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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headlines

- Calcium and boron exhibited negative and positive concentration gradients respectively from the stalk, mid-section and to the blossom end in fruit exhibiting Blossom End Rot.
- Evidence from the literature review suggests that calcium deficiency is linked to restricted growth and yield of courgette.

Background

A soft, wet rot extending from the flower scar to rot courgettes whilst still on the plant has been termed 'blossom end rot' (BER) by growers (HDC Technical update TU-FV 001). Although not a new problem, losses due to BER can be high in wet and damp years. Additionally, the rot may also present to the end customer as internal browning, causing supermarket rejections and creating uncertainty in the courgette industry.

It has been reported that rots from the blossom end typically start with a rot of the flower that has failed to dry up, senesce and detach from the fruit fully. This happens more frequently in wet weather as the flower may adhere to the fruit outer surface, and then act as a bridge for any pathogens to access the mature fruit through the flower scar. Varieties are reported to differ in their susceptibility to BER by many growers, and their differences in timing, flower size, and flower scar size may contribute to this. Certain irrigation methods may avoid water splash and transfer of rot pathogens to the fruit.

A number of microorganisms are known to cause fruit rots in cucurbits, both fungal and bacterial (as detailed in HDC Factsheet 07/13). The majority of fungicide sprays applied to courgette are for the control of powdery mildew, and, especially if the problem is bacterial in nature, it is unlikely these would control the pathogen. If the problem is caused by a fungal pathogen however, it is likely that some of the broader spectrum fungicides approved for use on courgettes would offer some control. The problem in applying plant protection products to courgette lies with harvest intervals, as picking takes place regularly over a long harvesting period.

Traditionally, BER is thought to be caused by localised calcium deficiency, and a similar symptom has been well documented for tomatoes and peppers. Some growers report the problem in early season crops of courgette, at times when they are growing more quickly and under stress as a result. Typically, it is avoided under protection by encouraging water uptake and translocation of calcium into the fruit rather than the leaves of the plant, by management of irrigation and glasshouse humidity. Management of soil nutrients is key to avoiding calcium deficiency and most growers perform soil analyses prior to planting their crop. Some outdoor courgettes are irrigated, and it is likely that improved control of water uptake, for example by using mulches or installing trickle tape, would improve matters. Some growers have already implemented these changes and report less obvious rots in the field. It is likely that soil structure and root health play a role in the development of calcium deficiencies at the growing point of fruit.

There are a number of potential solutions to BER, be it a problem with a pathogen or with crop nutrition. However, the initial cause of the problem must first be identified so that targeted solutions can be trialed. It is likely that nutritional and pathological factors are working in tandem to cause rotting at the blossom end in courgettes when environmental conditions are favorable.

Summary

Aim: To utilise scientific literature, technical information from both the UK and abroad and specialist grower knowledge to deliver a series of potential solutions to the problem of blossom end rot in courgettes

Objective 1 - To define the problem of blossom end rot in courgettes and its incidence through grower liaison, review of technical literature and analysis of fruit.

Grower liaison

In total, 14 growers and industry professionals were contacted, primarily by telephone but also via email. The table below (Table 1) summarises some of the opinions and ideas to come out of this liaison. Potential alleviation options suggested by growers have been incorporated into Objective 3.

Table 1. Factors that are believed to contribute to the incidence of BER in UK crops

Factor	Number who believed this affected BER	How?
Calcium transport	14	Classical BER, localised Ca deficiency
Wet weather	14	Allows pathogens to infect flower, and invade fruit, hinders transpiration stream
Grow through plastic	2	Water may pool on plastic, and keep fruit damp and in contact with soil
Foliar feeds applied	4	Difficult to tell, not been applying for long
Stored courgettes	3	Yes, can develop or worsen in storage
Leave waste in field	1	Inoculum builds up
Overhead irrigation	1	Favours pathogen development
Variety	3	Blossom scar size, uneven flower shape, older varieties worse
Ventilation	1	Disrupts effective transpiration
Soil type	1	Avoid leachy soils with too much drainage
Late crops/season	12	Crops more ‘tired’, under stress
Flower detachment	5	Allows pathogens entry to fruit more easily
Planted through plastic	1	Water pools more easily
T-tape	1	Fertigation provides Ca where it is needed for uptake at the root

Overall, calcium deficiency and wet weather causing flower rot and retention (Figure 1) were the two most cited factors contributing to blossom end rot by growers.

Figure 1. Wet weather causes flowers to hold water, favouring pathogens and prevents the flowers from dropping from set fruit - South West, 2015.

Technical literature

- A number of researchers and industry professionals were contacted overseas, and no specific work on this disorder was reported.
- The disorder is not common or viewed as particularly problematic in countries with a drier climate than the UK.
- Where BER was observed, explanations of calcium deficiency and of a wet flower failing to abscise from fruit were given.
- There is an abundance of technical information detailing the various rots courgette fruit are susceptible to, but little in-depth information on blossom end rot specifically.
- Some information is available online, but much is provided by amateur gardeners and as such the solutions suggested are not viable for commercial settings.
- Calcium deficiency is most often cited as the cause in online sources.
- The problem is reported as occurring both late season and early season.
- Abundant technical literature on management of BER in solanaceous crops and tipburn in lettuce could be tested for use in courgette.

The small amount of technical literature that is available comes from state university research stations in the USA, where the disorder is regarded as analogous to that in tomato, pepper and aubergine. Here, the rot is described as brown and dry, and a number of alleviation options are suggested. These options were considered and summarised within Objective 3.

Fruit analysis

Fruit was sent to an analytical laboratory for testing and mg/kg dry weight reported back. It was clear that courgettes varied considerably in their content of some nutrients from site to site, and on an individual basis. The calcium levels cited for healthy courgettes in the literature were also extremely variable (ranging from 100 to 5900 mg/kg), and calcium levels reported back for apparently healthy courgette fruit sampled also reflected this (ranging from mean values of 2584 to 5349.5 mg/kg across sites).

When values returned for sampled fruit were averaged, the calcium levels differed between affected and unaffected portions of fruit as illustrated in Figure 2 & Table 2 below. It is notable that sites in the South West and Midlands had a more obvious blossom end rot problem when sampled in comparison to sites in East Anglia and the South East, where the gradient between calcium concentration in different parts of the fruit is less evident.

Varieties of courgette grown differed between sites, but it is more likely that regional differences occurred due to the different climatic conditions around the UK.

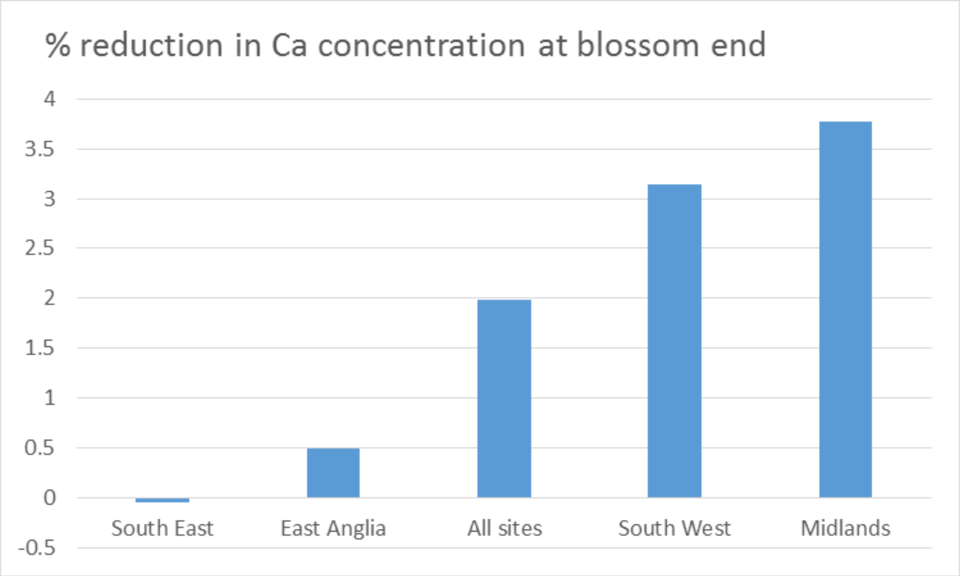

Figure 2. Average reduction in Ca concentration (mg/kg) at the blossom end compared to unaffected stalk and mid portions of the fruit for each region individually, and when data from all sites is combined and averaged.

Table 2. Mean calcium content of courgette fruit affected by BER, split into 3 sections from stalk to blossom end

	Calcium (mg/kg dry weight)				
	Stalk end	**Mid-section**	**Stalk & Mid (average of unaffected tissue)**	**Blossom end**	**% decrease**
South West	3122	2479	2800	2713	3.2
East Anglia	7038	5206	6122	6092	0.5
South East	5665	4450	5058	5061	0
Midlands	9632	8490	9061	8719	3.8
Average of all sites	6364	5156	5760	5646	2

Another nutrient noted to differ between affected and unaffected tissue was boron, which was reported at generally higher levels in the blossom ends of affected fruit (Table 3). However, this is likely to be due to how boron is accumulated in plants, largely dependent on the transpiration stream and concentrating at leaf/fruit tips.

Table 3. Mean boron content of courgette fruit affected by BER, split into 3 sections from stalk to blossom end

	Boron (mg/kg dry weight)				% increase
	Stalk end	Mid-section	Stalk & Mid (average of unaffected tissue)	Blossom end	
South West	14.70	20.07	17.38	22.38	28.74
East Anglia	19.13	25.63	22.38	29.43	31.51
South Coast	22.40	29.20	25.80	30.83	19.48
Midlands	24.63	29.70	27.16	29.25	7.69
Average of all sites	20.21	26.15	23.18	27.97	20.66

Other nutrients did not significantly differ between affected and unaffected tissues, and variability between sites was high. Due to the high variability between fruit sampled, and the differing soil types and crop husbandry between sites, it is envisaged that a high number of samples would have to be taken and tested to gain clearer results using this methodology. However, results certainly seem to add weight to calcium deficiency contributing to BER, and they certainly do not refute this hypothesis.

Objective 2 - To carry out a literature review covering potential causes of the problem, (covering both nutrition and disease) and exploring treatment/alleviation options from the UK and overseas, which will include information from other crops.

The full review can be found in the Science Section, but the main points are summarised below.

Blossom end rot in courgette:

- Calcium deficiency in courgette has been found to reduce growth and reduce the plants ability to transport auxins (plant growth hormones), which may have some impact on fruit formation.
- Calcium deficiency in marrow is reported to cause tipburn and concave cupping of very young leaves, as well as patchy chlorosis between veins.
- Boron deficiency in courgettes has been observed to affect cell wall elasticity, but this is not thought to be as severe as in some other crops.
- Traditionally blossom end rot is viewed as being caused in field conditions by rapidly changing weather conditions and uneven irrigation affecting the transpiration stream
- Reduced calcium nutrition and lowered calcium content of tissues is reported to make many crops more susceptible to pathogen attack.

Treatment options:

- Appropriate pH (aiming for 6.5) and salinity levels should be maintained.
- Fertigation with calcium at periods of fruit setting has been utilised in glasshouse crops to successfully mitigate blossom end rot symptoms.
- Yields of summer squash were improved when trickle irrigation was used, although the impact on blossom end rot was not discussed.
- Changes to auxin transport referred to above were observed to be reversed with the addition of calcium ions.
- Altering the nitrogen source may alleviate the problem as calcium uptake was observed to decrease with increasing proportion of ammonium fertiliser used to fulfil nitrogen requirement, and this also increased yield. The authors of this study suggest NH_4-N was competing with other cations for uptake.
- Growers may increase fruit yield by using a predominantly NO_3-N source fertilizer through the vegetative growth stage and by shifting the NO_3:NH_4 ratio during the reproductive phase.
- Greater total calcium was found in courgette fruit grown hydroponically with increasing NaCl (up to 120 g/m^2 in irrigation water).
- The use of rootstocks in other cucurbits such as melon has been observed to improve uptake of water and nutrients.
- Increasing dry matter content was observed in courgette with use of a sodium silicate top dressing.
- Although use of bio-pesticides proves more difficult in an outdoor environment, use of elicitor/stimulant type products that may induce resistance could reduce the incidence/severity of rots and biocontrol agents may reduce the chances of successful infection by pathogens present.
- Treatment with biological products in storage has been shown to slow development of rots in storage on a variety of fresh produce, although it is unclear if this would be worthwhile in the courgette production system where storage is not utilised for long periods.
- There may be potential for breeding programmes to increase fruit calcium content as traditional courgette morphotypes were found to contain greater concentrations of calcium and other nutrients than pumpkin or vegetable marrow and variation within courgette morphotypes was observed.

Objective 3 - To critically evaluate potential solutions for immediate uptake by courgette growers

The potential solutions to come out of this review and the small piece of field work carried out are summarised in Table 4. Options are described and awarded a ranking based on practicalities, costs and potential efficacy. This is based on a combination of factors including the findings of this review and grower consultation. It is important to note that the majority of alleviation options are preventative in nature. Should blossom end rot be observed, removal of affected fruit and the use of foliar sprays containing calcium may have some benefit, but preventing occurrence of the disorder in the first place is preferable.

Table 4. The most promising treatment options for blossom end rot in courgette are evaluated

Treatment option	**Current uptake**	**Potential efficacy**	**Ease of implementation e.g. R & D required?**	**Initial cost to grower**	**Ongoing cost to grower**	**Practicality for grower**	**Overall score**
Highest score of 3 awarded	**High uptake**	**High efficacy**	**Easily implemented**	**Low cost**	**Low cost**	**High practicality**	**out of 18***
Fertigation	Low - 1	3	2	1	2	1	10
Foliar fertiliser	Increasing - 2	2	2	3	1	3	13
Mulching	Common - 3	2	3	1	2	1	12
Flower removal	Low - 0	1	3	2	3	1	10
Removal of waste	Very low - 0	1	3	2	3	1	10
Variety choice	Some - 2	2	0	3	3	3	13
Post-harvest treatments	Very low - 0	1	1	2	2	1	7

*Higher score indicates more useful options

Financial Benefits

- Crop losses to BER vary considerably by location and season.
- Estimates of % loss range from <1% to as high as 20% of a single harvest.
- Assuming a harvest of 6000 kg per acre at 60 pence per kilo, then a 20% loss would represent a financial loss of £720 to the grower per harvest affected.
- Reducing the incidence of this disorder would increase marketable yield and profitability.
- Reducing the disorder could also decrease the number of fruit affected in storage, improving scheduling of product to the supplier.
- Options explored from the growers perspective, ensuring suggested control options are practical and cost effective and can be implemented quickly.

Action Points

Analyses

- Carry out soil analysis annually on fields that are historically badly affected and treat fields appropriately.
- Carry out more in depth soil analysis and amendment at the start of the season to rectify any issues with pH (potentially by liming) or calcium content (a possibility to add gypsum or ulexite, which also contains boron).
- Consider carrying out foliar analysis on crops throughout the season (as in some protected edibles).

Soil management

- Use of mulches or adding organic matter may help to slow the loss of soil moisture on quick-draining sites.
- Planting of courgettes on a ridge, as some growers do, rather than on flatter ground may provide better drainage and a more even water supply to roots (except where soils are excessively sandy).
- Evening out the supply of water to the rootzone in this way will ensure transpiration is properly regulated.

- The use of mulches for weed control could have the added benefit of improving soil moisture.

Fertiliser

- If fertigation is impractical, targeted and regular application of foliar feeds may offer some benefit.
- Foliar feeds containing calcium may also decrease susceptibility to some foliar diseases.
- Incorporation of additional organic matter may also improve the soil's ability to hold moisture, allowing the crop to uptake calcium more efficiently.

Irrigation

- Installation of fertigation may allow a more even irrigation regime, and would also facilitate effective delivery of fertiliser to the root zone of the crop.
- Avoidance of overhead irrigation will prevent the flower becoming wet in drier conditions.

In the field

- Wherever possible, clear trash from fields to lower pathogen inoculum.
- Encourage pickers to carefully (and hygienically) remove flowers that remain attached to set fruit when seen, especially if wet weather is forecast.

SCIENCE SECTION

Introduction

A soft, wet rot extending from the flower scar to rot courgette fruits whilst still on the plant has been termed ‘blossom end rot’ (BER) by growers (HDC Technical update TU-FV 001). Although not a new problem, losses can be high in wet and damp years, and additionally, the rot may only present as internal browning and may continue to develop in store, causing supermarket rejections and creating uncertainty in the courgette industry.

It has been reported that rots from the blossom end typically start with a rot of the flower that has failed to dry up, senesce and detach from the fruit fully (growers pers. comm). This happens more frequently in wet weather as the flower may adhere to the fruit outer surface, and then act as a bridge for any pathogens to access the mature fruit through the flower scar. Varieties are reported to differ in their susceptibility to BER by many growers, and their differences in timing, flower size, and flower scar size (NIAB variety trials, 2014-2015) may contribute to this. Certain irrigation methods may avoid water splash and transfer of rot pathogens to the fruit. It was found that yields of summer squash were improved when trickle irrigation was used rather than in-furrow irrigation, although the role of blossom end rot was not discussed (Amer, 2011).

The majority of fungicide sprays applied to courgette are for the control of powdery mildew, and, especially if the problem is bacterial in nature, it is unlikely these would control the pathogen. If the problem is caused by a fungal pathogen however, it is likely that some of the broader spectrum fungicides approved for use on courgettes would offer some control. The problem in applying plant protection products to courgette lies with harvest intervals, as picking takes place regularly over a long harvesting period. Fungicides such as Frupica SC (mepanipyram) or Amistar (azoxystrobin) that may offer some control of pathogens such as *Botrytis* cannot be applied whilst the crop is being harvested as they have harvest intervals of 2 and 3 days respectively. The number of sprays permitted for these products is also limited, and this may be why the problem is seen more towards the end of the season by some growers, along with wetter weather. A number of biological fungicides are approved on courgette, and it may be that these could be used to offer protection in high risk periods when spraying conventional chemicals is not permitted. Inoculation of courgette with both a *Glomus* sp. and a *Trichoderma* sp. was found to improve growth parameters in field-grown courgette (Colla *et al.,* 2015). The use of microbials is often more difficult in an outdoor environment, but has been shown to be effective (Tesfagiorgis *et al.,* 2014).

Traditionally, BER is thought to develop by localised calcium deficiency, and has been well documented for tomato and pepper. BER occurs at the plant's growing points during periods of rapid growth and due to environmental factors such as uneven irrigation and rapidly changing weather conditions (Adams & Ho, 1993). Some growers report the problem in early season crops of courgette, at times when they are growing more quickly and under stress as a result. Typically, it is avoided under protected conditions in crops such as tomato, pepper and aubergine by encouraging water uptake and translocation of calcium into the fruit rather than the leaves of the plant by management of irrigation and glasshouse humidity. Management of soil nutrients is key to avoiding calcium deficiency and most growers perform soil analyses prior to planting their crop. Ensuring appropriate ratios are maintained to avoid antagonism between nutrients which may inhibit uptake (Chance *et al*., 1999), and ensuring pH is not allowed to drop too low or electrical conductivity (EC) to climb too high will encourage effective calcium uptake. Some outdoor courgettes are irrigated, and it is likely that improved control of water uptake, for example by using mulches or installing trickle tape, would improve matters. Some growers have already implemented these changes and report less obvious rots in the field. It is likely that soil structure and root health play a role in the development of calcium deficiencies at the growing point of fruit. Size of the fruit stalk may also affect how well water and calcium are translocated into fruit. Calcium deficiency in courgette is known to both reduce growth and reduce the plant's ability to transport auxin, a plant growth hormone (Allan & Rubery, 1991) which may impact on fruit formation.

Additionally, any occurrence of stress conditions in tomato (e.g. water stress, pathogen infection) are thought to contribute to the development of blossom end rot (Saure, 2014) and the avoidance of stressed courgette crops may be key to avoiding similar issues. The level of salinity may also affect the level of calcium in courgette fruit tissues (Villora *et al.*, 1997), though it is unlikely levels in UK soil are approaching problematic levels unless in certain coastal regions. In addition to calcium, deficiencies of boron are also associated with disorders in some crops, for example stem splitting in tomatoes and brassicas. The ideal range for boron is narrow and it is possible that lack of boron may be contributing to cracking at the blossom end as observed by some growers. Any damage on fruit is likely to be rapidly colonised by rot pathogens. Boron deficiency in courgettes has been observed to effect cell wall elasticity, although is not thought to cause membrane 'leakiness' as severely as in other crop groups (Findekelee & Goldbach, 1996). It has also been hypothesised that courgette roots suffer extensively when exposed to a boron-deprived environment (Yu *et al*., 2003). *Cucurbita pepo* has also been observed to be sensitive to excess boron (Landi *et al.,* 2013) and when grown with excess boron leaf conductance to water vapour was significantly less than when grown with optimal boron nutrition, before any symptoms characteristic of toxicity appeared (Bates, 1984). To avoid obvious deficiencies, growers do generally carry out soil analyses where possible, although do not always include trace elements. Many growers do account for calcium levels, and may add foliar sprays of calcium and other elements to their crop. Many calcium-containing products are available that claim to improve crop condition. As a deficiency in the surrounding soil is not always the problem, there are also products on the market that claim to improve calcium uptake. Silicon is known to improve cell strength and structure, and has applications for powdery mildew control in cucurbits, though the mechanisms at work are complex (Tesfagiorgis *et al.,* 2014). Further research into the effects of foliar feeds containing silicon in courgette may be worthwhile, although application of silicon at the rootzone may be required to elicit an effect on cell structure (Marschner, 2012). Additionally, plant species may be silicon accumulators or non-accumulators, and this will impact treatment efficacy (Heine *et al.,* 2005).

There are numerous potential solutions to BER, be it a problem with a pathogen or with crop nutrition. However, the initial cause of the problem must first be identified so that targeted solutions can be trialed. BER is reported far less in crops overseas where courgettes are grown under cover or in drier conditions, and it may be that overseas growing systems and climate discourage development of BER. It is likely that nutritional and pathological factors are working in tandem to cause rotting at the blossom end in courgettes when environmental conditions are favourable.

Aim: To utilise scientific literature, technical information from both the UK and abroad and specialist grower knowledge to deliver a series of potential solutions to the problem of blossom end rot in courgettes

Objectives:

1. Define the cause of blossom end rot in courgettes through grower liaison, review of technical literature and analysis of fruit.
2. Carry out a literature review covering potential causes of the problem, (covering both nutrition and disease) and exploring treatment/alleviation options from the UK and overseas, which will include information from other crops.
3. Critically evaluate potential solutions for immediate uptake by courgette growers.

Materials and Methods

Objective 1 – Define the cause of blossom end rot in courgettes through grower liaison, review of technical literature and analysis of fruit.

Grower liaison

A number of UK growers were contacted by telephone throughout the growing season, as well as agronomists and industry experts. A standard set of questions was used as a basis for each conversation to ensure that essential information was covered each time. Additional growers and industry professionals were contacted via email.

Technical literature

Technical literature from a variety of countries was sought that dealt specifically with the problem of blossom end rot in courgette or squash. As this was somewhat lacking, a number of sources detailing similar problems in other crops were sourced. A number of grower associations and researchers overseas were also contacted with a view to establishing if technical literature existed there, or if any work on the problem was ongoing.

Crop monitoring

Four sites were monitored as part of this project that were geographically spread across UK courgette growing areas. These sites are listed below.

1. South West
2. East Anglia
3. South East
4. Midlands

A temperature and humidity logger was placed in each crop after emergence/transplanting (Figure 3), and collected towards the end of cropping. Alongside this, host growers were asked to report significant incidences of blossom end rot in their harvests.

Figure 3. Logger placed in an early courgette crop on the South coast, 2015

Each site was visited once for courgette fruit to be sampled. This occurred at each site when a significant outbreak of the disorder occurred, as reported by growers. This was to ensure sufficient numbers of affected fruit for sampling. Symptoms observed in the field were variable in severity, ranging from a dark brown, slightly soft blossom scar, to internal browning, to a well-developed rot of the blossom end (Figure 4).

Figure 4. Courgettes sampled exhibited a wide variety of symptoms that could fall under the label of 'blossom end rot'

After fruit were sampled (Figure 5), they were taken back to the ADAS pathology laboratory and examined using conventional pathology methods. Symptoms were examined under a microscope, and any fungal structures observed were recorded. Approximately 70 fruit were taken from each site

Figure 5. An example of the symptomatic fruit sampled at each visit – Midlands, 2015.

Additionally, tissue from the leading edge of the rot was surface sterilised and placed on Potato Dextrose Agar (PDA). Some tissue pieces were placed onto agar unamended with antibiotics, whilst some were plated onto PDA amended with the antibiotic streptomycin. This was to ensure a larger range of potential pathogens were captured, including bacteria. Plates were incubated at 21°C and assessed 7 to 10 days after isolation. Isolations were also performed with tissue from flowers which remained attached to fruit (Figure 6).

Figure 6. Flowers are more easily retained at the blossom scar during wet weather, and begin to rot more easily – South West, 2015.

Fruit with classic BER symptoms were also sampled to undergo nutrient analysis. Approximately 60 fruit with blossom end rot were sampled at each site as well as approximately 10 healthy fruit to provide baseline 'healthy' levels for each site. Calcium levels found in previous studies on courgette were also sought to give a more general impression of deficiency and toxicity levels for courgette fruit. Fruit were stored in cool boxes until arrival at ADAS Boxworth or the laboratory sub-contracted for nutrient analysis.

Results

Objective 1 – Define the cause of blossom end rot in courgettes through grower liaison, review of technical literature and analysis of fruit.

Grower liaison

Growers who had agreed to send samples gave their opinion on the problem of blossom end rot, and current and potential solutions were discussed. In addition to the four host growers, ten further growers with farms of varying size and using various growing systems were contacted for contributions, as well as a number of other industry professionals. The results of this liaison are summarised by subject area below, and in Table 5.

BER:

- All growers were familiar with the problem, but some experienced the problem far more severely than others.
- Although very difficult to quantify, loss estimates ranged from less than 1% in some locations to as high as 20% when an outbreak occurred; severity was variable across the country and also varied with season.
- Most growers reported the problem as most severe in autumn, when crops were older and growing more slowly and when conditions were damp.
- BER was also reported as a problem in early crops as fruit may be held in closer contact with the ground.
- Crops under stress may be more susceptible.
- There was a strong association of BER with wet weather and/or high humidity around the fruit.
- Rots are seen at harvest and may also develop post-harvest in store.
- Ineffective uptake and/or movement of calcium through the plant is often implicated, but failure of the flower to dry up and fall from the blossom scar is also thought to be a strong contributing factor.

Soil:

- All growers contacted had carried out soil analysis. The frequency of this ranged from twice annually to once every 3 years, although some growers did not test all fields.
- Some growers did report adding additional calcium to the soil at the start of the season (though this was more for purposes of pH adjustment).
- A variety of soil types were reported and growers contacted had good geographical spread.
- Growers who use black plastic for weed control and those who plant into bare soil both experienced problems with courgette rots.
- No specific distribution pattern in fields was reported.

Variety:

- A range of varieties are grown in the UK (11 were specifically named during this process).
- Many growers reported no difference in varietal susceptibility.
- It was reported by some that varieties do differ in susceptibility to blossom end rot, but reports were conflicting.
- Certain varieties are strongly favoured in certain areas of the UK, so it is impossible to separate effect of variety from effect of location.
- Though two crops of Cronos were visited, BER was reported at different points in the season.
- Varietal susceptibility could be linked to efficiency of calcium transport, size of blossom scar or flower, and/or propensity to hold or drop flowers.
- Although some of these aspects are assessed as part of ongoing courgette variety trials, no link with rot development is immediately evident, and BER is not specifically assessed (NIAB variety trials).
- Whether crops were planted as seeds or transplants did not seem to affect BER incidence, although there was some suggestion that drilling may improve root development.

Foliar sprays:

- Many of the growers contacted did not apply foliar feed as a general rule.
- A number of those contacted had started to apply foliar feeds over the last few seasons.

- Many of the products cited were calcium-containing, including TeCal, Calmax, Stopit and InCa.
- Sprays containing magnesium, boron and manganese were also mentioned.
- Anecdotally, the majority of growers applying foliar feeds have noticed no improvement in BER as a result.
- Fungicide sprays through the season are generally for powdery mildew control and products are applied on a tight programme.
- Harvest interval is the most limiting factor for use of fungicides in courgettes.
- Fungicides are rarely applied for other diseases or specifically against fruit rots.

Irrigation/fertigation:

- Some growers employed no artificial irrigation at all, relying purely on rainfall.
- Overhead irrigation was in use quite commonly, and some growers had installed drip irrigation in the form of t-tape on their courgette fields.

Table 5. Factors that are believed to contribute to the incidence of BER in UK crops (based on responses from 14 Growers)

Factor	Believed to effect BER incidence?	How?
Calcium transport	14	Classical BER, localised Ca deficiency
Wet weather	14	Allows pathogens to infect flower, and invade fruit, hinders transpiration stream
Grow through plastic	2	Water may pool on plastic, and keep fruit damp and in contact with soil
Foliar feeds applied	4	Difficult to tell, not been applying for long
Stored courgettes	3	Yes, can develop or worsen in storage
Leave waste in field	1	Inoculum builds up
Overhead irrigation	1	Favours pathogen development
Variety	3	Blossom scar size, uneven flower shape, older varieties worse
Ventilation	1	Disrupts effective transpiration
Soil type	1	Avoid leachy soils with too much drainage
Late crops/season	12	Crops more ‘tired’, under stress
Flower detachment	5	Allows pathogens entry to fruit more easily
Planted through plastic	1	Water pools more easily
T-tape	1	Fertigation provides Ca where it is needed for uptake at the root

Management options suggested

- Breaking off the flower early by hand.
- Active irrigation strategies – sub-irrigation such as t-tape would be most suitable
- Increase crop ventilation e.g. increase crop spacing.
- Measurement of humidity in crops could identify high risk periods for BER but would need to be complemented with appropriate management strategies.
- More in-depth soil analysis.
- Potential to carry out foliar analysis on crops over season (as in some protected edibles), but reference values for courgettes may need to be updated (foliar values found in Mills & Jones (1996)).
- Regular application of high quality foliar calcium fertilisers may be worth exploring, especially as many growers are already investing.
- Clearing waste from fields may reduce inoculum of potential rot pathogens (Figure 7).

Figure 7. Some growers leave rotting or out of specification courgette fruit in the field, where they will further rot allowing for the growth, sporulation and spread of pathogens

Technical literature

Over the course of the project, grower associations and/or researchers in Italy, Spain, France, Canada, the USA and Australia were contacted. There have been varying levels of response, and no ongoing work into this disorder has been reported. As in the UK, the condition is thought to be due to a localised calcium deficiency or due to failure of the flower to effectively abscise in wet conditions.

A number of technical organisations were contacted over the course of this project, including grower associations and seed companies. Information provided was largely on the fungal and bacterial pathogens that courgette fruit are susceptible to. Of the technical literature available to growers, there is relatively little with mention of courgette blossom end rot, and any literature to solely focus on the problem is rare. In terms of UK technical information, the problem is mentioned in the HDC Crop Walkers' Guide, HDC Technical Update TU-FV 001 and Factsheet 07/13 on cucurbit fruit rots. In each of these sources a definitive cause of the problem is not identified. These sources, and many others, detail the fungal and bacterial pathogens that courgette fruit are commonly affected by.

In courgette variety trials carried out by NIAB, aspects such as flower retention, blossom scar size and presence of rots have been assessed for varieties submitted by eight seed companies. BER incidence is not scored specifically in these trials but it is probable that at least some of the in-field rots observed were what we are classifying as blossom end rot, and this was observed to differ between the varieties grown (NIAB variety trials, 2014; 2015). Flower retention was not observed to differ, so it may be that flower retention for long periods is more related to weather conditions. In terms of blossom scar size, those with larger blossom scars were not always the varieties where more fruit rots were found, and it is possible that multiple aspects of fruit architecture affect ease of infection by pathogens. In the 2015 trials the two varieties where more rotten fruit were reported had medium to large blossom scars, rather than small.

In the USA there is some information on blossom end rot, described as a localised calcium deficiency. It is worth noting that in information sheet HGIC 1321 (Sideman, 2005) this disorder is described as a dry rot, in comparison to many reports from UK growers of water-soaked symptoms. This could be due to secondary colonisation of rot pathogens in damp conditions, but could also point to there being two separate issues at play. Some technical literature on blossom end rot of squash is available, although it is largely aimed at home gardeners and is provided by University Extension services (Voyle, 2015).

Industry professionals contacted in Australia (pers. Comm., DAFWA) also attribute the problem to calcium deficiency. The disorder is usually caused by poor watering regimes in Western Australia. Uptake of calcium is reduced during periods when the soil temporarily dries out and there is not a constant water supply to the plant. Strong drying winds, high humidity, high temperatures and water logging can also cause a temporary reduction in the uptake of calcium, due to plant stomata closing to maintain water status. It was also recommended that the pH of soil should be checked to ensure it is the ideal range for courgettes (6.5 - 7). Furthermore, where a pathogen has entered the plant, it is usually soft rot (*Erwinia* or *Pseudomonas* species) as a result of the plant having a weak point at the blossom scar, due to the calcium deficiency. This theory has not been tested in the lab but is anecdotal evidence developed from grower and researcher experience.

France also experiences the problem, and it is viewed as an abiotic condition linked to calcium uptake, similar to blossom end rot observed in tomatoes (pers. Comm., INRA). Similarly, little to no research is currently ongoing into this problem.

Crop monitoring

As part of this project, a small amount of practical work was included. This involved analysis of affected fruit, as well as seeking grower opinions on the issue and looking at any technical literature available. The results of this work are detailed here.

In this year's growing season, four UK sites were monitored for the first occurrence of BER (Table 6). Temperature and relative humidity in the crop canopy were also measured. Varieties differed between early and late crops, but the primary variety as sampled is listed.

Table 6. A summary of sites sampled in the UK, 2015

Site	Location	Variety	BER first reported	Sampled	Logger retrieved
1	South East	Cronos	12.08.15	27.08.15	Lost
2	Norfolk	Mykonos	14.09.15	17.09.15	Yes
3	South West	Tosca	21.08.15	21.08.15	Yes but incomplete
4	Midlands	Cronos	28.08.15	03.09.15	Yes

Logger data can be viewed in Appendix 1. For the sites 2 and 4 where a complete data set is available, and for site 1 where a logger in a nearby field has been substituted, there does seem to be a trend for first occurrence when higher humidities were reached (and possibly also lower temperatures, influencing dew point). For more conclusive data on this aspect, a full trial with regular assessments of symptoms would have to be carried out.

Once affected samples were returned to the ADAS pathology laboratory, isolations were carried out to eliminate the possibility of a common or novel pathogen causing the symptoms observed in the field. On assessment of the agar plates, it was seen that a wide variety of potential pathogens had developed. As such, it is unlikely blossom end rot is solely due to a single causal pathogen. However, when courgette fruit are damaged or weakened they become very susceptible to attack by a wide range of pathogens, especially in damp conditions. This may explain why so many of the rots observed in the field are wet in character, rather than the dry blossom end rot described in the USA and seen in glasshouse crops. Isolations were taken from symptomatic and healthy tissue, and flowers that failed to detach were also plated onto agar. In some cases symptomatic tissue failed to produce any fungal or bacterial growth on agar plates, which may point to a more physiological cause. Results can be seen below in Tables 7, 8 and 9.

Table 7. A summary of the most common potential pathogens and/or saprophytes isolated from courgette flowers that failed to detach from fruit from four sites in the UK, number of colonies out of 20 pieces plated

	Site			
Pathogen/Saprophyte	**South West**	**East Anglia**	**South East**	**Midlands**
Fusarium	1	3	1	0
Botrytis	2	5	0	5
Rhizopus	1	0	0	0
Mucor	1	3	5	5
Bacteria	5	2	2	1
Cladosporium	3	3	3	2
Trichoderma	0	0	0	1
No growth	7	4	9	6
TOTAL	20	20	20	20

Table 8. A summary of the most common potential pathogens isolated from healthy courgette fruit from 4 sites in the UK, number of colonies out of 20 pieces plated

	Site			
Pathogen	**South West**	**East Anglia**	**South East**	**Midlands**
Fusarium	2	2	1	1
Botrytis	0	0	2	1
Rhizopus	0	0	0	0
Mucor	1	3	8	2
Bacteria	1	0	0	0
Cladosporium	2	0	1	0
Rhizoctonia	0	1	0	0
Colletotrichum	0	1	0	0
Sclerotinia	0	1	0	0
No growth	14	12	8	16
TOTAL	20	20	20	20

Table 9. A summary of the most common potential pathogens/saprophytes isolated from symptomatic courgette fruit from 4 sites in the UK, number of colonies out of 20 pieces plated

	Site			
Pathogen/Saprophyte	**South West**	**East Anglia**	**South East**	**Midlands**
Fusarium	0	4	1	2
Botrytis	2	2	0	3
Rhizopus	4	0	0	0
Mucor	1	1	0	4
Bacteria	4	0	0	2
Pythium	0	1	0	0
Cladosporium	1	0	0	1
Plectosphaerella	0	0	1	0
Stemphylium	1	0	0	0
Alternaria	1	0	0	0
Trichoderma	1	0	0	0
No growth	5	12	18	8
TOTAL	20	20	20	20

The number of pieces plated from which no fungal or bacterial growth developed is similar between the healthy and symptomatic courgette tissue, which may point to the issue being physiological in cause. Additionally, a number of pathogenic species were isolated from healthy fruit and from flowers remaining attached. This illustrates the fact that should any damage or weakness occur in fruit, rotting pathogens are ever-present to colonise. Of the symptomatic fruit, the most prevalent pathogen varies from site to site, but *Fusarium* spp., *Botrytis cinerea* and bacteria (likely *Pectobacterium*) were all commonly isolated.

A summary of the results of nutritional analysis can be seen in Appendix 2 for all four sites sampled. For some nutrients, such as iron, there was high variability across sites. Much higher iron concentrations were reported in fruit from the Midlands than the other three sites. This made possible trends and correlations difficult to identify. Calcium content of asymptomatic, healthy fruit were also highly variable, which made it somewhat difficult for a valid comparison to be made. Foliar levels of calcium are given as 1.4% (approx. 14,000 mg/kg). Results found in the literature for healthy courgette fruit calcium concentration gave ranges from 100 to 5900 mg/kg (Martinez-Valdivieso *et al.,* 2014), and 2500 to 3600 mg/kg (Rouphael & Colla, 2009) making deficiencies difficult to quantify. A summary of calcium levels found in healthy and affected portions of fruit can be seen in Table 10 below.

Table 10. Mean calcium content across four sites for healthy courgette fruit.

	Total calcium mg/kg (dry weight)
South West	3250
East Anglia	5333
South East	2584
Midlands	5350
Average	4129

Table 11, below, illustrates the reduction in calcium from stalk end to blossom end. The result is negligible for East Anglian and South Eastern sites, but is more noticeable for the South West and Midlands. It is notable that the South West and Midland sites had more severe and widespread symptoms than the other two sites, and typically experience a damper, more humid climate.

Table 11. Mean calcium content of courgette fruit affected by BER, split into 3 sections from stalk to blossom end (n=48 pooled samples, 192 courgettes in total)

	Calcium (mg/kg dry weight)				% decrease
	Stalk end	Mid-section	Stalk & Mid (average of unaffected tissue)	Blossom end	
South West	3121.50	2479.33	2800.42	2712.60	3.14
East Anglia	7038.25	5206.00	6122.13	6091.75	0.50
South East	5665.25	4450.25	5057.75	5060.50	-0.05
Midlands	9632.00	8490.25	9061.13	8719.25	3.77
Average of all sites	6364.25	5156.46	5760.35	5646.03	1.98

Most of the other nutrients did not exhibit an observable trend between healthy or symptomatic fruit. However, for boron, there was a distinct increase in concentration from the stalk to the blossom end in affected fruit at all four sites. Boron deficiency is often associated with physiological disorders in field vegetables, and boron toxicity is reported for some plants, but generally occurs in low rainfall areas or through over-fertilisation (Camacho-Cristobal *et al*., 2015). Symptoms also more typically manifest on older leaves due to how boron is accumulated, however for some plants leaf chlorosis and necrosis are reported (Marschner, 2012). The levels reported here do not approach levels likely to cause toxicity (e.g. around 100 mg/Kg in cucumber (Marschner, 2012)) and it is likely this gradient merely reflects how boron is accumulated naturally in courgette. Average boron levels are summarised below (Table 12).

Table 12. Mean boron content of courgette fruit affected by BER, split into three sections from stalk to blossom end (n=48 pooled samples, 192 courgettes in total)

	Boron (mg/kg dry weight)				
	Stalk end	Mid-section	Stalk & Mid (average of unaffected tissue)	Blossom end	% increase
SW	14.70	20.07	17.38	22.38	28.74
NOR	19.13	25.63	22.38	29.43	31.51
SE	22.40	29.20	25.80	30.83	19.48
MID	24.63	29.70	27.16	29.25	7.69
Average of all sites	20.21	26.15	23.18	27.97	20.66

As well as nutritional analysis, fruit % dry matter was also recorded, as this may be an indicator of general fruit strength, and therefore of shelf-life. However, as Table 13 illustrates, there was no discernible gradient in dry matter between healthy and affected portions of fruit, although % dry matter was approximately double for Midlands fruit.

Table 13. Mean % dry matter of courgette fruit affected by BER, split into 3 sections from stalk to blossom end (n=48 pooled samples, 192 courgettes in total)

	% Dry Matter			
	Stalk end	Mid-section	Stalk & mid-section (average of unaffected tissue)	Blossom end
South West	3.98	3.50	3.74	3.75
East Anglia	4.60	5.03	4.81	4.70
South East	4.63	4.60	4.61	4.65
Midlands	8.30	7.03	7.67	7.70
Average of all sites	5.38	5.04	5.21	5.20

Objective 2 - Literature review

Nutrition

As BER is likely linked to localised calcium deficiency, application of calcium-based products may offer some improvement, however, products must be of high quality, applied often and appropriately targeted. Calcium deficiency in courgette is known to result in reduced growth and a reduced ability to transport auxin (plant growth hormone) (Allan *et al.,* 1993). Changes to auxin transport were observed to be reversed with addition of calcium ions (Allan & Rubery, 1991). Calcium deficiency in vegetable marrow (also *Cucurbita pepo*) was reported to cause tipburn and concave cupping of very young leaves, which may progress to convex cupping and a ‘clawed’ leaf shape. Patchy chlorosis is also reported, but blossom end rot is not mentioned (Scaife & Turner, 1983).

Calcium uptake was found to decrease with increasing proportions of ammonium fertiliser used to achieve the appropriate nitrogen requirement, where increasing the proportion of nitrate increased uptake (Bar-Yosef *et al.,* 2008; Chance *et al.,* 1999). As such, though more expensive, it may be better to investigate the effect of using a greater quantity of more expensive, nitrate based nitrogen fertilisers in fields where blossom end rot is a commonly observed problem. In pepper, limiting nitrogen overall also reduced incidence of blossom end rot (Paradikovic *et al*., 2007). Additionally, a greater total amount of calcium was found in courgette fruit grown hydroponically when an increased concentration of NaCl was applied, up to 120 g/m^2 (Villora *et al.,* 1997). Ideal soil pH for courgettes is 6.5, and this should be monitored year and year and maintained to achieve optimum nutrient uptake (Assured Produce Guide).

If the problem is related to a plant’s inability to take up and translocate sufficient calcium, there may be potential for the use of grafted plants. Many growers plant their field crops as transplants, although others plant as seed and the majority contacted use a combination of transplants and seed. Initiating the use of grafted plants would represent a greater financial outlay to propagators and would not be suitable for growers who prefer to use seed. Rootstocks are more commonly used in cucurbits such as melons, and it has been illustrated that their use improves produce quality through improved uptake of water and nutrients (Han *et al*., 2009). However, the introduction of rootstocks to courgettes is unlikely to be commercially viable.

As well as calcium, numerous other elements are known to impact on plant strength and fruit quality, and may confer benefits and increased resistance to rots. In pear, application of sodium selenite to both leaves and directly to fruit was found to increase the selenium content in fruit, which in turn increased firmness and increasing shelf life (Pezzarossa *et al.,* 2012). In courgette, application of sodium silicate as a top dressing was also found to increase dry matter content of fruits (Martinetti & Paganini, 2006).

If the condition is analogous to blossom end rot observed in tomatoes and other solanaceous crops, then treatment and alleviation options utilised in the Protected Edibles sector could be well utilised against courgette blossom end rot. Though manipulation of the environment is more difficult in an outdoor cropping environment, changes to irrigation, fertiliser programmes and harvesting practice could have a positive impact. Typically, in tomatoes, BER is viewed as a localised calcium deficiency, but more recently has also been strongly linked to abiotic stresses on the plant before any detectable deficiency is present (Saure, 2014). In protected environments, the condition is usually avoided by management of hydroponic nutrition, (which can be more easily manipulated than soil nutrition), irrigation and humidity control. In an outdoor crop, soil testing is carried out by many growers, but this may not be performed in sufficient detail. As is well known in the case of tomatoes, calcium deficiency in the soil/feed is rarely the problem, but rather the plant's ability to take calcium up is compromised. Where natural water supply is variable, irrigation should be utilised to ensure an even supply of water to plants and superfluous applications of nitrogenous fertilisers should be avoided. High salinity has been shown to reduce calcium present in tomato fruit, resulting in lower calcium at the distal end of the fruit than proximal, prior to development of BER and is also related to high solar radiation (Adams & Ho, 1993).

The condition of tipburn in lettuce is caused by localised calcium deficiency in growing shoots, and alleviation methods for this condition may be more transferrable to field grown courgette. In outdoor lettuce, the potassium to calcium ratio in the soil was found to correlate with tipburn incidence (with a correlation coefficient of 0.78) (Altintas & Candar, 2012). Amendment of the soil is more difficult than adjustment of hydroponic nutrition, and levels cannot be altered once the crop is planted. As such, the use of foliar fertilisers containing calcium may be the most practical option. Although no work has been done specifically on courgette BER, the use of foliar calcium applications has been shown to significantly reduce tipburn in lettuce (Corriveau *et al.,* 2012) and contribute to a reduction in BER when used in combination with non-susceptible varieties of tomato (Liebisch *et al.,* 2009).

Pathology

If courgette fruit are deficient in elements such as calcium, it is likely they are more susceptible to pathogen invasion, especially if the blossom scar does not heal effectively or weather is damp. Tomatoes deficient in calcium have been found to be more susceptible to bacterial canker (Berry *et al.,* 1988) and bacterial wilt (Jiang *et al.,* 2013) and improved calcium nutrition led to reduced severity of *Botrytis cinerea* infection (Elad *et al.,* 1993). It has also been found that susceptibility of courgette fruit to some pathogens, such as *Phytophthora capsici*, is dependent on fruit length, with fruit becoming resistant once at full length but exhibiting increased susceptibility when fruit are young and rapidly elongating. Cucumber fruit that were field-grown were also found to be most commonly affected at the blossom end (Ando *et al.,* 2009).

A number of microorganisms are known to cause fruit rots in cucurbits, both fungal and bacterial (as detailed in HDC Factsheet 07/13). These commonly include *Botrytis cinerea,* *Sclerotinia sclerotiorum, Didymella bryoniae, Colletotrichum orbiculare* (anthracnose), *Cladosporium cucumerinum* (scab) and many *Fusarium* species. *Mycosphaerella melonis*, the causal agent of gummy stem blight in glasshouse cucumber, may also infect field-grown cucurbits. Bacterial diseases and soft rot bacteria such as *Pectobacterium carotovorum* will commonly colonise any damaged tissue on fresh produce. It was this soft rotting bacteria that was discovered on one of the only samples of courgette blossom end-rot to be sent off for analysis prior to this review (grower communication). In pumpkin, it has been hypothesised that infection with a fungal pathogen like *D. bryoniae* may allow effective colonisation by bacterial pathogens that use fungal mycelium for translocation (Grube *et al.,* 2011). Courgette are also susceptible to a number of fruit rot pathogens not yet established in the UK, for example *P. capsici* mentioned above.

Control options are limited in the UK with regards to bacterial pathogens, and the short harvest intervals required for products to be used on courgettes also limits the use of fungicides which may offer control of any causal fungal pathogens. As such, biopesticides such as microbial or biostimulant products may prove useful. Bio-pesticides may have a positive impact on reducing rots observed on courgettes in the field, and induced systemic resistance has been illustrated to occur in glasshouse cucumber after application of a *Bacillus subtilis* product (Kloepper *et al.,* 2004). Other elicitor or biostimulant products may also be able to play a role in generally boosting cucurbit natural defence mechanisms (Ovadia *et al.,* 2000) and reducing blossom end rot. In pumpkin, numerous naturally occurring bacterial isolates (e.g. Pseudomonads) were tested for their biocontrol activity against *Didymella bryoniae* and bacterial pathogens, and a number of different strains were found to reduce disease severity (Fuernkranz *et al.,* 2012). However, these products are not yet on Annexe 1 or approved on courgette. For use in field grown courgettes the biopesticides currently approved are Serenade ASO (*Bacillus subtilis*), Prestop (*Gliocladium catenulatum*) and Contans WG (*Coniothyrium minitans*). Whilst Contans WG is highly specific for control of Sclerotinia, Serenade ASO and Prestop may have useful activity against a variety of secondary colonisers of damaged courgette tissue.

The use of inorganic salts specifically to control disease is well known, and is successful against powdery mildew in cucurbits (Deliopoulos *et al.,* 2010; Defra Project PS2125). Potassium bicarbonate is commonly incorporated into spray programmes to control powdery mildew; silicon also has well known efficacy against powdery mildew (Dik *et al.,* 1998), and phosphites have known efficacy against oomycete pathogens (Thao *et al.,* 2009). Although often less effective than conventional fungicides, this approach is more suited to courgette production as during harvest, fruit is picked daily and many products have prohibitively long harvest intervals. The trace element boron is also known to influence structure and fruit formation in many plants, and although deficiencies have been found to affect courgettes negatively, a study of nutrient uptake by courgette, found plants were found to take up boron from soil efficiently (Gyulai *et al.,* 2012). Additionally, boron deficiency in courgettes was not found to contribute to 'membrane leakiness' as strongly as in other plant groups (Findeklee & Goldbach, 1996).

Cropping

Ultimately the UK climate is not ideal for the courgette plant, which prefers a more Mediterranean climate. To more effectively deliver calcium to the root zone in crops that are not irrigated, installation of methods such as trickle irrigation may improve nutrient delivery to where it is needed. Trickle irrigation was found to enhance squash yield, and was found to be more effective than furrow irrigation (Amer, 2011). However, this study was carried out in northern Egypt where irrigation need is far greater than in the UK, where furrow irrigation would be unnecessary. In another study, drip irrigation was found to result in higher yields of courgette in the spring-summer season than sub-irrigation, although fruit quality was higher where sub-irrigation was used. No differences were found in the summer-autumn crop between the two irrigation systems, and this crops yield was over 30% lower than the spring-summer crop (Rouphael & Colla, 2005). Courgette yield, shoot weight and root growth were enhanced by the use of aerated sub-surface drip irrigation in a field trial in Queensland (Bhattarai *et al.,* 2004), though this may prove impractical in the UK. In more traditional glasshouse crops, such as pepper, delivery of increased calcium at times of large fruit sets has been shown to mitigate blossom end rot symptoms (Byeon *et al*., 2012). However, these plants were being grown hydroponically, and the results may not translate to a field-grown crop supplied with supplementary irrigation. Additionally, incidence of fruit rots in these trials were not reported. In terms of irrigation, a fertigation system seems ideal, but where irrigation systems are not present or will not be installed it may be sensible to use mulch. As well as effective weed control, this will serve to help retain soil moisture. Black plastic, as used by many growers for weed control, may also perform this function.

Reports on variety performance in terms of BER vary, but variety choice may be a practical and easily implemented control method. Incidence of tipburn in lettuce is known to vary with cultivar (Assimakopoulou *et al.,* 2013) as is blossom end rot in tomato (Liebisch *et al.,* 2009). Calcium levels in fruit were found to vary in a survey of 34 morphotypes of courgette and pumpkin (Martinez-Valdivieso *et al.,* 2015) so it is possible that this could be a target for variety improvement by plant breeders. Breeders do not currently give information on BER susceptibility, but the ongoing NIAB variety trials do assess rots present at harvest.

Early crops in the UK are commonly grown under covers of plastic or fleece, which is likely to create a very humid micro-climate, favouring the development of fungal pathogens. Commercially, courgettes are planted at a density of around 6,000 plants per hectare, and it is unlikely this could be altered in order to lower humidity. Similarly, covers are required to offer frost protection and encourage earlier growth, and it is unlikely this practice could be discontinued. Especially in periods of rapid growth, avoiding periods of low daytime humidity ensures plants do not lose large amounts of moisture through transpiration, however this would prove difficult in an outdoor environment. A crop grown under more controlled conditions may be easier to manipulate, however as long as courgettes remain an outdoor crop, environmental control options that may have relevance to protected edible and indoor lettuce are somewhat limited. If production of courgette were to become protected, profit margins would be lessened and the problem of effective pollination would require the use of phytohormones. The problem of poor pollination is already the subject of an HDC research project (PC 118) and presently, glasshouse production of courgette in other parts of the world is dependent on the use of plant auxins to produce plants by parthenocarpy rather than by the use of natural pollinators (Martinez *et al.,* 2014).

The use of beneficial organisms for the purposes of growth enhancement rather than disease control has been illustrated successfully on courgette, with mycorrhizal fungi improving marketable yield under alkaline conditions (Cardarelli *et al.,* 2010) and co-inoculation of *Trichoderma atroviride* and *Glomus intraradices* improving transplant establishment (Colla *et al.,* 2015). Experimentally, some applied plant hormone products have been shown to inhibit the development of BER in tomato at low calcium availability (Saure, 2014). However, none of these products are currently available for use. Improving plant establishment may contribute to reducing plant stress, known to be a contributing factor in tipburn development in lettuce (Saure, 1998).

Storage

Treatment with calcium either in the field or prior to storage has been illustrated to improve shelf life in a wide variety of crops, for example pre-harvest application of calcium chloride improved shelf-life in both strawberry (Bakshi *et al.,* 2013) and broccoli microgreens (Kou *et al.,* 2014). Treatment of figs with calcium chloride post-harvest but prior to storage was also observed to impair growth of bacteria and moulds and increase shelf life and quality (Irfan *et al.,* 2013). Microbial products may also have a part to play in reducing the development of rots in storage. *Bacillus subtilis* isolates were found to inhibit storage rotting in yam (Okigbo, 2005). An HDC research project (FV 439) is currently underway focusing on improved storage of pumpkin, and it is likely that the findings of this project could also apply to courgette. However, unlike pumpkins, courgettes are unlikely to be stored for long periods of time, and this may not reflect such a critical control point. A chilled storage environment, though observed to reduce development of rot, is unsuitable for courgettes as they are prone to chilling injury and pitting (Carvajal *et al.,* 2015a). However, it has been illustrated that pre-treatments (Carvajal *et al.,* 2015b) or packaging fruit individually can reduce injury (Megas *et al.,* 2015). Manipulation of environmental conditions, such as use of ozone, may also contribute to improved courgette storage (Glowacz *et al.,* 2015) as well as treatment with UV-C (Erkan *et al.,* 2001).

Discussion & Conclusion

It is likely that the condition termed 'blossom end rot' in UK courgettes is a combination of a number of factors. Localised calcium deficiency at the blossom end of fruit would serve to weaken the fruit structurally and leave it more vulnerable to invasion by pathogens. A variety of pathogens were found to be present on courgette fruit sampled, and it is also likely that wet flowers that do not easily detach facilitated pathogen entry to the fruit. A trend for lower calcium concentrations at the blossom end of fruit may be evident for some sites sampled, but for this to be confirmed a larger sample size would likely be required.

Objective 3 - To critically evaluate potential solutions for immediate uptake by courgette growers

Promising alleviation and control options arising from the literature review were critically evaluated by level of current uptake, practicality, cost and possible efficacy. Possible solutions suggested by growers themselves or in technical literature were also considered. Communication with growers, fertiliser and pesticide companies and other industry professionals allowed options to be ranked. Each option was awarded a score on a 1-3 index for each criteria, with scores awarded further explaining in the table header. Ultimately, each option was awarded a final score, reflecting suitability for uptake. A summary of options can be seen below (Table 14).

Table 14. The most promising treatment options for blossom end rot in courgette are evaluated

Treatment option	Current uptake	Potential efficacy	Ease of implementation e.g. R & D required?	Initial cost to grower	Ongoing cost to grower	Practicality for grower	Overall score
Highest score of 3 awarded	**High uptake**	**High efficacy**	**Easily implemented**	**Low cost**	**Low cost**	**High practicality**	**out of 18***
Fertigation	Low - 1	3	2	1	2	1	10
Foliar fertiliser	Increasing - 2	2	2	3	1	3	13
Mulching	Common - 3	2	3	1	2	1	12
Flower removal	Low - 0	1	3	2	3	1	10
Removal of waste	Very low - 0	1	3	2	3	1	10
Variety choice	Some - 2	2	0	3	3	3	13
Post-harvest treatments	Very low - 0	1	1	2	2	1	7

*Higher score indicates more useful options

In light of the scoring system summarised in Table 14, it appears that the most suitable options for immediate uptake would be use of foliar calcium-containing fertiliser, mulching and variety choice. Storage treatments or manipulation of storage/transport conditions may be impossible for some growers who do not store their own produce and are not in full control of their own logistics. Furthermore, unlike some other cucurbits, courgettes are not suitable for storage for more than a few days, which would give any potential treatments a limited time to have an effect. Removal of trash or of flowers that are reluctant to drop on their own would no doubt contribute to best practice, but the exact impact on BER incidence is difficult to quantify. This could also represent a considerably increased labour cost, and it has been reported that damage can be done to setting fruit should the flower be removed too soon. Fertigation, though promising and likely to preclude any nutritional deficiencies occurring, would represent a considerable financial outlay, and disruption to cropping. Where land is rented, or where rotation with other crop species (especially those where fertigation would convey no benefit) occurs, installing costly infrastructure would also not be practical. Supplying calcium at the root zone rather than to the foliar parts of the plant means it is more effectively taken up by the plant, so on grower holdings where irrigation such as t-tape is already installed, this may be a practical, effective option. It is unlikely a crop would need irrigation throughout the whole season, but treatments could be focused to points in the season where blossom end rot was a significant risk (e.g. wet, humid weather).

There are a variety of calcium based foliar feeds currently available on the market, as well as a number of other trace elements that growers may apply. Some growers apply trace element sprays already, so this option would require lower initial outlay of costs and represents a more practical option. However, it is necessary to apply calcium regularly for maximum effect and it is likely that a set programme of sprays is required, rather than a knee jerk reaction to an already visible disorder. The most commonly used products, and recommended application programmes are summarised below (Table 15).

Table 15. A summary of potential calcium-containing foliar products available to UK growers (not an exhaustive list)

Product	**Calcium containing ingredient***	**Recommended rate**	**Recommended timing**
InCa	5% Ca	1 L/ha, 1.5 L/ha if water vol exceeds 600 L	1st flower to harvest, every 7-14 days
Stopit	160 g/L Ca (22.5% w/v CaO)	5 L/ha recommended for tomato in 200 L water	Every 7-14 days
Calmax	15% Ca w/w (as CaO)	3.5-8.5 L/ha (minimum 200 L water) for various, courgette not listed	14 day intervals suggested
Calmag max	2% chelated Ca (glucoheptonate) + 4% Mg	2-5 L per 200 L water	At least 6 times a season

Tecal	CaO 7% w/v (+ other elements e.g. 0.1% B)	20 Litres per Ha in 80-200 L of water	At 4-6 true leaves, then every 2-4 weeks. Spray when abiotic stresses on crop
Agroleaf Power Calcium	6.4% total Ca (9% CaO), 0.04% B	Dissolve 3 – 5kg of in 200 – 1000 liters of water per ha	Recommended during fruiting

*Note that products may also containing other oxides/elements and the information available varies

In general, single or few bulk applications will be ineffective in solving any localised deficiencies over an entire season, and a planned programme of multiple, smaller applications is advised for maximum efficacy. As such, foliar sprays may represent a more practical option for growers, and could be taken up immediately with no cost at the outset. However, a large number of products are available and some have limited or no information on their application to courgette, as such care must be taken to avoid low quality products, phytotoxic effects or making applications needlessly. It is also likely important to target application to times when conditions favouring BER development are likely to occur. A formal evaluation of the numerous products currently marketed to courgette growers may prove useful in establishing if applications are worth the time and cost, and in establishing how many sprays are required, and how frequently.

Knowledge and Technology Transfer

HDC News article (to be in February issue)

PowerPoint presentation at cucurbit grower group meeting, 19th January 2016

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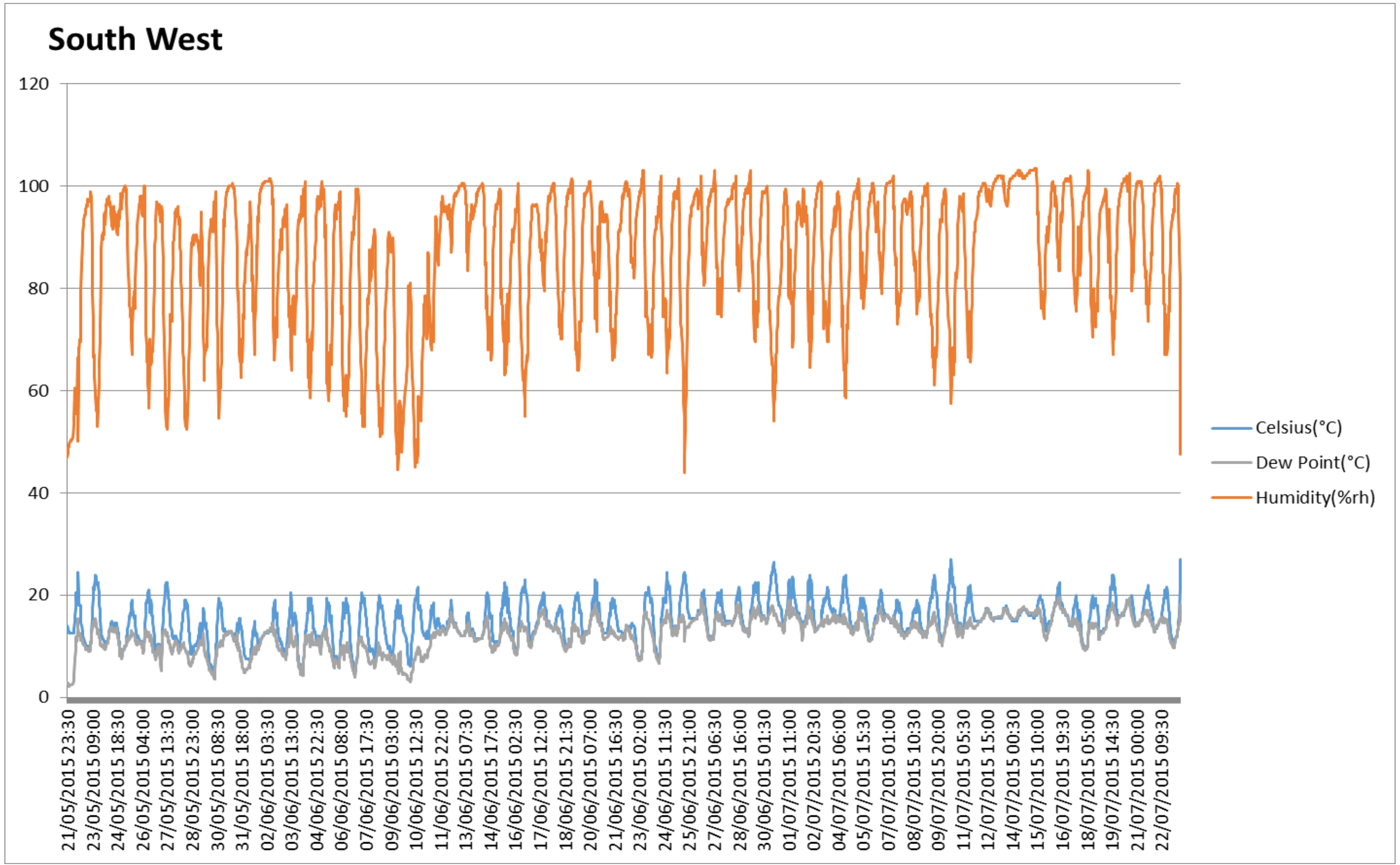
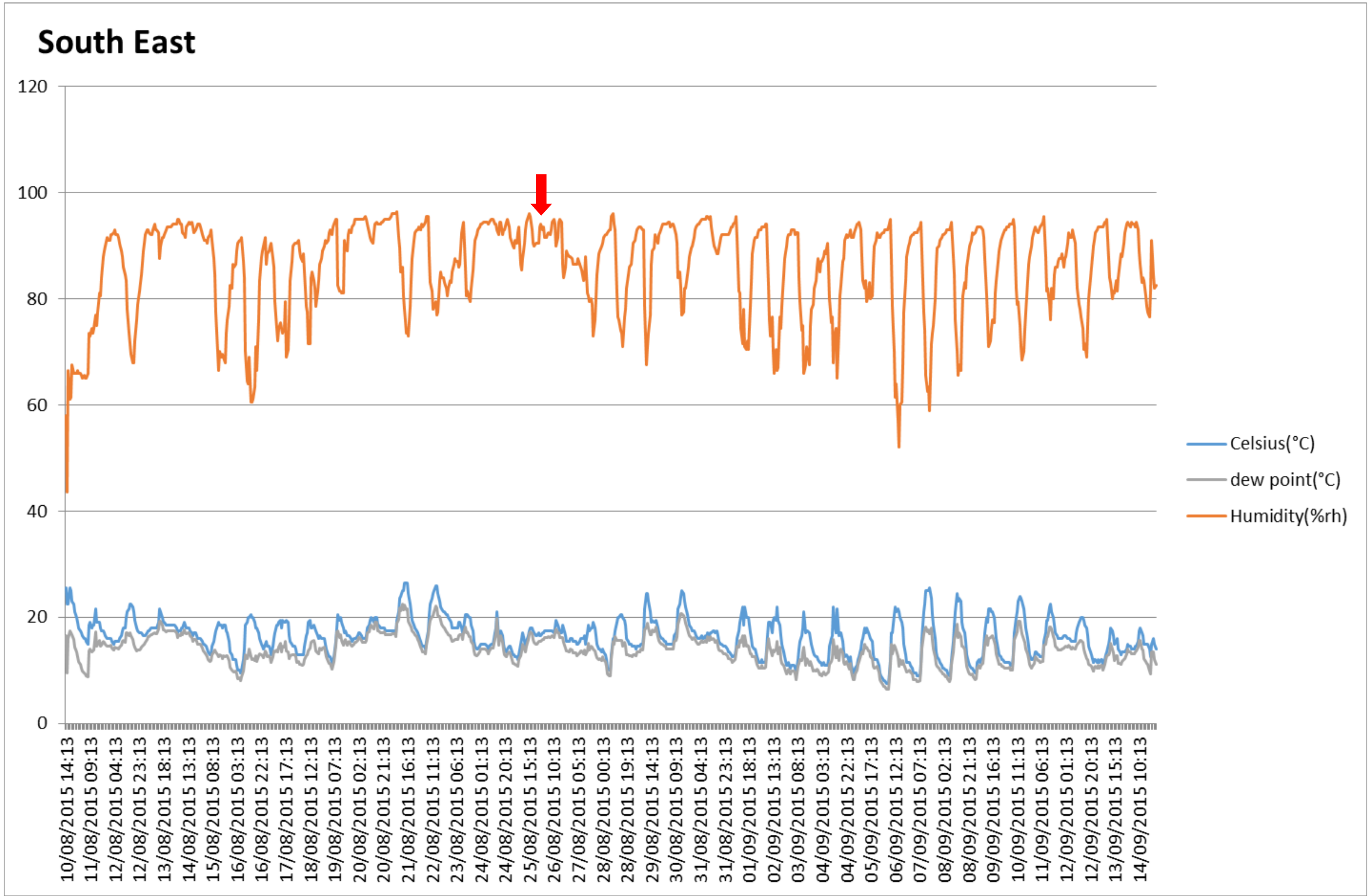
Appendices

Appendix 1. Temperature and humidity data from four monitored sites (red arrows indicate first occurrence of BER; South West logger was lost before BER was reported)

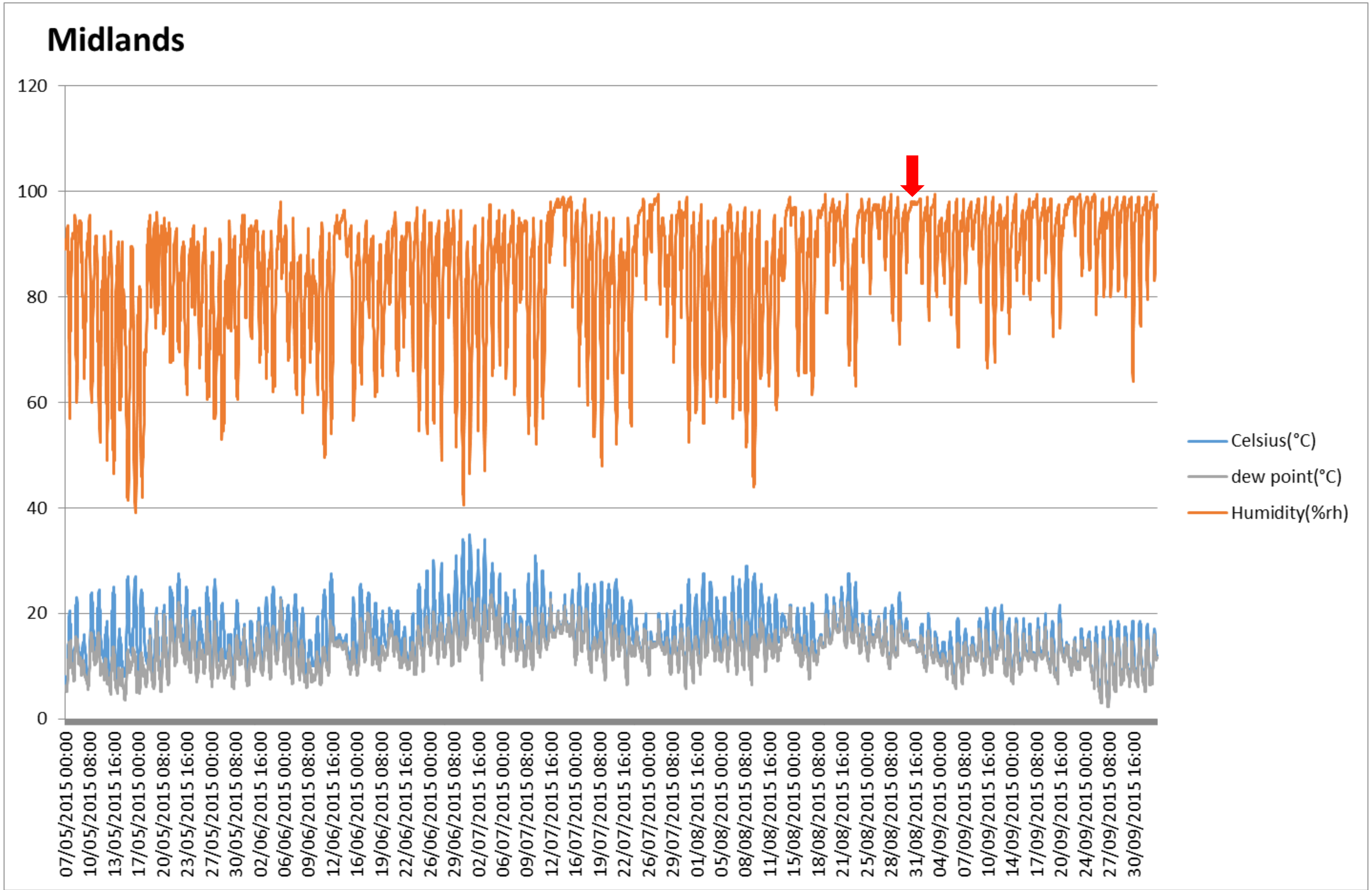
Weather Data – South West



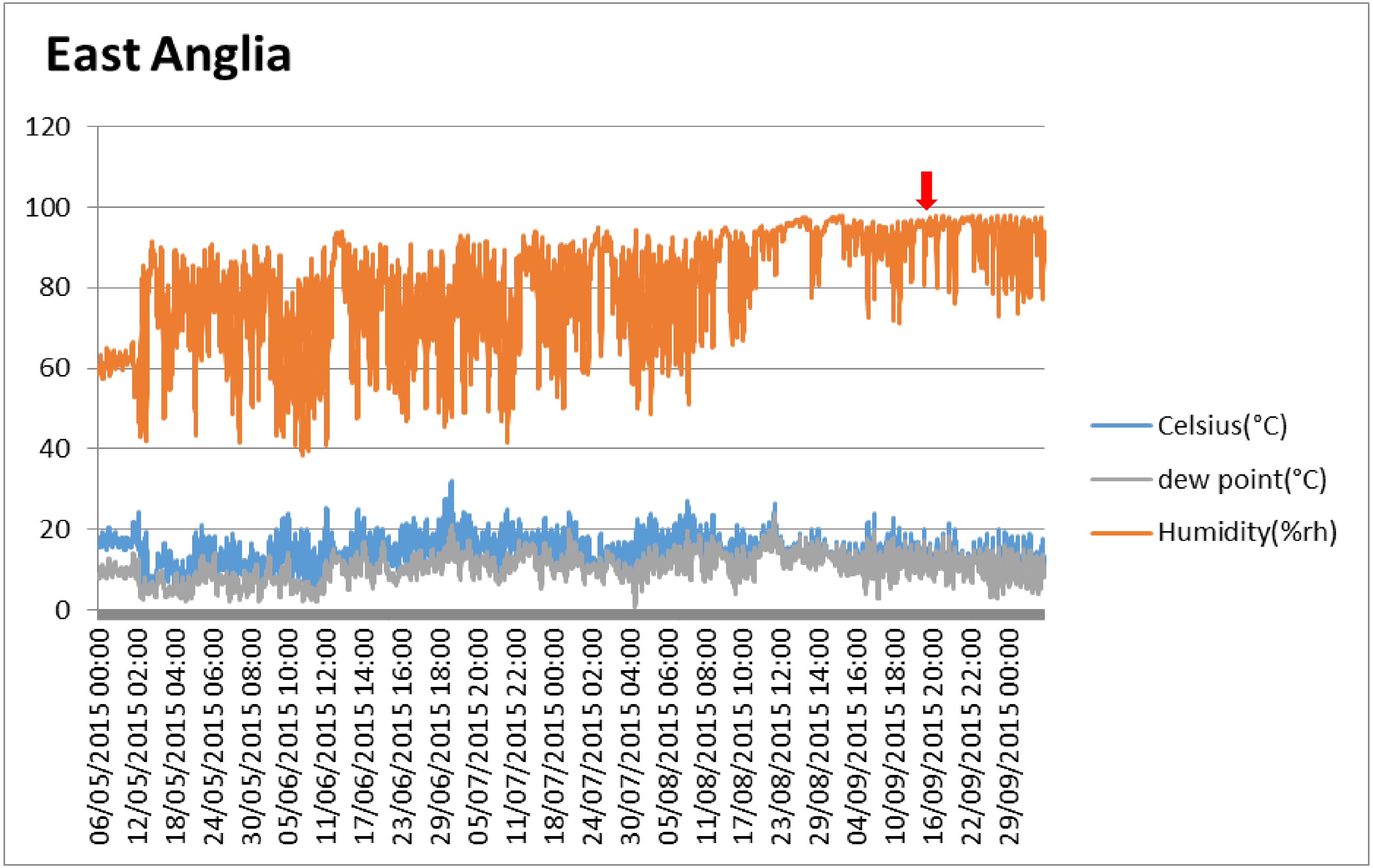
Weather data – South East



Weather data – Midlands



Weather data – East Anglia



Appendix 2. Averaged results of nutrient analysis of courgette fruit for all nutrients included, all sites

	Total Nitrogen DUMAS	Total Phosphorus	Total Potassium	Total Calcium	Total Magnesium	Total Sulphur	Total Manganese	Total Copper	Total Zinc	Total Iron	Total Boron	Dry matter
	% w/w	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
South West												
Healthy fruit	3.47	8168.00	41699.00	3250.00	2789.50	1972.50	17.85	14.10	58.85	151.00	19.30	7.25
BER end	4.83	9296.40	47735.80	2712.60	2602.60	2291.00	27.42	18.30	66.68	337.60	22.38	7.70
BER mid	4.80	8897.00	44716.33	2479.33	2477.67	2202.67	20.43	16.77	64.40	214.00	20.07	7.03
BER stalk	4.25	8395.50	40653.00	3121.50	2238.00	2107.25	19.83	14.80	58.88	268.50	14.70	8.30
East Anglia												
Healthy fruit	5.14	9606.50	47701.00	5333.00	4014.00	2547.00	23.25	14.50	94.20	182.00	23.00	5.60
BER end	4.76	10617.00	48787.75	6091.75	3942.25	2507.25	20.95	13.15	81.03	215.50	29.43	4.70
BER mid	4.62	9768.75	41456.00	5206.00	3691.50	2411.00	21.35	12.70	86.48	167.75	25.63	5.03
BER stalk	4.12	9040.25	43138.25	7038.25	3989.75	2247.25	16.73	11.80	71.95	151.25	19.13	4.60
South East												
Healthy fruit	3.27	7427.00	38139.00	2584.00	3307.00	1945.50	20.75	13.60	60.30	105.70	25.75	4.15
BER end	3.55	8712.75	46003.50	5060.50	3884.50	2326.50	27.15	15.68	66.08	207.00	30.83	4.65
BER mid	3.56	8821.25	46308.00	4450.25	4031.25	2343.50	33.28	16.25	72.80	322.00	29.20	4.60
BER stalk	3.10	8341.50	43617.75	5665.25	4017.50	2185.75	21.03	15.30	68.93	143.50	22.40	4.63
Midlands												
Healthy fruit	5.16	6991.00	61530.00	5349.50	3436.00	3026.50	21.95	11.30	61.85	141.00	28.30	5.25
BER end	3.93	8223.75	52479.00	8719.25	3771.50	2539.00	54.28	15.48	59.20	2392.75	29.25	3.98
BER mid	3.88	8633.75	53375.50	8490.25	3736.25	2719.50	37.88	15.98	64.43	1010.50	29.70	3.50
BER stalk	3.75	8644.00	55482.75	9632.00	4044.75	2465.50	21.65	14.95	60.28	381.75	24.63	3.75

