cambridgeshire, Perthshire and Herefordshire. These introduce the concept of Lean and show how labour productivity can be improved. Full details of the SmartHort programme are available at [ahdb.org.uk/smarthort](http://ahdb.org.uk/smarthort)

In a new venture for AHDB Horticulture, the power of social media to influence consumer behaviour has been tested with the #WatercressChallenge promotion. The results are on page 33.

As chair of the Field Vegetables Panel and a sector board member, I am always keen to hear your thoughts about AHDB research and how we are investing your levy. We are currently writing the new strategy for AHDB Horticulture and would like your input. Please get in touch with me or a member of the panel to discuss how we are working for you.



**Martin Evans**  
Field Vegetable Panel  
Chair





## Pests and diseases

### Research programmes

In 2017, AHDB took the decision to move away from funding reactive proposals to a more manageable, proactive approach to commissioning new work; working in this way means that staff in the technical team work with growers, panels and committees to develop programmes which are aligned with the AHDB Horticulture strategy.

This change in approach means that we can plan and commit funds to a particular topic much more effectively and that there is greater visibility of the various work streams, whether they are focused on nutrient management, weed control, soils or investigating product efficacy in programmes like SCEPTREplus.

Wherever possible, we try to develop programmes of work, or projects, which have value across the crop sectors of AHDB – Horticulture, Cereals & Oilseeds and Potatoes. Where this isn't appropriate, the work might be Horticulture- or even crop-focused when we can see that a generalised approach isn't suitable.

We are aware that growers are concerned that this approach means that there won't be clear outcomes for their crop from cross-sector projects. However, we do work hard when developing tenders, and in discussion with our contractors and steering groups (which are composed of industry representatives), to ensure there are clear outcomes and deliverables for all sectors funding the work.

Did you know our crop protection team submit around 135 applications each year to the Chemicals Regulatory Division to secure extensions of authorisation for minor use (EAMUs)? So far in 2019, we have secured 37 authorisations to help plug gaps in the crop protection armoury for field vegetable crops. See Table 1.

### Risk registers

AHDB's risk registers (Table 2) give us a clearly defined level of risk that may be posed by a failure to control a particular pest, weed or disease problem. The numerical values assigned are calculated by considering the likelihood of the issue occurring and the impact that it could have in terms of crop loss.

We use previously collected information from gap analyses and interaction with technical groups to identify all pest, weed and disease targets. Additionally, we interrogate the Plant Health Risk Registers run by Defra to raise awareness of any pests or diseases that may be on the horizon. Early notification of these issues raises awareness and, if the pest or disease does arrive in the UK, it means that we are capturing risk ratings on it from very early on.

We gather opinions on the risk for each crop group based on the current levels of mitigation used to manage the problem, e.g. plant protection products, resistant varieties or avoidance of heavily infected land.



The risk scores can be used in a number of ways:

- To quantify the risk and level of response required
- To monitor pest, weed and disease issues for increasing impact and to develop research work accordingly
- To identify key active ingredients used by growers and take steps to fill any gaps that may occur through the loss of products before alternatives appear
- To gather data for use in extension of authorisations for minor use or emergency applications

The risk registers also show the plant protection active ingredients that are currently approved for use against

that target, as well as a 'risk of loss' score, indicating the likelihood and date of the product being lost.

We have found that growers and agronomists really value this information, which helps them manage future production decisions.

So far, we have concentrated mainly on crop protection risks during meetings with technical groups. However, a similar approach can be used to assess the risks or benefits of a number of other issues that vegetable growers face. This can help us to ensure that work is developed to try and mitigate against problems faced, or provide information or resources to increase productivity.

Table 1. Some of the EAMUs secured for field vegetable crops in 2019

Category	Product	Crop	Target	EAMU no.
Herbicides	Gamit 36 CS	Beans without pods	Various weed species	3047/2019
	Emerger*	Celery	Fat hen and volunteer oilseed rape	2716/2019
	Emerger	Carrots, parsnips and root parsley	Various weed species	1607/2019
	Devrinol	Herbs and spinach	Various weed species	2121/2019
	Venzar 500SC	Spinach, baby leaf, red mustard and fresh herbs	Black bindweed, brassica weeds and polygonums	1524/2019
	Centurion Max	Leeks and salad onions	Black grass & annual meadow-grass	0792/2019
	Hurricane SC	Carrots	Various weed species	0180/2019
	Emerger	Outdoor crops of caraway, dill and parsley	Various weed species	1617/2019
	Emerger	Garlic, onions and shallots	Various weed species	1616/2019
Insecticides	Benevia 100D*	Outdoor leafy brassicas	Diamondback moth	2930/2019
	Benevia 100D*	Leeks, onions and salad onions	Thrips	2917/2019
	Decis Protech	Outdoor rocket, red mustard, herbs and edible flowers	Aphids, caterpillars (including cutworms and wireworms), leaf miners, whitefly, flea beetles	1177/2019
	Batavia	Sweetcorn	Bird cherry-oat aphid, English grain aphid and rose-grain aphid	3152/2019
Fungicides	Plover	Cardoon, celery, Florence fennel and rhubarb	Late blight, leaf spots and leaf blight	2713/2019
	Rudis	Red beet	Alternaria, powdery mildew and leaf spots	3126/2019

\*Denotes an Article 53 Emergency Authorisation and the expiry date may have passed before this review is published.

Table 2. Snapshot of the asparagus crop protection risk register

Crop protection		With current mitigation options			Without mitigation options		
Pests	Crop(s) affected	Likelihood	Crop loss	Risk	Likelihood	Crop loss	Risk
Asparagus beetle <i>Crioceris asparagi</i>	Asparagus	4	3	12	5	4	20
Aphids <i>Various</i>	Various	3	1	3	4	2	8
Thrips <i>Thrips tabaci</i>	Various	3	1	3	3	3	9
Slugs <i>Deroceras panormitanum</i> , <i>Oxyloba pfeifferi</i>	Various	5	3	15	5	4	20

## SCEPTREplus

The four-year SCEPTREplus programme is now in its third year and it has already delivered a number of extensions of authorisations for minor use (EAMUs) for field vegetables, with further applications being progressed.

Targets have been selected based on existing priorities identified by growers, panels, manufacturers and AHDB's risk registers. Many of the trials continued work conducted in the previous years of the project to provide additional data on crop safety and product efficacy.

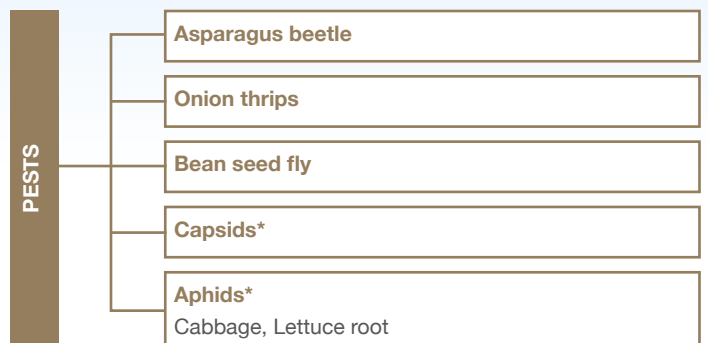
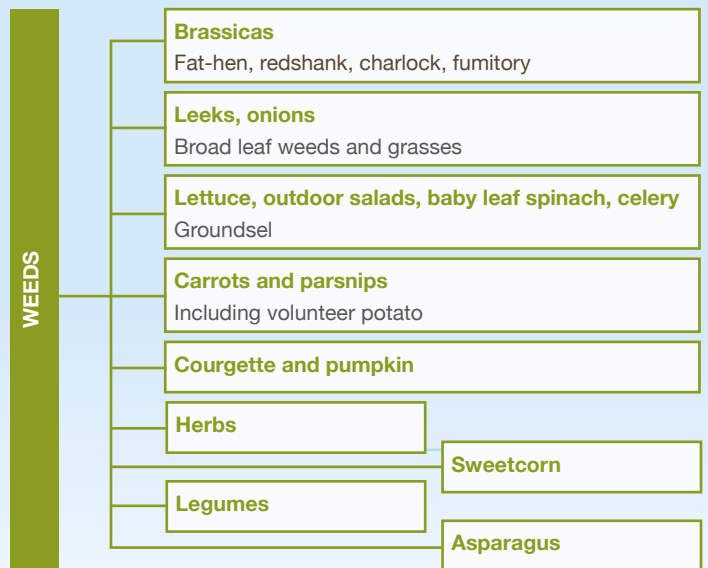
A number of EAMUs have been sought and secured based on work conducted within the SCEPTREplus programme. These include many applications for herbicides but also for pest and disease control products.

The knowledge exchange programme for SCEPTREplus has included open days for growers, agronomists and manufacturers, allowing them to visit the trial sites and look at the different plots to see for themselves how the products have performed.

With the final year of the project approaching, we will be looking at filling any gaps which have not been covered so far in the programme. We are also looking at how to continue the programme once this four-year period comes to a close.

Table 3: EAMUs secured for field vegetable crops so far, following SCEPTREplus trials

Product	Type	Crop
Devrinol	Herbicide	Herbs, spinach
Dual Gold	Herbicide	Sweetcorn
Emerger	Herbicide	Garlic, onions, shallots, caraway, dill, parsley
Flexidor	Herbicide	Carrots, horseradish, parsnips
Gamit	Herbicide	Carrots
Hurricane	Herbicide	Carrots
Venzar 500SC	Herbicide	Outdoor leafy veg and fresh herbs
Wing P	Herbicide	Courgettes, squash, pumpkins, sweetcorn
Serenade ASO	Fungicide	Cabbage
Teppeki	Insecticide	Cabbage



Targets being tested for field vegetable crops in the third year of SCEPTREplus trials

\* Model crop approach



## SCEPTREplus: Herbicide trials

**AHDB project code:** CP 165

**Lead contact:** Ed Moorhouse,  
Agri-food Solutions Ltd

**AHDB contact:** Joe Martin

Finding crop-safe solutions to weed control issues in field vegetables has been an area of great demand within the SCEPTREplus project, and in the third year of this four-year programme the requirement for this work remains high. In part, this is due to losses of key herbicides such as linuron and changes to authorisations which add restrictions to the use of existing products.

Herbicide screening, to identify potential new products and increase authorisations for field vegetable growers, was carried out on a range of crops in 2018, including brassicas, carrots, parsnips, herbs, onions, leeks, lettuce, wild rocket, spinach, courgettes and pumpkins. Work in 2019 continued on many of these crops to take forward products identified in 2018. New trials were commissioned in 2019 on asparagus and beans. In addition, sweetcorn and celery trials were included this year to build on trials carried out in 2017.

As well as product screening, precision approaches to application have been considered, such as band and inter-row spraying for row crops. Products for SCEPTREplus trials are selected to ensure that there is the likelihood of a route to authorisation. The programme has generated eight product authorisations for herbicides from the work so far, with other potential leads in the pipeline.

## SCEPTREplus: Baby leaf salad diseases

This year, NIAB is undertaking product tests for the control of Rhizoctonia root rot and Pythium in protected baby leaf salads. These two soilborne diseases cause significant losses of young plants in this speciality sector, and industry has identified a need for product evaluation specifically under protection, selecting some of the products that have shown promise in outdoor crops.

We are working with baby leaf spinach, and the tests will take place in NIAB's soil-floored glasshouse. Soil will be steam-sterilised prior to planting to remove any extraneous pathogens which might affect results. The soil will then be deliberately infected with the two diseases, in separate areas of the glasshouse, before the crop is planted. Production of inoculum is already underway, using a maize meal and vermiculite or barley grain 'carrier' so that the disease can be incorporated evenly into the soil by raking in this infected material.

Using deliberate inoculation techniques such as this is valuable when dealing with soilborne diseases, which can occur unevenly in commercial situations, potentially leading to inaccuracies when comparing products. The test will be assessed by counting surviving plants, the degree of root rotting observed and the fresh weight of marketable leaf. Results should show specific product efficacy against either Rhizoctonia or Pythium, and the best combination products can then be identified.



Growers looking at SCEPTREplus herbicide trials for carrots

## SCEPTREplus trials on field vegetable pests

SCEPTREplus trials have been testing control options for a range of key priority pests for field vegetable crops over the last three years. Applications for some plant protection products tested in the trials are underway, including Gazelle for asparagus beetle and FLIPPER has been authorised for aphid control on field vegetable crops.

### Asparagus beetle

The results for trials on asparagus beetle in 2017–2018 were very promising, with all treatments controlling asparagus beetle larvae. Timing your applications to coincide with larval emergence is critical.

Conventional treatments tended to act more quickly than the bioinsecticides and kill a greater proportion of the larvae, but all treatments increased mortality to levels above 80%.

Thirteen treatments (including an untreated control) were evaluated by applying them to fresh pieces of fern on which the insects were maintained in cages. For tests on larvae, the fern was infested before spraying, while for adults, the beetles were released into the cage containing the treated fern.

With no direct contact action (which would probably be the case with field applications since the adult beetles are so mobile), the adults were more difficult to kill, but the most effective conventional insecticide treatments increased mortality to above 80% after six days. None of the bioinsecticides had significantly increased mortality after six days.

The tests showed that cypermethrin (a pyrethroid) was ineffective against the adult beetles and Dr Steve Foster, Rothamsted Research, has recently confirmed that there are varying levels of resistance to pyrethroids in field populations of asparagus beetle.

### Aphids

Trials were undertaken on peach-potato aphid, cabbage aphid, willow-carrot aphid and currant-lettuce aphid in 2018–2019.

A good proportion of the conventional insecticides killed all the aphids after six days and some were sufficiently persistent to kill new aphids, which were placed on the plants six and thirteen days after treatment. Overall, a few bioinsecticides showed promising results. There were some differences in the level of efficacy of certain products against the different species of aphid.

Plants of an appropriate host crop were grown in pots and infested with aphids prior to treatment with foliar sprays of the products, some of which were bioinsecticides. The numbers of live aphids were then recorded over time. If all of the aphids were dead after six days, then the plants were reinfested and the same was done after thirteen days. The conventional insecticides were applied once and the bioinsecticides twice, with the plants being resprayed after seven days.

### Lettuce root aphid and cabbage aphid

A field trial was undertaken at Warwick Crop Centre in 2018 to assess conventional insecticides which might be used to replace the neonicotinoid seed treatment, Cruiser.

Most of these were applied as Phyto-Drip® treatments at sowing, one was applied as a drench to the block before transplanting, and two treatments were based on either one or two sprays of Movento. Unfortunately, the very hot conditions in 2018 led to poor levels of infestation and there was insufficient data to compare treatments. The trial has been repeated this summer, with much better levels of infestation, and was assessed in early August, but the data has yet to be analysed.

The same treatments were evaluated in a pot trial at Warwick Crop Centre in autumn 2018 against currant-lettuce aphid and three of the Phyto-Drip® treatments appeared to provide good control. A similar field trial is being undertaken on brassicas to determine the efficacy of potential Phyto-Drip® treatments and a novel seed treatment against cabbage aphid. The plants will be infested artificially for this trial so that product persistence can be monitored.

### Bean seed fly

Bean seed fly is a persistent problem on several crops, and control methods are limited, particularly on legumes. A review was undertaken by PGRO and the University of Warwick to identify potential methods of controlling the pest. As a result of this review, PGRO conducted a field trial in summer 2019 to evaluate some potential treatments on a pea crop; most were applied to the furrow – an approach used in North America.

The trial was drilled on 14 May 2019 and layers mash was added to attract the flies. Most plants were attacked by bean seed fly larvae, except where a coded conventional insecticide was applied. The data has yet to be analysed.

A PhD on bean seed fly to understand more about its biology and useful methods of cultural control will also be funded by the University of Warwick, PGRO and AHDB and a student has recently been appointed.





Bean seed fly pupa

# AMBER: Improving biopesticide performance

The wider use of biopesticides could add significant strength to integrated pest management (IPM) strategies. However, these natural agents need careful nurturing to provide the level of control required in commercial production systems.

The control provided by synthetic chemistry is relatively predictable. However, it is not so easy to achieve consistency with biopesticides because of the complexity of natural systems.

## Pros

- Safe to people and environment
- Maximum residue levels exempt
- Short harvest intervals

## Cons

- Slower acting
- Many biopesticides are contact and not systemic in their activity
- Low persistence
- May be impacted by environmental conditions

In 2016, AHDB commissioned a five-year project, AMBER – Application and Management of Biopesticides for Efficacy and Reliability – to help the industry make the most out of biopesticides.

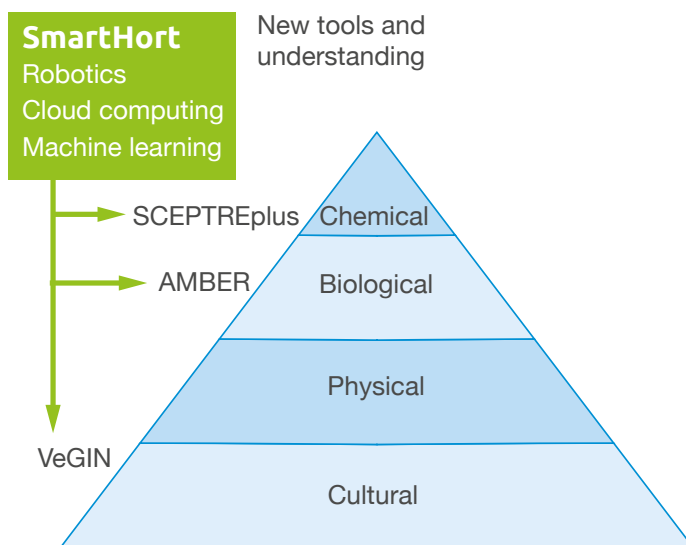
AMBER is focusing on identifying why biopesticide efficacy can be inconsistent and developing management tools and practices to improve performance.

## Making spray application more efficient

Trials conducted by Silsoe Spray Applications Unit have been looking at the relationship between water volume and percentage of spray retained on crop. They have found that:

- Water volumes greater than 100 L/ha help neither the quantity of active substance on the plant, nor distribution of the product over the plant
- Higher water volumes can be required to slow down drying, for operator exposure reasons and to improve coverage (but probably only up to around 500 L/ha)
- Optimum volume is highly dependent on the plant structure and leaf surface and the interaction with product formulation and spray application parameters

## Sustainable crop protection: the IPM pyramid



## Biofungicide performance

Little is known about the persistence of biopesticides on the crop. A trial in 2018 showed poor persistence of AQ10 but good persistence of Prestop when looking at tomato foliage in the absence of the host. It also showed that Prestop can survive at least 14 days after application in the absence of the host under optimum conditions. Timing of AQ10 is more critical, as powdery mildew is needed for the survival of *A. quisqualis*. Work this year aims to help growers decide when to apply AQ10 so that powdery mildew is present over a sufficient area to support the hyperparasite and allow it to keep the mildew in check.

## Bioinsecticide performance

Horticulture uses a wide array of growing environments. To test biopesticides in just a few of these environments is both expensive and time-consuming, even with small-scale laboratory and greenhouse experiments. In response, the AMBER research team has looked at the potential to use computer models to make sense of the complex biopesticide world, with relatively low costs.

The AMBER model predicts how pest populations change over time and how biopesticides influence these changes. The development of each individual pest within a population can be tracked as it moves from one stage of development to the next, until it reaches adulthood and reproduces.

### Results so far:

- Pest population size affects microbial performance
- Correct water volumes need to be used during the application to improve performance
- Effective dose is important in order to understand how much product is required on the plant and where and when it should be applied





## Integrated control of Allium white rot

**AHDB project code:** FV 449a

**Lead contact:** Dr John Clarkson, Warwick Crop Centre, University of Warwick

**AHDB contact:** Dr Dawn Teverson

Allium white rot (AWR), caused by the fungus *Sclerotium cepivorum*, is a soilborne disease of Allium crops such as garlic, bulb and salad onions. Disease results in collapse and decay of roots, leading to reduced crop vigour, chlorosis and plant death. This project aims to evaluate a range of treatments for the integrated control of AWR, with a focus on salad onions, where the disease is more prevalent. Field experiments testing both conventional fungicides and biological control agents (BCAs) showed that products based on SHDI and DMI chemistry gave good levels of AWR control when applied early in crop development, with single or double applications generally proving to be similarly effective. However, BCAs did not reduce disease levels.

Commercial products based on garlic extracts were tested in the lab for their ability to artificially stimulate germination of *S. cepivorum* sclerotia – an approach which could be transferred into the field to reduce levels of inoculum in the absence of an Allium host. Several formulated products resulted in a high level of sclerotial germination, while food-grade garlic granules also had a positive effect. Future work will aim to combine these different AWR disease management approaches and also evaluate the potential of biofumigants as an alternative method of reducing the number of *S. cepivorum* sclerotia in soil.

## Carrots: development of artificial inoculation techniques for cavity spot

**AHDB project code:** FV 391/FV 391b

**Lead contact:** Dr John Clarkson, Warwick Crop Centre, University of Warwick

**AHDB contact:** Dr Dawn Teverson

Cavity spot of carrots, caused by the soilborne oomycete pathogen *Pythium violae*, continues to be one of the most economically damaging diseases for carrot growers. Management of the disease relies on metalaxyl-M fungicide and there is therefore an urgent need to identify new products and management approaches, including new fungicides and biological control agents (BCAs). However, field trials to evaluate such products often fail due to no, or low levels of, cavity spot development. This project aimed to develop artificial inoculation approaches to induce cavity spot in both glasshouse-based pot experiments and in the field.

Inoculation of growing media in pot tests resulted in some seedling death, reduced seedling size and a decrease in the amount of carrot foliage. At harvest, there was a high incidence of small, stubby and stunted carrots, each with a few typical cavity spot lesions. However, the level of disease symptoms was variable between experiments. In field macrocosms, consisting of a sandy field soil mixed with *P. violae* inoculum contained within concrete pipes, carrots were not stunted and we observed up to 40% cavity spot incidence. Artificial inoculation therefore shows promise, but there are challenges associated with the variability in disease levels and scaling up inoculum production for the field.



## Downy mildews

**AHDB project code:** CP 184, CP 186

**Project leads:** Tim Pettitt, University of Worcester; Alison Lees, James Hutton Institute  
**AHDB contacts:** Cathryn Lambourne, Kim Parker

Downy mildew diseases can develop rapidly on field vegetable crops such as lettuce, spinach, onions and peas and have the potential to cause complete crop loss. For example, lettuce downy mildew (*Bremia*) is estimated to cause in excess of £15 million in crop losses per year. Downy mildews, together with late blight diseases, are caused by a group of fungal-like pathogens called aerial oomycetes, which are responsible for a number of key diseases across horticulture and potatoes.

For field vegetables, control of downy mildew diseases currently relies heavily on fungicide applications, but with the continuing loss of fungicide actives, as well as the potential for development of fungicide resistance, chemical control does not always provide a sustainable solution. For crops such as lettuce and spinach where disease-resistant varieties are widely deployed, new pathogen races can evolve rapidly, leading to a breakdown in host resistance.

An AHDB-funded project that started in January 2019 aims to improve integrated management and reduce the economic impact of important horticultural diseases caused by aerial oomycetes. The work is being tackled by a consortium of researchers from the University of Worcester, James Hutton Institute (JHI), STC, NIAB and RSK ADAS Ltd. A complementary AHDB-funded PhD at James Hutton Institute started in October 2019 to focus specifically on *Bremia*.

In the short term, a series of reviews, best-practice grower guides and related knowledge exchange activity will consolidate current global knowledge on the biology and control of key downy mildews, ensuring that measures which can be adopted quickly are shared with industry, while also identifying potential barriers to uptake. Information will be collated for specific crops and crop sectors on pathogen biology, cultural control, fungicides as a component of IPM and control options for the future, such as elicitors. The project builds on current knowledge to develop and validate the tools required for a longer-term integrated approach.

Tim Pettitt, the project manager based at the University of Worcester, said: “Our goal is to help the industry develop and improve integrated management strategies. Knowledge gaps, such as the dynamics and significance of seedborne infection and the effects of supra-visual lighting regimes, will be investigated. We will draw on experience in other sectors to develop innovative tools for the detection, monitoring and characterisation of these pathogens.”



Onion downy mildew sporulation

“ We will draw on experience in other sectors to develop innovative tools for the detection, monitoring and characterisation of these pathogens ”

Tim Pettitt, project manager  
based at the University of Worcester



## Seedborne inoculum

Downy mildews infecting spinach, stocks and basil are known to survive on or in seed, but the importance of seedborne inoculum in disease epidemics is currently difficult to measure. In a bid to minimise seed as a source of downy mildew diseases in high-value crops, Dr Tom Wood at NIAB is developing and comparing new methods for detecting viable pathogen DNA in the seed of spinach, stocks and basil. The project will also establish effective seed-sampling procedures to ensure seed lots can be assessed in the most representative and effective way to optimise pathogen detection and efficiency for commercial testing purposes. A semi-quantitative assay using amplified DNA will also be designed as a cost-effective method for testing large numbers of samples.

## Fungicide-sensitivity testing

A range of different fungicide groups are available for the control of downy mildews in UK horticultural crops. However, some of the most important and effective fungicides currently used (e.g. azoxystrobin and metalaxyl-M) are also highly prone to the development of fungicide resistance in their target pathogen populations. As a first step towards a future surveillance system for fungicide resistance in downy mildew populations, Dr Alison Lees at JHI has developed tests that she is using to monitor fungicide sensitivity over time for downy mildews of lettuce, spinach and stocks, as well as tomato late blight.

## Diagnostics for *Bremia*

The development of a diagnostic assay suitable for the field detection of *Bremia* spores will provide a tool that could be used in real-time risk monitoring for lettuce downy mildew. This could subsequently be linked to appropriate models or forecasts for *Bremia* to assist fungicide scheduling. To date, a molecular diagnostic tool (LAMP assay) has been designed by JHI, with initial tests demonstrating that it is specific to lettuce downy mildew. Borrowing techniques from their experience of potato blight sample collection, the JHI team is successfully using 'FTA card' technology so that *Bremia* DNA can be collected from infected leaves and stored easily for later use in molecular diagnostic assays.

## Population markers for *Bremia*

A key focus of CP 184 and 186 is the use of new tools for the genotyping of *Bremia* populations. Once genotypic information is linked to phenotypic characteristics such as race and fungicide sensitivity, this could provide a step change in our understanding of population diversity, helping to inform resistance breeding and fungicide stewardship. This approach is currently being used very successfully for potato late blight. As well as collecting UK *Bremia* isolates as the basis for this work, JHI researchers are collaborating closely with international *Bremia* experts in the USA and with member organisations of the International *Bremia* Evaluation Board (IBEB) to ensure consistent approaches are used.



Lettuce downy mildew



# Fusarium diseases: investigations into the control of basal rots in crops

**AHDB project code:** FV POBOF 452

**Project lead:** Dr John Clarkson, University of Warwick

**AHDB contacts:** Dr Dawn Teverson, Wayne Brough

Many *Fusarium* spp. cause plant diseases, but *F. oxysporum* is one of the most important and economically damaging for horticulture and can be a major constraint to the production of many food crops, from onions to watermelons, as well as non-food crops, such as carnations and narcissus. Symptoms of infection include wilting, yellowing, root rots and bulb rots.

*F. oxysporum* is a species complex and comprises non-pathogenic isolates, as well as a large array of more than 100 pathogenic formae speciales (f.spp.), each of which is adapted to infect a specific plant host. The close genetic relationship between *F. oxysporum* f.spp. means that conventional DNA-based methods for identification do not distinguish between them. One of the major aims of this project was therefore to develop molecular tests to detect and quantify key *F. oxysporum* f.spp. causing basal rot of onion (*F. oxysporum* f.sp. *cepa*, FOC) and daffodil (*F. oxysporum* f.sp. *narcissi*, FON) as well as fusarium wilt of column stocks (*F. oxysporum* f.sp. *matthiolae*, FOM).

In addition to assembling isolates of these pathogens, *Fusarium* spp. from leek, asparagus and rocket was collected and identified. In these cases, several *Fusarium* spp. were identified, suggesting a disease complex. Genes associated with pathogenicity were identified from genome sequencing of FOC, FON and FOM and unique targets found to allow each *F. oxysporum* f.spp. to be distinguished using quantitative PCR assays. These assays successfully detected each pathogen in both soil and plant samples and were shown to be highly specific, following testing against a panel of over 60 DNA samples from different *Fusarium* species, *F. oxysporum* f.spp. and other common soilborne pathogens. In addition, the critical level of FOC, FON and FOM inoculum required to cause disease in each crop host was defined and work begun to correlate the levels of DNA detected using the PCR assays with spore numbers and disease levels.

“ These assays successfully detected each pathogen in both soil and plant samples... ”

**John Clarkson**  
University of Warwick



Using the FOC and FOM qPCR assays, it was also shown that root colonisation of onions and stocks respectively can occur within two days in an artificially inoculated system – suggesting that any potential treatments may need to be targeted at an early stage of crop development. These molecular tools therefore show promise for assessing disease risk following soil testing or for assessing colonisation of young plants. Furthermore, for onions, bulbs could also be tested post-harvest to determine the risk of disease development in store. Finally, a novel approach for determining the abundance of *Fusarium* species simultaneously, either in soil or plant roots, was developed, paving the way for the development of a community-based analysis of *Fusarium* pathogens and the ability to identify and quantify the components of *Fusarium* disease complexes.



## Lettuce: biology and management of fusarium wilt

**AHDB project code:** FV PE 458

**Project lead:** Dr John Clarkson,  
University of Warwick

**AHDB contact:** Kim Parker

Fusarium wilt of lettuce is a new disease to the UK which was first observed in protected crops in Ireland and Lancashire in 2016 / 2017 and has subsequently spread to additional sites in those areas, as well as two sites in Cambridgeshire. So far, Fusarium wilt has not been identified in outdoor lettuce production.

DNA-based testing of diseased plant samples from outbreaks confirmed that in all cases disease was caused by *F. oxysporum* f.sp. *lactucae* (FOL) race 4, first recorded in the Netherlands and Belgium. In the first part of this new project, improved molecular diagnostic tools were developed following genome sequencing, allowing identification and quantification of FOL in plants and soil, using quantitative PCR and loop-mediated isothermal amplification (LAMP) assays. This latter assay is very rapid and the LAMP machine is portable, meaning that tests could potentially be carried out at grower sites. In a recent experiment, preliminary results suggested that FOL race 4

causes significant lettuce infection at temperatures as low as 12°C, whereas FOL race 1, the most commonly occurring race worldwide, requires a temperature of at least 20°C for infection to occur. This year, colonisation of non-hosts by FOL race 4 will be examined to identify suitable crop plants that could be used in rotation, while the efficacy of heat and disinfectant treatments in eliminating spores of FOL race 4 will also be assessed.

## Treatments to reduce fusarium wilt of lettuce

**AHDB project code:** CP 165 SCEPTREplus

**Project lead:** Dr John Clarkson,  
University of Warwick

**AHDB contact:** Joe Martin

As part of SCEPTREplus, a range of fungicides and biological control agents were tested against FOL race 4 in inoculated pot tests in the glasshouse. While single applications of chemical fungicides at planting did not reduce disease, three applications of T34 Biocontrol containing strain T34 at sowing, transplanting and one week post-transplanting resulted in a significant reduction in fusarium wilt symptoms. The fumigant Basamid (dazomet) provided complete control of FOL race 4, although this product can only be used once every three years.



Lettuce Fusarium wilt



## Investigating the timing of transmission of carrot viruses to improve management strategies

**AHDB project code: FV 460**

**Project lead:** Adrian Fox, Fera Science

**AHDB contact:** Dr Dawn Teverson

Previous AHDB-funded research has revealed a high incidence of aphid-transmitted virus infections in carrots, including infections by previously unknown pathogenic viruses. In some cases, 100% of carrots tested from fields were carrying virus, often as multiple infections. These viruses can cause yield reduction but also reduce marketable yield through root deformation (e.g. splitting) and internal blemishes (root necrosis). Such a high incidence of virus infection implies that current management strategies may be insufficient to control aphid-transmitted viruses.

In addition to the willow-carrot aphid (*Cavariella aegopodii*), the peach-potato aphid (*Myzus persicae*) has been shown to be a vector of carrot red leaf virus and carrot yellow leaf virus. Before management strategies can be revised, it is important to confirm which species of aphid are driving virus transmission in the field. To do this, researchers from Fera Science Ltd and Warwick Crop Centre are working together to monitor the transmission of carrot viruses over time, through weekly sequential covering/uncovering of field plots of carrot. The aim of the project is to determine how virus transmission is related to the pattern of immigration by aphids. Analysis of results from the first year of the project is currently underway.

## Surveillance of pea crops for the presence of viruses

**AHDB project code: FV 459**

**Project lead:** Adrian Fox, Fera Science

**AHDB contact:** Dr Dawn Teverson

PGRO and Fera Science Ltd are working together to investigate the presence and impact of viruses in pea crops. The aim of this project is to develop a more effective, efficient approach to surveillance, using high-throughput sequencing, combined with conventional testing (PCR and ELISA), to determine the presence and incidence of viruses.

Focusing on peas, a crop which has not been directly surveyed for the presence of viruses for at least two decades, the project has already uncovered a well-characterised virus – turnip yellows virus (TuYV) – which has not been previously recorded in UK pea crops but has been recently reported from pea crops in Australia and Germany.

The viruses traditionally associated with pea crops, such as pea enation mosaic virus (PEMV), were present in three of the first fifteen crops tested, at levels ranging from <1% through to around 30%. By comparison, TuYV was found to be present in eight of the fifteen crops, at levels ranging from 2% to 93% incidence. TuYV causes major issues in oilseeds and brassicas, but the impact on pea crops is not yet known. Through the project, the yield impacts of the viruses identified in the study will also be investigated.





## Novel approaches to manage viruses in UK crops

**AHDB project code:** FV 461

**Project lead:** Dr Aoife O’Driscoll, RSK ADAS

**AHDB contact:** Sue Cowgill, Dr Dawn Teverson

This project is a comprehensive review of virus management research and solutions at a national and international level to identify control strategies that lower dependence on insecticides. It will benefit UK crop production in field vegetable, cereals and oilseeds, sugar beet and potato crops.

The project brings together information from scientific, commercial and web sources on virus management, including first-hand knowledge of problems and solutions. Furthermore, it means that information on existing and developing viral diagnostic tests, and testing facilities within the UK, is now available for each crop in a single place.

It identifies effective methods and treatments against virus infection and gives a prioritised list of research strategies based on current state-of-the-art knowledge in the UK and internationally.

With increasing losses of crop protection products, alternatives are urgently needed. This review gives a prioritised list of control options which are used successfully in the UK and abroad which should be further evaluated or validated under UK conditions and highlights research and knowledge gaps for UK virus management.

## Bacterial disease in UK crops

**AHDB contact:** Cathryn Lambourne

Diseases caused by bacterial pathogens continue to cause economic losses to growers, particularly in field vegetables, hardy nursery stock and protected ornamentals.

A new project to investigate the impact and control of bacterial diseases in UK crops is currently being commissioned. The work will focus on a number of areas to build knowledge of the sources of infection and look at a number of control mechanisms. These will include host resistance, healthy start and novel management options. Additional supporting work on control using conventional and biological product efficacy will be carried out within SCEPTREplus.

The majority of horticultural crop sectors are represented in the planned work. In the vegetable sector, the focus is on:

- Spear rot in broccoli
- Black rot of brassicas
- Coriander bacterial blight
- Parsley bacterial blight

The research will cover: producing high-health seeds and plants; understanding how infection spreads; the availability of resistance in current commercial varieties; inspecting the status of seed health; managing irrigation in propagation; and bacteriophage treatments for seeds and plants.



Spear rot on a broccoli head

## Pest Bulletin

**Project lead:** Dr Rosemary Collier,  
University of Warwick

**AHDB contact:** Dr Dawn Teverson

The AHDB Pest Bulletin provides growers with forecasts and up-to-date reports on most of the key field crop pests. It indicates periods when infestations are likely to occur, to help growers make informed pest control decisions. Data is collected from various locations around the UK, giving regional information, as well as providing historical data for year-on-year comparisons of pest numbers.

The Pest Bulletin provides day degree forecasts for currant-lettuce aphid, lettuce root aphid and willow-carrot aphid and predicted dates for first, 10% and 50% activity of black-bean aphids.

Forecasting is a vital part of integrated pest management (IPM) and the Pest Bulletin also provides day degree forecasts for the start of cutworm (turnip moth) flight activity and outputs from the cutworm risk model. In addition, forecasts are produced for carrot fly, large narcissus fly and pollen beetle.

As well as the sampling and forecasts provided for a range of pests, the bulletin includes monitoring information from Warwick Crop Centre at Wellesbourne for more than 20 species, including cabbage root fly, carrot fly, pollen beetle, flea beetle, bean seed fly, willow-carrot aphid, small and large white butterfly, turnip moth, silver Y moth and diamondback moth.

Migrant moths are a particular challenge, for which the Pest Bulletin provides a range of real-time data. Diamondback moths are recorded by UK brassica growers using pheromone traps. Likewise, citizen science information on sightings of diamondback moth and silver Y moth in several Northern European countries is available to help predict moth invasions.

The Pest Bulletin is also used as evidence of specific issues for regulatory bodies and was recently used to support an emergency 120-day authorisation for 'Benevia 100D' on leafy brassicas.

The AHDB Pest Bulletin alert is sent out weekly during the growing season, and reports are hosted on [syngenta.co.uk/ahdb-pest-bulletin](http://syngenta.co.uk/ahdb-pest-bulletin). If you're not currently getting the email alerts and would like to, please contact [comms@ahdb.org.uk](mailto:comms@ahdb.org.uk)

## Integrated management of cabbage stem flea beetle

**AHDB project codes:** 21120049, 21120064, 21510042

**Project lead:** Steve Ellis, ADAS; Stephen Penfield, JIC; Tom Pope, HAU

**AHDB contact:** Charlotte Rowley

Cabbage stem flea beetle (CSFB) is a major pest of oilseed rape and in recent years has become more difficult to manage, with widespread pyrethroid resistance emerging.



This in turn has impacted upon vegetable brassicas, as high numbers of CSFB are being seen across the country. AHDB Cereals & Oilseeds currently fund three research projects focusing on this problematic pest.

The first is a three-year project which aims to develop an IPM strategy for CSFB in oilseed rape. Researchers have conducted a meta-analysis based on 14 years' worth of trial data to uncover some of the risk factors surrounding CSFB damage. Alongside this, the team at RSK ADAS Ltd. have done trials looking at the impacts of variety and seed rate and have been exploring alternative methods of control, including winter defoliation of crops to reduce larval numbers and trap cropping of adults using volunteer oilseed rape.

Further work is being done by PhD researchers at John Innes Centre and Harper Adams University. The first of these projects is looking to uncover a genetic basis for CSFB resistance in oilseed rape, and the second is seeking novel methods of control using biopesticides.

It is hoped that through this work, the control of CSFB will become more manageable, leading to reductions in populations. The research will also uncover more information about flea beetle biology and ecology, which could have wider implications for the management of brassica flea beetle species.

## Major shake-up of weed investment required

**Project lead:** RSK ADAS, AHDB

**AHDB contact:** Joe Martin

The way the UK invests in weed management needs a radical rethink if weeds are to be kept below economically damaging levels. This was one of the key findings from a major cross-sector review, which also concluded that the industry is in danger of forgetting lessons from the past.

Commissioned by AHDB and BBRO, the review explored weed management in horticulture, cereals, oilseeds, potatoes, sugar beet, legumes and grassland systems. Despite decades of research and investment, the authors



warned that a great deal of knowledge, especially on basic weed biology, is at risk of being lost to the industry, simply because essential reference sources are not being archived effectively.

Joe Martin, AHDB senior crop protection scientist for weeds, said: “The UK has been at the forefront of weed research in the post-war era, laying the foundation for management. However, the legacy of this research is being eroded. Key reference sources, such as those published by Defra and its predecessor, MAFF, are gradually being lost.”

In addition to identifying, protecting and translating weed management information, the RSK ADAS Ltd.-led review team highlighted that information can become trapped within high-science, peer-reviewed journals. As a result, it recommended that a mechanism be identified to get essential information out to farmers and growers faster.

A review of global weed management tactics culminated in one of the most comprehensive assessments of non-chemical control methods to date. Mechanical, electrical and thermal weeding techniques were found to have great potential. Genomic approaches, to disrupt weeds and to develop herbicide-tolerant crops, were also earmarked as avenues of exploration.

### ‘Knowledge-intensive’ approach

The future of weed control is likely to require a far more ‘knowledge-intensive’ approach, according to the review’s authors. This is because weeds need to be tackled across the whole system, rather than within individual crops. Such system approaches will see a greater dependence on the use of cover crops, minimum cultivation systems, inter-row management, inter-cropping, drone technology and weed maps.

Lynn Tatnell, one of the review’s authors at RSK ADAS Ltd., said: “An in-depth knowledge of the life cycle of weeds is needed to make the most out of non-chemical control methods. Planning and patience are required too – the solutions need time, with results being seen across the wider rotation and not just within one season.”

Investment in weed monitoring also needs to be sustained to allow growers to react to population changes. This includes the funding of basic research to investigate, for example, how weeds spread (e.g. via organic materials) and how herbicide-resistant populations can be tracked and managed.

Currently, herbicides are the main method of control across cropping sectors. As chemistry will continue to play an essential role, it was recommended that substances to support it be developed, such as adjuvants and soil stabilisers. Improved targeting of herbicides was also cited as key, including the development of weed thresholds for patch spraying. Alternative chemistry, including biopesticides, was also considered to have strong potential, especially in horticultural crops.

The full review can be accessed via [ahdb.org.uk/weedreview](http://ahdb.org.uk/weedreview)





## Monitoring and managing insecticide resistance in UK pests

**AHDB project codes:** FV 344a (Cross-sector: C&O 21510015; Potatoes 1120037; Horticulture 31120004)

**Project lead:** Dr Steve Foster, Rothamsted Research

**AHDB contacts:** Sue Cowgill, Dr Dawn Teverson

This project aims to make the most of the shrinking number of effective pesticides available to UK growers. This is being achieved by developing appropriate insect management strategies and providing robust scientific support to the regulatory decision-making process.

By monitoring the sensitivity of key pest species to insecticides, it is possible to find out which actives will work and which will not. This is being done primarily using bioassays on live insect samples. This approach is most effective because it provides an early indication of any reduced sensitivity to insecticides where resistance is not currently seen, in anticipation of the evolution of economically significant resistance that would lead to control failures.

Insect sampling has been conducted across the UK through the continued involvement of several stakeholders, including agronomy and agrochemical companies and subcontractors. For some established resistance mechanisms, Rothamsted Research is also continuing to use DNA-based diagnostics, which are specific for the mutations associated with particular resistance traits. Samples of peach-potato aphids (*Myzus persicae*) are being screened for their response to a range of insecticides.

The project team, headed by Dr Steve Foster, is also screening other important aphid pests: potato aphids, currant-lettuce aphids, willow-carrot aphids, grain aphids, bird cherry-oat aphids and rose-grain aphids, when suspected insecticide control failures occur. Baseline bioassay data is being established for the relevant insecticides.



Onion thrips

The project also now includes resistance monitoring for other important UK insect pests, including cabbage stem flea beetles, pea and bean weevils, pollen beetles, diamondback moth, silver Y moth, asparagus beetle and onion thrips.

A good example of the value of this work can be seen with diamondback moth, a serious pest of brassicas. In 2018, six diamondback moth samples (collected from the main brassica-growing areas of England and Scotland) contained pyrethroid-resistant moths. However, there was no evidence of resistance to diamides and spinosad as there was 100% control in these bioassays. This resistance profile was the same as seen in diamondback moth samples in 2016 and 2017. This vital information has had significant impact within industry and helps to avoid the inadvertent spraying of beneficial insects.



Diamondback moth caterpillar



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## Labour and automation

### Smart ideas to labour challenges

**Our SmartHort campaign to help horticulture address the challenge of accessing affordable labour continues to grow, with the launch of three new Strategic Centres and a challenge to help bring automated solutions into the production line.**

While crop protection research remains at the heart of AHDB activity, we understand that access to affordable labour is one of the biggest concerns.

The SmartHort programme was launched in 2018 to increase industry resilience to labour challenges, from rising wage costs to difficulties in recruiting and retaining staff. Changes in the language and dexterity skills of staff now applying for work in the sector have also added to the challenge. SmartHort has two clear strands: to look at improving management practices for the existing workforce; and to identify new technologies and innovation, such as robotics and automation, which could provide longer-term solutions.

#### Smart labour management

Management techniques such as ‘Lean’, Champion and Continuous Improvement can improve labour efficiency in businesses of all shapes and sizes and can be applied throughout the production system, from picking to packing. These techniques are about helping businesses to get the best out of the workers that they have.

To help demonstrate the benefits of implementing ‘Lean’ and efficiency techniques, and to support growers bringing them into their own businesses, we have launched three new Strategic SmartHort Centres.

The centres are located in Cambridgeshire (Volmary), Herefordshire (Haygrove) and Perthshire (Thomas Thomson). Each business has offered to implement ‘Lean’ to improve their labour management and demonstrate their progress with local growers as a live case study for productivity improvements.

Local businesses attending the three workshops at each centre are also being guided by training specialists Fedden USP to develop their own labour-efficiency plans. Businesses that invest time and effort to complete and implement the activities covered during the workshops should expect to see labour and productivity improvements of between 25–40%.

Neil Fedden, the productivity consultant running the strategic centres, explains: “We are taking the host centre, as well as the workshop attendees, through the ‘Lean’ process, which is really about identifying, and then cutting out or reducing, those activities that don’t add value to the business. When you reduce waste and use your resources more efficiently, you can add significant value to the business.”



The workshops cover:

- Process mapping and waste identification
- Practical problem-solving using a technique called Plan, Do, Check, Act
- Encouraging continuous improvement across the whole organisation
- Visual management boards and metrics to check improvements have worked

Francis Mizuro, operations manager of Volmary Ltd, said: “We’re delighted to have been chosen as one of the first SmartHort Centres. We’re very excited to bring the investigative trial work to our site and to be a key part of the development of systems and technologies that will help both the industry as a whole and our own business.”

## Smart technology

The ultimate solution to the shrinking pool of available labour is automation. Our survey in 2017 showed over 84% of businesses planned to invest in automation or robotics to offset labour challenges. However, no growers yet have end-to-end automated processes. This is most likely due to a combination of poor fitting ‘off-the-shelf’ solutions for the diverse production systems many growers work with and an unfavourable cost/benefit ratio for the current trading climate.

To help accelerate automation in horticulture, AHDB launched the pioneering SmartHort Automation Challenge. This offered a UK horticulture business the opportunity to work collaboratively with experts to deliver an applied automation prototype solution to their production system. This new initiative, managed by experts from the WMG department of the University of Warwick, will adapt and assemble off-the-shelf solutions to function effectively within live commercial systems.

In response to our call, we received ideas from 22 different growers across horticulture, ranging from correcting the position of pots on potting lines for smoother operation, through to developing smarter irrigation booms for precision application of water and pesticides, and autonomous guided vehicles (AGVs) in different nursery situations. Solving any of these problems would reduce labour inputs and improve productivity for each business.

Thanks to the large pool of postgraduate students at WMG, this initiative will additionally address several projects, by feeding the challenges set by growers through to student projects.

At the time of writing, final decisions were being made, but the current lead project, based around AGVs, has the potential to meet the needs of three different businesses which all posed similar challenges. We also expect the final solution to be suitably adaptable so that it can meet the needs of a large number of horticultural businesses.

Finally, our SmartHort 2019 conference in March explored the future of automation and robotics, with the aim of driving innovation into horticulture. Guest speakers from around the world shared some of the most impressive technological developments that could change the way you grow. If you missed the conference, you can watch it again online.

To find out more about the SmartHort campaign and how it could help your business, visit [ahdb.org.uk/smarthort](http://ahdb.org.uk/smarthort) or contact [grace.emeny@ahdb.org.uk](mailto:grace.emeny@ahdb.org.uk)

## Vegebot: Delicate robotic handling of fresh produce for harvesting

**AHDB project code: CP 172**

**Project lead:** Fumiya Iida,  
University of Cambridge

**AHDB contact:** Jim Dimmock

The Vegebot project is a research collaboration between the University of Cambridge and G’s Growers to develop robotic harvesting systems for fresh produce, primarily iceberg lettuce. AHDB is supporting the project through Luca Scimeca’s PhD studentship, aimed at developing sense and touch capabilities to improve robotic handling of delicate vegetables and other fresh produce.

Following Luca’s work in the first year of his PhD, in which he successfully developed and demonstrated a robotic system for peeling off the outer leaves of iceberg lettuces, he is now developing methods of assessing crop quality.

One crucial aspect of fresh produce quality is ripeness. In some cases, such as strawberries and bananas, visual cues are sufficient to make a suitably accurate judgement. In others, such as kiwis, blueberry or mango, there is little difference between the colour of ripe and unripe fruits, representing a challenge for robots.

The approach used by the Bio-Inspired Robotics Laboratory (BIRL) team to address this issue is haptics – technology that stimulates the senses of touch and motion, in this case used to assess produce without human interaction. The BIRL research team has designed a sensorised gripper to replicate human handling, palpating the fruit gently to measure the properties of the fruit’s pulp and skin and employing haptics to determine ripeness.

While initial laboratory work has focused on mangoes, the technology is robust and fully transferable to other crops and could be used, for example, to assess curd development in cauliflowers or to objectively measure the freshness of stored produce.

The project is based at the university’s Bio-Inspired Robotics Laboratory (BIRL) and is primarily funded by EPSRC, BBSRC and the Royal Society.



## Resource management

### Stop the rot

**AHDB project code:** FV 457

**Lead contact:** Dave Kaye, RSK ADAS Ltd.

**AHDB contact:** Georgina Key

UK cucurbit production is dominated by courgette and Halloween pumpkin, with an estimated market value of £29m and £15m respectively (Defra, 2018). Edible pumpkin represents a further £4.5m.

Blossom end rot (BER) is a wet rot that develops in fruit from the flower scar. It reduces marketable yields in courgettes. This project, *Calcium nutrition in cucurbits*, reviewed and evaluated the role of nutrition in reducing BER.

BER is linked to poor calcium uptake and distribution during fruit development, which weakens cell structure, increasing the risk of pathogen entry. Calcium is transported in water via the xylem, and once in cell walls, it is not easily recirculated. Dry conditions, poor root function and high humidity reduce calcium uptake and movement.

A range of methods is needed to manage BER.

- Keep soil pH between 5.5 and 7.5
- Apply foliar calcium sprays, particularly with boron and magnesium, if economical
- Spraying should be in dull, overcast weather, using nozzles that create a fine mist and even coverage
- Spray from first flowering until fruit maturation begins in courgettes; in pumpkins, sprays should continue until two weeks before harvest

Growers could consider alternative growing systems, e.g. using grafted plants or growing hydroponically.

### Soil Biology and Soil Health Partnership

The AHDB–BBRO Soil Biology and Soil Health Partnership is a five-year cross-sector programme of research and knowledge exchange, aiming to improve on-farm understanding of soil biology. It is also aiming to develop and validate a range of physical, chemical and biological indicators of soil health. These indicators are





being brought together in a 'soil health scorecard', which colour-codes results from soil assessments as red, amber or green, depending on where they fall in the expected range for UK soils and climatic regions. Red means there may be a risk to crop production, or to the environment in the case of some nutrients, and further investigation is required. Amber results are borderline and flag up that additional monitoring should be carried out, whereas green indicates that no action is currently needed.

Working with farmer and grower groups across the UK, the project team is getting feedback on the usefulness of this approach and the ease of interpreting the results, as well as validating the thresholds for some of the indicators in different soil types and production systems, including field vegetable production. Indicators being tested for routine on-farm monitoring of soil health are standard nutrient analyses (P, K, Mg), pH, soil organic matter, a visual evaluation of soil structure and earthworm counts.

Additional biological indicators of soil health are being researched at a series of long-term experimental sites; these include microbial activity and diversity, nematodes and mesofauna. While these are not currently ready for routine on-farm monitoring of soil health, work is underway to improve understanding of how soils can be managed in favour of beneficial soil biology.

Approaches for managing healthy soils include the application of organic materials or growing cover crops to increase biological diversity, both in the rotation and below ground. Ongoing trial work is investigating the effects of green compost and a cover crop mix (rye, vetch and phacelia) ahead of onions on soil health, crop yield and disease. Detailed grid sampling has also taken place at this replicated trial site as part of a PhD studentship looking at predicting crop disease from molecular assessment of the distribution and quantification of soilborne plant pathogens.

Understanding soil biological communities – including soilborne pathogens – can be challenging, but molecular techniques are revolutionising the way in which the functions and diversities of soil communities are investigated, through analysis of directly or indirectly extracted DNA. Another PhD studentship within the Soil Biology and Soil Health Partnership is using high-throughput molecular techniques to measure changes in soil biology in response to long-term management practices. The research is aiming to improve understanding of how various practices can encourage beneficial or disease-suppressive soil microbial communities across a rotation.

For further information, and examples of the soil health scorecard, visit [www.ahdb.org.uk/greatsoils](http://www.ahdb.org.uk/greatsoils)



## GREATsoils Rotations Partnership

**AHDB project code:** 91140001

**Lead contact:** NIAB

**AHDB contact:** Alice Sin

This integrated research programme for soils and water aims to optimise the agronomic and economic performance of rotations that include potatoes and root vegetables. The project is concentrating on the physical properties of soil that affect productivity and will lead to better quantification of soil quality and resilience.

A combination of on-farm trials led by researchers and growers are investigating the effects of different rotation types (e.g. length and composition), soil amendments, cover crops and cultivation strategies on key soil metrics and rotational sustainability for a range of soil types used for crop production in Great Britain.

Running parallel to the field experiments is a comprehensive survey that is gathering information on the performance of crops in relation to inputs (e.g. organic amendments, fertiliser use and irrigation) and in terms of land use within the rotation (e.g. previous cropping and use of cover crops).

Other research is exploring the interaction and response of root systems of different crops and cultivars (e.g. in carrots and parsnips) to soil structural differences and water availability as a result of soil management practices, and the impact on crop productivity.

Finally, the project is applying existing precision-farming technologies, imaging systems and models to develop tools to support the management of soil resources – such as electromagnetic induction (EMI) scans of soil to improve understanding of some of the causes of variation in crop yield and quality. Novel spectroscopic techniques to establish the chemical composition and quality of organic matter are also being investigated.

### Results so far

About 70 crop surveys have been completed, covering a wide range of soils, climatic conditions and rotation types.

Direct yield benefits have been measured from the use of cover crops and organic amendments. Results so far suggest that these were associated with small improvements to bulk density, porosity and aggregate stability.

Both tracked and wheeled tractors caused similar amounts of soil damage. Soil compaction could be reduced by reducing tractor tyre pressures during seedbed cultivations.

### Next steps

Growers' data will be analysed for both agronomic performance and the economics of rotations.

A model of compaction risk from machinery loading is being developed for soils in Great Britain. Currently, the tool has information available for Scottish soils, although users can input their own soil type manually into the Terranimo® model, which is available at:

**[www.terranimodel.com](http://www.terranimodel.com)**



## Transition to responsibly sourced growing media

**AHDB project code:** CP 138

**Project lead:** Barry Mulholland, RSK ADAS Ltd.

**AHDB contact:** Wayne Brough

Defra's '25 Year Environment Plan' has a target to phase out peat use in horticulture by 2030. The aim of this project is to develop a model to predict how different raw materials, such as coir, wood fibre, bark, green compost and other novel materials, would behave in growing media mixes. The mixes were then tested on nurseries across multiple crops (field vegetables, herbs, mushrooms, ornamentals and soft fruit) to see if the model worked. The physical properties of media, such as available water, dry bulk density and particularly air-filled porosity, were found to accurately predict how new mixes (prototypes) would behave on nurseries.

### Results so far

Trials were carried out on Chinese cabbage 'Kaboko' and spring cabbage 'Caraflex'. In each case, plants grown in prototype mixes were compared with plants grown in the standard growing media mix used by the nursery. There was no notable difference in germination rates.

Fresh and dry weight, plant height, root development and visual indicators such as leaf colour and fullness were all

used to assess crop quality. In both Chinese and spring cabbage, a prototype (mix one) performed well, producing plants of very similar quality to those grown in the nursery's standard mix. The prototype contained materials that retain moisture well but provided suitable air-filled porosity, helping root development in the plugs. Spring cabbage also grew well in a further prototype (mix six).

Overall, younger crops (such as herbs and propagated cabbage) were much more sensitive to changes in growing media than older, more established crops (such as ornamental shrubs).

Experiments putting different media mixes through tray fillers and potting machines were carried out alongside the field trials. While some mixes got caught up (e.g. wood fibre which can be very fibrous), most of the mixes went through the machinery smoothly. The experiments worked out the proportion of wood fibre which can be included in a blend so that it will smoothly go through tray fillers and potting machines.

The project team is also exploring how to make the model commercially available. The main target audience is growing media manufacturers; however, it is hoped that the model will also be available to interested growers.

The model and trials should give confidence to growers that the process of identifying new, more sustainable alternatives to peat can be fast-tracked and that high-quality plants can be grown in new growing media mixes.



Chinese cabbage



# Sustainable soil management for asparagus

**AHDB project code: FV 450a**

**Project leads:** Dr Rob Simmons, Dr Sarah De Baets and Lucie Maskova, Cranfield University

**AHDB contact:** Kim Parker

Conventional operations associated with UK asparagus production, such as annual re-ridging, spray operations and harvesting (foot-trafficked and/or hand-harvested using picking rigs) can result in progressive and severe compaction of inter-bed wheelings. Subsoiling operations to alleviate compaction and annual re-ridging can damage storage roots and increase crop susceptibility to crown and root rots (CRR) caused by *Phytophthora* and *Fusarium* species. Both root damage and crown and root rots are known to contribute significantly to yield decline and reduced stand longevity. In the UK, over a 10-year cropping cycle, asparagus decline largely attributed to CRR can result in up to 60% loss of plant stand, amounting to c.£16m in lost revenue per annum. A 10% reduction in yield losses due to CRRs would amount to a saving of >£1.6m to UK asparagus growers per year.

In April 2016, replicated long-term field experiments were established at Gatsford Farm, Ross-on-Wye, within a 4.5 ha asparagus field. Asparagus 'A' crowns of both Gijnlim and Guelph Millennium varieties were planted in April 2016. The overall aim of project FV 450/FV 450a

is to develop and share a suite of best management practices to facilitate long-term sustainable profitability and environmental protection.

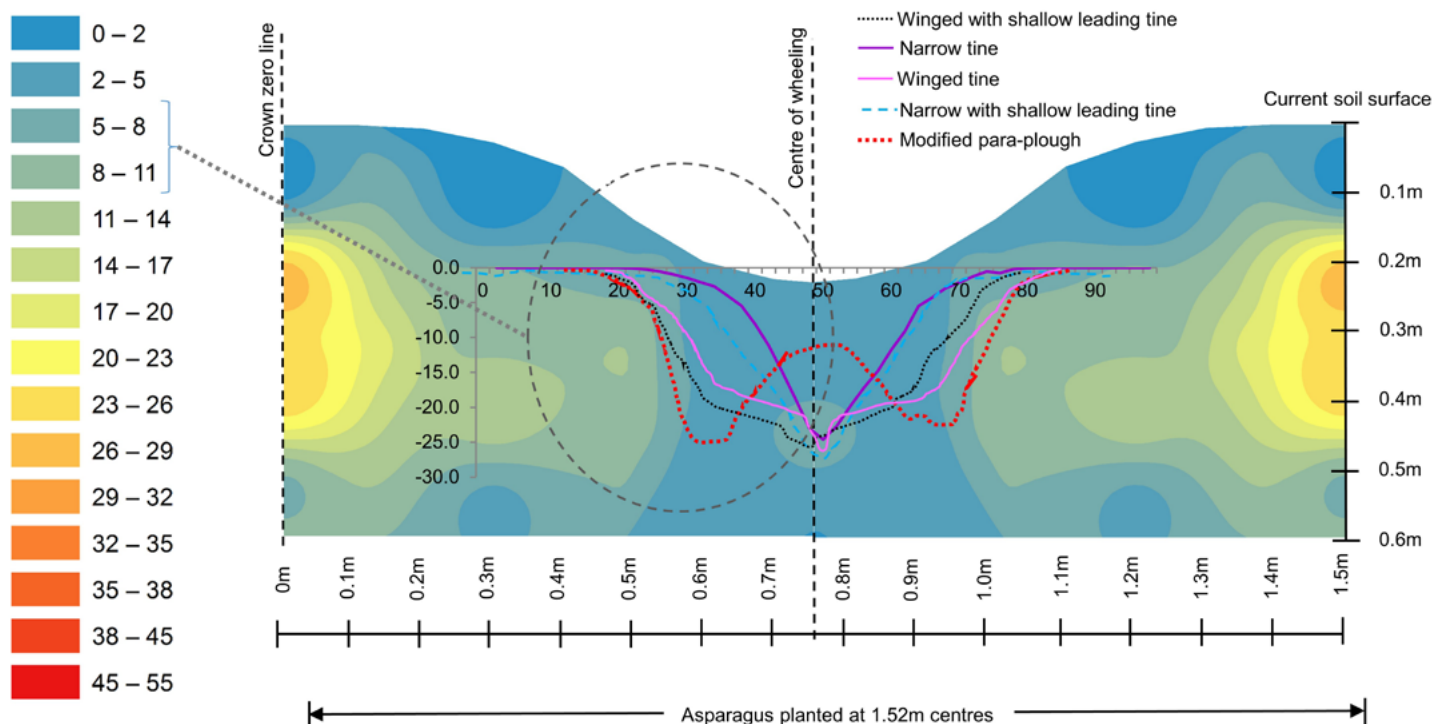
Key results from the long-term field trial indicate that:

- In 2018, for both Gijnlim and Guelph Millennium, if ridging tines disturb soil at 0.15–0.30 m depth, 0.3 m and 0.6 m from the crown zero line, there is a risk of damaging c.2–6% and 2–5% of total plant root biomass respectively
- However, yield data indicates that for both two-year-old Gijnlim and Guelph Millennium, re-ridging does not result in a negative effect on yield
- Varietal yield results indicate that Guelph Millennium is associated with between 16–31% significantly lower yields compared with the equivalent Gijnlim treatments
- For the pre-2019 harvest, no significant differences in storage root carbohydrate (CHO) levels were observed between treatments. Across all treatments, storage root (CHO) values ranged from 507–631 mg g<sup>-1</sup>. This is within the upper target range of CHO for optimum harvest
- Significantly higher storage root CHO levels were observed for Gijnlim as compared with Guelph Millennium treatments, with mean values of 518 and 600 mg g<sup>-1</sup>, respectively

## Grower B Field 1

**Total Root Biomass (TRB) %**

Year Planted	Variety	Establishment method	Row spacing (m)
2016	Gijnlim	A Crowns	1.52



\*Source: Niziolomski et al. (2-16) Tine options for alleviating compaction in wheelings. Soil and Tillage Research, Vol. 161, pp 47-52. Note: Horizontal axis indicates the mean horizontal disturbance (cm); Vertical axis indicates the mean vertical disturbance (cm)



The 2019, asparagus root architecture, CHO and yield data are currently being analysed and will be reported in the 2020 Annual Report

Results of a wider grower survey of asparagus roots conducted in 2018 indicate that annual re-ridging has the potential to damage between 5–14% of the total root biomass, depending on variety, age of stand and distance between wheeling centres. This has significant implications for the risk of CRR and long-term stand longevity.

In order to prevent storage root damage through re-ridging or subsoiling operations, growers should undertake exploratory root profile distribution surveys prior to commencing re-ridging and/or subsoiling operations. A factsheet and guidance video, 'Asparagus root coring', can be found at [ahdb.org.uk/knowledge-library/asparagus-root-growth](http://ahdb.org.uk/knowledge-library/asparagus-root-growth)

## Water resources review

Restrictions on abstraction of water and spray irrigation during the 2018 and 2019 growing seasons provide a glimpse into the difficulties that the sector may increasingly face in the future. Lower than average rainfall combined with hot weather in summer increases irrigation need at precisely the time when the environment can least provide it. Low winter rainfall in 2018 meant that water stored in growers' reservoirs was less than ideal. Groundwater levels also did not recover to average expected levels for the start of the season. These factors raise questions about prospects for the 2020 irrigation season. The pattern of rainfall over the coming weeks and months will provide some indication, but another year of low winter rainfall would be of concern. The AHDB WeatherHub can be used to track the current situation and growers can compare this with historical data for the time of year – [ahdb.org.uk/weatherhub](http://ahdb.org.uk/weatherhub)

Long-term river flow forecasting is being developed by researchers at the Centre for Ecology and Hydrology for use by regulators and the water industry. An experimental forecasting system is available for 300 catchments. Although this won't predict drought, information on the likelihood of Hands off Flow conditions could be helpful for growers to assist in planning. Anyone willing to discuss the potential use of forecasting available should contact [nicola.dunn@ahdb.org.uk](mailto:nicola.dunn@ahdb.org.uk). The system is still under development and feedback from growers will help researchers understand growers' needs and will help shape the system.

AHDB water work focuses on creating resources using existing information, rather than investing in new research. Information and guides recently created to explain the drought and water availability situation can be found at [ahdb.org.uk/weather](http://ahdb.org.uk/weather). While new research may not be necessary, there may be an opportunity to test new ideas through the demonstrations at Strategic Centres. For example, the Strategic Potato Farm (North) trialled trickle irrigation against spray irrigation in 2019. Such trials could be replicated for field veg crops, giving growers a chance to consider the practicalities, together with potential financial costs or savings. Perhaps there are questions on drought tolerance or irrigation strategies when water is restricted? Growers can send ideas for work to [nicola.dunn@ahdb.org.uk](mailto:nicola.dunn@ahdb.org.uk) or discuss them at grower meetings.

If you already abstract water for trickle irrigation and want to continue to do so next year, remember that you must have a validated application with the Environment Agency by the deadline of 31 December 2019. There is a hotline service to help fill in the application forms – 03708 506506.







# Production systems

## Horticulture Strategic Centres for Field Vegetables

**AHDB contact:** Dr Dawn Teverson

Launched this year, the Strategic Centres for Field Vegetables will showcase the latest ideas, science and technology to improve integrated pest management (IPM) strategies. The trials have been selected by growers.

The funding will also give continuity to the variety evaluation trials for brassicas, carrots, onions and vining peas. These trials provide independent performance evaluation of yield, quality, shelf life and storage potential of the four crops and are the reference used by growers for selection of varieties. The use of appropriate varieties is the cornerstone of good IPM.

Trial sites are located around the UK and are all on growers' farms and typical of the usual growing conditions for each crop.

### Brassicas

Selecting an appropriate brassica variety for the regional growing conditions and intended market is very important, with growers basing decisions on factors such as tolerance to diseases, harvesting date, market requirements and uniformity of maturity and yield.

Continuity of supply can be managed by growing a range of cultivars with different maturity times. There are new cultivar introductions most years, with at least 25–30 different cultivars grown commercially by growers to cover the harvesting period, often with at least three cultivars overlapping the same harvest window to ensure supply. Only five cultivars survived between 2007 and 2017, with

the remainder being superseded by new and improved cultivars. This highlights the need to continue to evaluate new cultivars alongside existing ones to ensure that yields, quality of product and continuity of supply are maintained throughout the harvest period.

Established variety trials are conducted by Duchy Cornwall, with an annual results factsheet produced for growers. Additional brassica demonstrations are being held in Lincolnshire.

Additional trials this year included diagnostics work with growers in Cornwall. Demonstrations in Lincolnshire include herbicide screening on cauliflower, kale and collards, insecticide screening for aphid control, and a fungicide timing trial using new diagnostics.

### Carrots

The Carrot Demonstration Day, organised by the BCGA, in October is an annual event which is usually attended by over 200 visitors, exhibitors and seedsmen – just about the whole UK carrot industry.

In 2019, there were 75 different varieties from eight different seed companies, which will all be tested for breakage characteristics. In addition to the trials, there were trade stands showcasing products and services ranging from crop protection, to machinery, and including packhouse grading and cooling equipment.

In 2018, British Carrot Growers Chairman Rodger Hobson said, "This unique event brings together growers, packers and the wider carrot industry to see the latest developments in varieties and machinery. It has something for everyone, and with the numbers attending, it shows how important it is for UK carrots. In my opinion, this is the best event we have ever held."

An additional trial this year will see work on the impact of seed size, sowing depth and crop density on yield and quality.





## Vining peas

The Legume Industry Panel has identified varietal selection as an important element of crop production and need a guide to the performance of varieties in areas typical of pea production. Commercial programmes are based on the use of a minimum of four varieties and it is more likely that six or seven will be used to give a spread of maturity and to allow production for special markets.

Varietal characteristics affect yield, quality (colour, flavour, size and texture), ease of harvesting, disease susceptibility, maturity and ease of integration in the harvest programme.

AHDB funding allows a duplicate trial to be grown on a representative soil type and location near Holbeach, in South Lincolnshire.

To map the distribution of bean seed fly in the UK, PGRO has updated its app to allow growers and agronomists to record the incidence of bean seed fly larvae in any crop.



## Onions

The data generated in AHDB-funded onion trials provides independent assessment of the growth habit, yield, quality and storage potential of new onion varieties, propagated from seed, to meet grower requirements, i.e. high marketable yield, disease resistance, good quality and storability. The data generated is the only independent, verifiable, comparable record of onion storage potential.

Relatively small differences between varieties can have a significant impact on profitability. Independent, relevant results are essential if growers are to maximise their profits. The wrong variety choice or use of incorrect husbandry on an otherwise suitable variety can be costly.

Bruce Napier, project lead from NIAB EMR, said: “One of the primary objectives is to assess the storage potential of new varieties. There’s nothing more soul-destroying than seeing all of your efforts go to waste, so it is vital that the harvest yield is maintained in store. A 40% difference in storage performance would equate to the equivalent of 24 t/ha extra lost in the poorest-performing varieties.”

An annual factsheet is published updating industry with the most recent results.

Further work for onions includes spacing trials in order to increase crop size in line with supermarket specifications.

“ One of the primary objectives is to assess the storage potential of new varieties ”

**Bruce Napier**  
Project lead - NIAB EMR





## Post-harvest

### Herbs flavour: determining the basis of variation in flavour

**AHDB project code: FV 455**

**Lead contact:** Ana Cristina Contente, Carol Wagstaff, University of Reading

**AHDB contact:** Kim Parker

Culinary herb consumption has increased, in part due to salt reduction campaigns which have resulted in food manufacturers and consumers seeking alternative ways to enhance flavour. This trend makes it important to understand the chemical profile of herbs and causes of variation, since flavour is a key attribute of these plants.

This project will provide UK herb growers with information to help them understand the causes of flavour variation in their products, consequently helping to deliver a more consistent product throughout the year. It aims to clarify the chemical and sensory profile of three culinary herbs and comprehend how season, agronomy, cultivation systems and environment influence flavour.

For this project, three herbs were selected: rosemary (*Rosmarinus officinalis*), coriander (*Coriandrum sativum* var. Cruiser) and basil (*Ocimum basilicum* var. Sweet Genovese). For each herb, a variety of production systems are being analysed (pot-grown, soil-grown under polytunnel protection, outside-field-grown and hydroponic production under glass) across different

locations in the UK. Fresh samples are being used for chemical analysis by measuring the volatile chemicals present in each sample's headspace. The experiment is repeated at different times of the year to study the impact of seasonal variation.

Complex and diverse aroma profiles were observed for each herb. There were significant differences between production systems: pot-produced rosemary and coriander had lower amounts of key compounds and were significantly different in the relative abundance of different compounds, compared with the other types of production. Looking at basil, significant differences were associated with geographical location: samples grown further north showed significantly lower amounts of volatiles compared with basil produced in the south.

We now have a better understanding of what the characteristics are of the compounds found in each herb, regardless of location or production type. This has been achieved by linking the chemical profiling to sensory panel assessment to fully characterise the herbs at the point of consumption. Volatiles detected in rosemary contributed to menthol and pine notes, while in coriander the compounds detected contributed to soapy and cut-grass notes. Basil volatiles contributed to sweet, clove and cut-grass notes. However, there are many variables involved in herb production, such as soil type, irrigation and fertilisers, which can all influence the chemical profile. Further analysis is needed to gain a clear understanding of how pre-harvest variables influence the flavour profile and relate this to consumer perception. Later in the project, consumer panels will help link chemical profiles to consumer preferences.



## Worried about chlorate and perchlorate in produce?

**AHDB contact:** Grace Choto

Chlorate and perchlorate are contaminants that arise when plants absorb chlorine-disinfected irrigation water through the roots during crop growth. Further post-harvest uptake occurs when produce is washed with chlorine-disinfected water and when it comes in direct contact with chlorine-disinfected equipment and surfaces. The two contaminants inhibit iodine uptake by the thyroid gland, interfering with its function. Thyroid hormones are important in human metabolism.

Chlorine and its compounds are used to disinfect water, equipment and surfaces in food production to ensure that foods are microbiologically safe to eat. The European Commission (EC) has been deliberating internally for some time on setting maximum residue levels (MRLs) for chlorate and perchlorate. At the time of writing, the EC intends to set an MRL of 0.05 mg/kg for perchlorate in most fruits and vegetables, with Cucurbitaceae and kale being set at 0.1 mg/kg and leafy vegetables and herbs at 0.5mg/kg.

With regards to chlorate, AHDB submitted UK grower 'chlorate in fruit and vegetables' data to the EC in November 2018, with the request that they consider it when proposing MRLs. The Commission took the data and that from other European Member States into account, as well as feedback received from stakeholders in response to the EC January 2019 chlorate MRLs consultation. The latest EC chlorate MRLs draft shows upped MRLs which, based on the data that AHDB holds, should be achievable for most crops. This appears to be good news for growers, but it is too early to celebrate, as both chlorate and perchlorate MRL proposals will need to be voted on by EC Standing Committees. AHDB will alert growers when the EC publishes final MRLs.

Growers should therefore continue to ensure that all fresh produce is safe to eat. Disinfectants must be used according to manufacturer instructions. Where high levels of contaminants are found as a result of government monitoring, it will be determined if the levels pose risks to the consumer. As far as AHDB is aware, no business has been prosecuted as levels found to date have been deemed as not posing risks to public health.

For more information, please contact [grace.choto@ahdb.org.uk](mailto:grace.choto@ahdb.org.uk)

## Marketing the #WatercressChallenge

In 2019, the AHDB Consumer Marketing Team were asked to help promote watercress to consumers. Approval for this activity had been granted by the Field Vegetables Panel.

Popular with an older audience yet relatively unknown by the young, AHDB aimed to raise awareness of watercress and encourage people to try it. A marketing plan was

produced which it was hoped could be replicated for other fresh vegetables.

Initially targeting a young, health-and-fitness audience, an engaging campaign was created that could also extend further.

Social media influencers on Instagram were asked to use watercress in a number of different dishes and share their experiences using the #WatercressChallenge. They passionately demonstrated the versatility of watercress through an array of colourful dishes and expounded its many health benefits. Their content really inspired followers, receiving many likes and shares, and it started lots of conversations.

Building on this momentum, the team reached out to journalists covering food, lifestyle and retail issues in the national press and radio, alongside sampling and a foodservice event where 65 people from the food industry received an eight-course meal in which each dish incorporated watercress as a key ingredient.

These #WatercressChallenge activities resulted in over 200 social media posts, delivering almost 3m impressions and 6.27m circulation in print, radio and online, including a double-page spread in The Telegraph.

A key aspect of the campaign was that growers got involved, helping with each activity, and this continued enthusiasm for the #WatercressChallenge is now central to their own ongoing marketing and social media activities.







## Project round-ups

**AHDB project code: CP 120** – Understanding the impact of phylloplane biocontrol agents on insects

**Term:** October 2016 to September 2019

**Project leader:** Robert Jackson, University of Reading

Aphids are major agricultural and horticultural pests that thrive in controlled-environment conditions. Decreasing pesticide availability, and reliance on suboptimal biocontrol, means there is a need to explore alternative approaches to aphid control. Previous work showed *Pseudomonas poae*, found on plant leaves (the phylloplane), to have the highest kill rate, reducing aphid populations on plants by 70%, as well as deterring them from colonising the plant.

This project used experimental evolution to progress the bacteria into a more efficient biological control agent. This process involves identifying the beneficial traits of the bacteria we want to enhance or develop, such as how lethal it is and whether biofilms – aggregations of bacteria that are able to stick to surfaces and form communities – can be formed, and selecting for these traits over several generations of bacteria, during a period of several weeks. The trade-offs between resulting traits were then examined.

Unfortunately, when this species of bacteria is evolved to form biofilms, it becomes less lethal to aphids and has poorer survival on the crop. The species is not suitable for developing into a commercial product, but this project shows that experimental evolution is a useful tool to investigate these new avenues.

**AHDB project code: CP 177** – Manipulating growth rates to reduce in-field leafy salad and vegetable crop variability

**Term:** October 2018 to March 2022

**Project leader:** Jim Monaghan, Harper Adams University

**PhD student:** William Johnson, University of Warwick

Uniform growth during the transplant-raising and field-growth stages of vegetable crops like lettuces and brassicas is essential to allow single-pass harvesting (lettuce) or a minimal number of passes (brassica) and reduce crop waste. Variation in growth of each individual plant is affected by a number of factors, including water availability, light levels and soil properties. Technology can now allow growers to monitor crop development at an individual plant level and for treatments to be applied to local areas or individual plants to try to reduce crop variation. This project is contributing to developing understanding and commercial treatments to reduce





variation in transplant size at planting, and to manipulate the growth of plants in the field post-transplanting to increase crop uniformity.

In the first year of this project, PhD student William Johnson has been looking at variation during the early growth stages, starting from seed germination, and developing image analysis to map variation in transplant trays. Trays produced in control conditions, and in commercial conditions, will be monitored to study the possible causes of variation, including light and irrigation, and this should lead to new approaches to reduce variability in lettuce and brassica transplants. In the next years, the student will develop work towards manipulating plant growth post-transplanting.

**AHDB project code:** CP 175 Turnip Mosaic Virus

**Term:** 01/10/2016–30/09/2019

**Project leader:** Guy Barker,  
University of Warwick

Turnip mosaic virus (TuMV) is a member of the largest family of viruses, Potyviridae, and causes significant losses in brassica production worldwide – affecting both yields and quality of produce. Although resistance to TuMV has been found in wild varieties of *Brassica rapa*, there has been no resistance found yet in *B. oleracea*.

The project aims to generate resistance to TuMV in *B. oleracea* by using gene editing to mimic the resistance

seen in *B. rapa*. The issue is that most brassica varieties are not transformable, due to the fact they are difficult to regenerate into full flowering plants after callus formation. Several approaches were used to overcome this. Firstly, to test the gene-editing tools were working correctly, single-cell protoplast assays were developed, which allow for quick testing without having to go through the regeneration process. Secondly, several novel techniques were tested which would allow for improved regeneration, or skipping of the regeneration step all together.

Knowledge learned here can be employed by plant-breeding companies so they can ascertain where to focus resources without being diverted by initially promising targets which prove, after many years of breeding, to be disappointing. In addition, it offers the potential to respond to growers' needs more quickly and integrate beneficial traits into elite lines.

“ Knowledge learned here can be employed by plant-breeding companies so they can ascertain where to focus resources... ”

**Guy Barker, University of Warwick**  
Project lead - CP 175 Turnip Mosaic Virus



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