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European Innovation Partnership (EIP) Wales

Improving Knowledge and Experience of Micronutrient Management in Cucurbit Production in Wales

Final Report

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GENERAL NOTES

Title: Improving Knowledge and Experience of Micronutrient Management in Cucurbit Production in Wales

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About EIP-AGRI

The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) was launched by the European Commission in 2012. It aims to foster a competitive and sustainable agriculture and forestry sector that "achieves more from less". It contributes to ensuring a steady supply of food, feed and biomaterials, and to the sustainable management of the essential natural resources on which farming and forestry depend, working in harmony with the environment.

EIP Wales

Menter a Busnes delivers the EIP Wales scheme on behalf of the Welsh Government and has received funding through the Welsh Government Rural Communities – Rural Development Programme 2014-2020, which is funded by the European Agricultural Fund for Rural Development and the Welsh Government.

For Welsh farm and forestry businesses to remain competitive, profitable and resilient, they will need to work on a continuous programme of improving both business and technical practices.

The aim of EIP Wales is to solve common agricultural and forestry problems by bringing people from practical and scientific backgrounds together. It's an opportunity for farmers and foresters to put their ideas into practice by testing new technologies or techniques.

This project aimed to evaluate micronutrient management approaches in commercial cucurbit crops. Cucurbits can offer increased resilience to farm shop-style businesses, with high-value returns from pumpkin pick-your-own (PYO).

A common problem within this crop group is blossom end rot (BER) which can render fruit unmarketable. It is believed that management of crop calcium nutritional status may provide a key method of controlling BER.

This project aimed to investigate the impact of foliar applications of calcium in commercial cucurbit production.

EIP Operational group

The businesses represented in the operational group are:

Organisation	Name	Farm/Location	Role
	Andy Matthews	Aberbran Fawr, Brecon LD3 9NG	Lead Farmers & principal contact
	David Phillips	Clearwell Farm, Pentre-Poeth Rd, Michaelston-y-Fedw, Newport	Farmer (2nd yr of trial)
	Gary Price	Gelynos Farm, Trallong, Brecon	Farmer (1st yr of trial)
FMC Agro Ltd	Geoffrey Bastard	Rectors Lane, Pentre, Deeside, Flintshire, CH5 2DH, UK	Commercial Director, Actor

Other members of the project

RSK ADAS Ltd	Chris Creed	ADAS Horticulture	Horticulture Specialist procured to carry out to work with the farmers
RSK ADAS Ltd	Ewan Gage	ADAS Horticulture	Horticulture Specialist procured to carry out to work with the farmers
RSK ADAS Ltd	Aldwyn Clarke	Canolafan Enterprise Park Llanafan Ceredigion SY23 4AY	Senior Scientist procured to carry out crop assessments
RSK ADAS Ltd	Guy Johnson	ADAS Horticulture	Horticulture Specialist procured to carry out work with the farmers
RSK ADAS Ltd	Will John	Henstaff Court Business Centre, Groesfaen, Cardiff CF72 8NG	Innovation Broker

EXECUTIVE SUMMARY

This project sought to trial novel micronutrient management approaches in commercial cucurbit crops. Cucurbits include several important crops, including courgette, marrow, pumpkin and squash. These crops are robust and can be grown in a variety of field conditions offering increased variety to farmshop-style businesses, or high-value returns from pumpkin 'pick -your-own' (PYO). As field crops, they can also be integrated into a mixed cropping system or offer an accessible diversification crop for arable farms. Historically a limited range of ornamental pumpkins have been grown with focus on conventional smooth orange types, although there has been a significant growth of alternative varieties in recent years, including warted skin, white rind or edible varieties with greater flesh texture and flavour. The outputs of this project are relevant to edible pumpkin and squash production which can offer a late-season vegetable for farmgate and vegbox sales, helping to address potential wastage issues from ornamental pumpkin production.

A common problem within this crop group is the development of rots which can render the fruit unmarketable, with blossom end rot (BER) the most common incidence. Rots develop when fungal (e.g., Fusarium, Botrytis) or bacterial pathogens become established in the developing fruit through a wound (e.g., cultivation or frost damage) or through decaying flower material at the blossom scar on the fruit base. Rots develop rapidly in damp conditions, especially where the flower does not fully abscise from the fruit providing an initial foothold for disease development.

The development of rots in the field is linked to several risk factors including climate, site location, local disease pressure and plant nutrition status. It is therefore difficult to understand how just one of these areas impacts overall disease development in isolation, but project results suggest that improving crop access to calcium using foliar feeds can be beneficial in reducing the incidence of rots in the field, and the progression of rots once they become established. Project results also suggests that different formulations of calcium can have different levels of effect, and therefore growers should be careful to consider all evidence when choosing a foliar feed rather than absolute calcium content. For example, three products which had comparable total dosage rates of calcium achieved markedly different effects in the mitigation of rot development. This would suggest that different formulations impact the ability of the plants to uptake and utilise calcium to strengthen tissues against pathogen invasion.

Future studies would benefit from a longer study period to understand further the relationship between rot development, plant nutrition and climate effects to better inform growers as to the risks of rot development and effective ways of mitigating them. The rot risk is a complicated interaction between these factors, and the late onset of damage sufficient to impact market quality can be traced back to a number of potential infection windows during crop development, such as infection from early pollination if there is high spore pressure during flowering. Furthermore, it would be beneficial to further understand the timing and dose requirements for optimum control of BER to ensure that maximum impact can be derived from this approach. Growers were keen to explore all opportunities for reducing BER, and improving their crops in this increasingly competitive market. Feedback indicated that from a practical and labour point of view spraying would be feasible every 3-4 weeks during early development, but difficult to continue following full canopy closure. The project 'actor' was aware of the impact of BER and keen to look at options to reduce incidence and agreed with the comments in the report.

CONTENTS

1 INTRODUCTION

1.1 Background and Introduction to the Sites

All three growers involved in the trials were located in South East Wales. Two growers grew pumpkins for direct-to-customer sales through pick-your-own (PYO) (Aberbran and Clearview), while the third site (Gelynos) grew for the wholesale market (although these are typically sold to other PYO growers for field restocking). The growers were interested in trialing novel micronutrient management approaches in commercial cucurbit (pumpkin) crops to reduce the impact of rots on the productivity of their land. Cucurbits include several important crops, such as courgette, marrow, pumpkin and squash. These crops are robust and can be grown in a variety of field conditions and can offer increased variety to farmshop-style businesses, or high-value returns from pumpkin PYO. PYO sales also fit with other farm tourism-orientated businesses (e.g., soft fruit or Christmas tree PYO) and can offer significant returns compared with conventional field crops. However, as field crops, they can also be integrated into a mixed cropping system or offer an accessible diversification crop for arable farms. While pumpkin has historically been grown as an ornamental crop, there has been continued growth of pumpkin as an edible crop with a number of prominent eating varieties now available to growers.

A common problem within this crop group is the development of rots which can render the fruit unmarketable, with blossom end rot (BER) the most common incidence (Figure 1). Rots develop when fungal (e.g., *Fusarium*, *Botrytis*) or bacterial pathogens become established in the developing fruit through a wound (e.g., cultivation or frost damage) or through decaying flower material at the blossom scar on the fruit base. Rots develop rapidly in damp conditions, especially where the flower does not fully abscise from the fruit providing an initial foothold for disease development.

Figure 1. An example of blossom end rot (BER) in pumpkin

The incidence of BER can be highly variable between different crop types and cultivars, although it can lead to significant crop losses and it is one of the primary sources of wastage in this sector. The development of rots can occur after harvest, significantly reducing shelf life of stored material. Fruit which are left in the field for marketing purposes (e.g., PYO pumpkins) or due to the lack of suitable storage conditions are particularly vulnerable to rot development through exposure to damp conditions. A limited range of fungal plant protection products are available, but as these are generic fungicides their use in an open field setting may be unsuitable. Furthermore, an evolving body of evidence supports the implication that crop nutrition issues provides a predisposition to rot development and it is this area that the project sought to address.

Disease Mitigation and Nutritional Management

Whilst a pathology issue, the development of BER is likely to be linked with crop nutritional status. Rots develop as soft, sunken, watery areas of rind which widen and collapse inwards into the fruit cavity as cells rupture and collapse, leading to further development of infection. Fruit with thin, poorly cross linked cell walls as part of a poorly developed rind are more vulnerable to BER development, and cell wall formation and development is strongly linked with crop nutritional status. Of primary impact is the availability of calcium in the fruit, and BER has been described as a physiological disorder due to localized calcium deficiencies in tomato, pepper, aubergine and watermelon (Taylor & Locascio, 2004). Correlation has been demonstrated between achieved calcium concentrations in the fruit and the development of BER, with the suggestion that higher levels of calcium improve cell membrane stability, improve strength and stability of the cell wall alongside a range of other biological processes (Suzuki *et al*., 2003; Jarvis, 1984; Biggs *et al*., 1997). Furthermore, poor calcium nutrition has been shown to negatively impact the ability of cucurbits to absorb and utilize other mineral nutrients such as nitrate, potassium and phosphorus (Prasil, 1975; Bavarri *et al*., 1999). In addition to calcium, the availability of boron has been implicated in improving the crop resilience to BER development due to its role in cell wall development and plasma membrane function as boron deficiency in pumpkin reduced cell wall thickness (Ishii *et al, 2001)*.

Nutrition Management

The management of calcium for the control of BER is confounded by a number of factors. While calcium (as the Ca^{2+} ion) shows reduced solubility at pH ranges targeted for cucurbits (pH 5.5 – 7.5) there should be sufficient calcium available for the crop, especially in soils that have been recently limed (although leaching is of concern in sandy or heavily irrigated soils). However, soil availability of calcium does not impact its uptake as long as levels are above a minimum threshold. The limiting factor on calcium uptake is the way it is transported through the plant. Calcium is transported in the xylem, so its rate of uptake and transport within the plant is directly related to the transpiration rate – the rate at which water is moved through the plant – and in conditions where transpiration is reduced (e.g., low soil water or high humidity) uptake of calcium will be reduced. Furthermore, the deposition of calcium in growing tissues is linked with the uptake of water at the roots and the flow of water through the xylem. Organs like leaves, which see a high rate of evapotranspiration, will see high concentrations of calcium, while organs which receive lower inwards flows from the xylem, like fruit, will see lower concentrations of calcium. In large fruits, greater levels of calcium deposition may be seen at the top of the fruit near the calyx, reducing by a gradient to the distal end of the fruit. This may weaken tissues at the fruit base, which coupled with the increased risk of infection penetration through the flower scar, leads to a heighted risk of rot development.

These aspects render nutritional control of BER through traditional approaches difficult in cucurbits. Calcium levels in the soil may be within desired thresholds, but restrictions of calcium uptake and movement to the fruit can still lead to suboptimal concentrations in the developing tissue. Nutritional testing of soil and foliar samples may not yield sufficient information about the nutritional status of the fruit. Deficiency symptoms are readily identifiable in the canopy (patchy chlorosis and necrosis and stunting of developing younger leaves) but as foliar calcium levels typically exceed that of fruit the canopy may appear healthy while poor nutritional status in the fruit leads to a high incidence of BER. Conventional management approaches are a preliminary step in mitigating BER, but these are of limited impact. Soil sampling and targeted fertilizer management can be used to ensure that levels of competing nutrients (e.g., ammonium, potassium) are maintained at the correct ratios, and to avoid high nitrogen levels (which can promote high growth rates which risk outpacing calcium supply). Ensuring adequate soil water status (e.g., through targeted irrigation) can ensure calcium uptake and use is promoted. However, these actions can only provide a foundation against which other factors (e.g., environmental influence on growth and transpiration rates) are overlaid.

Innovative Nutrition Management Approaches

As demonstrated above, management of crop calcium/boron nutritional status may provide a key method of controlling the incidence of BER, a key source of crop wastage. Use of nutritional control is precluded by the poor correlation between soil and crop nutritional status. This project sought to gain experience of innovative methods of nutritional management in cucurbits which could overcome this by uncoupling plant and soil nutritional status for BER control. We planned to investigate the impact of foliar applications of calcium in commercial cucurbit production. In this approach calcium is applied to the leaf and fruit surface as a mist, which is then absorbed either directly through the cuticle or through the stomata/lenticels. This provides a secondary source of nutrients that is separate from the constraints of soil uptake. Foliar feeding has been shown to have significant effect on the post-harvest longevity of fruit crops (e.g., apple) and there is emerging evidence that similar effects can be seen in cucurbits with foliar applications increasing fruit calcium content in melon (Bouzo & Cortez, 2012), and foliar feeding of calcium reducing rots in musk melon (Kuti & Boehm, 1994).

While the evidence supporting foliar feeding is well established, there is a scarcity of practical knowledge regarding its use, especially in niche crops such as pumpkin where information relating to optimum application rates and timing are not available. Furthermore, a wide range of commercial formulations are available which are comprised of different calcium forms (e.g., solubilized calcium oxide, or calcium chelates) in conjunction with different additives which may enhance uptake or promote growth through other routes (e.g., biostimulants) or additional nutrients (e.g., magnesium). Some commercial products are suitable for use in organic systems, providing growers with a way of enhancing crop nutritional status while fulfilling the requirements of organic production for higher-value produce. Evidence is scarce relating the comparative benefits of these products, alongside how their application can be managed to maximize the potential benefits e.g., timing of application relative to growth stage, growing conditions and cultivar. Technical experience of application methods (e.g., volume dilution, nozzle settings) is also in need of development. The cost of application varies significantly, and the absence of sufficient evidence for a cost: benefit analysis of application hinders commercial uptake of this approach. The niche nature of pumpkins as a field crop means that manufacturers guidelines are often absent for pumpkin, whilst generic recommendations for field vegetables may be unsuitable.

It is these knowledge gaps that were to be addressed over the course of this project. The project was formulated to test the efficacy of a variety of commercially available products in a range of settings and crops to produce core evidence as to the potential for foliar calcium applications to mitigate the risk of rot development in the field.

Project Ideation

The concept of this project was developed as a result of a shared challenge faced by each grower. Two of the three growers involved in the trial have developed pick your own pumpkins (PYO) as a diversification away from other cropping models, with the third site either selling wholesale or direct supplying nearby PYO enterprises. PYO pumpkin represents a high value product (reaching c. £1.50/fruit for small sizes, £5/fruit for standard sizes, or £10 for large varieties) or potentially up to

£40k/ha assuming a target density of 1 fruit/m^2) that can be marketed directly to the customer over a very narrow period that integrates well with other marketing models (e.g., Christmas trees), making it more attractive than conventional PYO crops (e.g., strawberry). However, to fully exploit this model crops must be left in the field and can only be marketed in a very narrow window approaching Halloween. As a result, post-harvest rots are a significant risk that can substantially impact marketable yields and can impact the customer experience, especially in warm, wet autumns when the crop matures early. This approach was considered as an additional route in the mitigation of BER that does not rely on ineffective conventional approaches. However, as no evidence is available as to the potential benefit of these products for BER control in pumpkin it can be difficult for growers to adopt this approach. Therefore, this project set out to test the benefits of foliar calcium feeding for BER control in Welsh PYO practice.

Project Objectives

1. To gain experience of commercially available foliar feed products, with technical evidence for best practice use guidance for a range of products.
2. To develop an evidence base to guide the decision-making process for foliar feeding, using commercially-relevant data to identify the positive effects that can be achieved by foliar feeding.

To produce a holistic review of nutrition management in cucurbit production to reduce the incidence and severity of BER, reducing wastage and requirement for fungicide application in commercial production in Wales.

1.1.1 Aberbran Fawr Farm

Aberbran Fawr is a mixed farm, located near Brecon (Figure 2) where pumpkins are grown for PYO. Annual rainfall for the area taken from Manner NPK is 1,417 mm per annum. The project sites were located between 160 and 200 metres above sea level. Soil type from soil maps indicates that the Year 1 field is Oglethorpe Association, a well-drained loam over red sandstone while the Year 2 field was of the Milford Association, a freely draining, fine loamy soil over rock. Aspect is north-westerly.

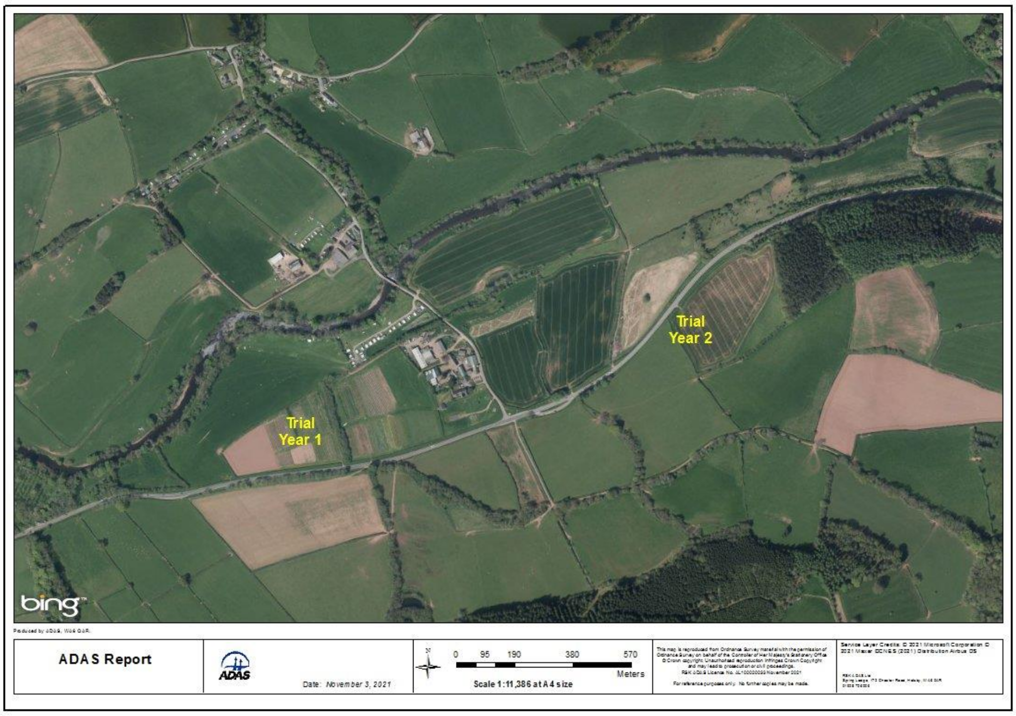

Figure 2. Aerial imagery of Farm showing topography

1.1.2 Gelynos Farm

Gelynos is also a mixed farm, located near Brecon (Figure 3) where pumpkins were grown for wholesale in Year 1 of the trial. Practicalities relating to the timing of sprays and commercial issues meant that the farm was unable to commit to the trial in year 2. Annual rainfall for the area taken from Manner NPK is 1,417 mm per annum. The project location was 190-200 metres above sea level. Soil type from maps indicates that the Year 1 field is of the Oglethorpe Association, a well-drained loam over red sandstone. Aspect is southerly.

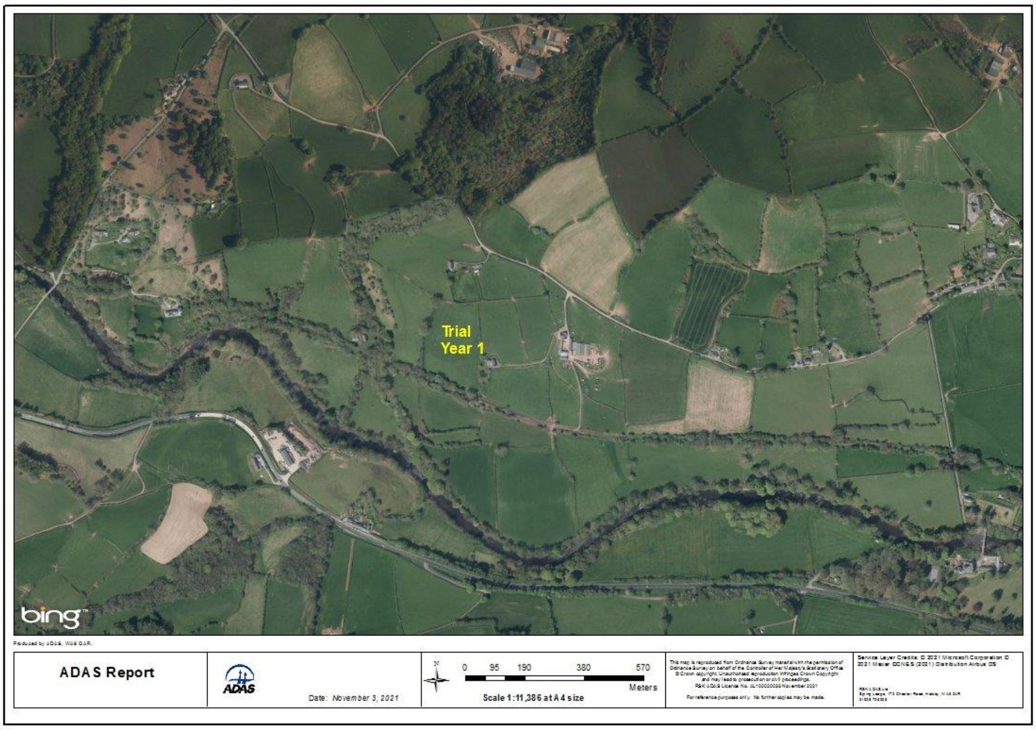

Figure 3. Aerial imagery of Farm showing topography.

1.1.3 Clearwell Farm

Clearwell Farm is a mixed farm, situated near Newport (Figure 4) where pumpkins were grown for PYO in the 2nd year of the trial, replacing Gelynos. Annual rainfall for the area taken from Manner NPK is 1,077 mm per annum. The project location was at 90 metres above sea level. Soil type from maps indicates that the fields are of the Salwick Association, a deep red loam of glaciofluvial origin. Aspect is north-westerly.

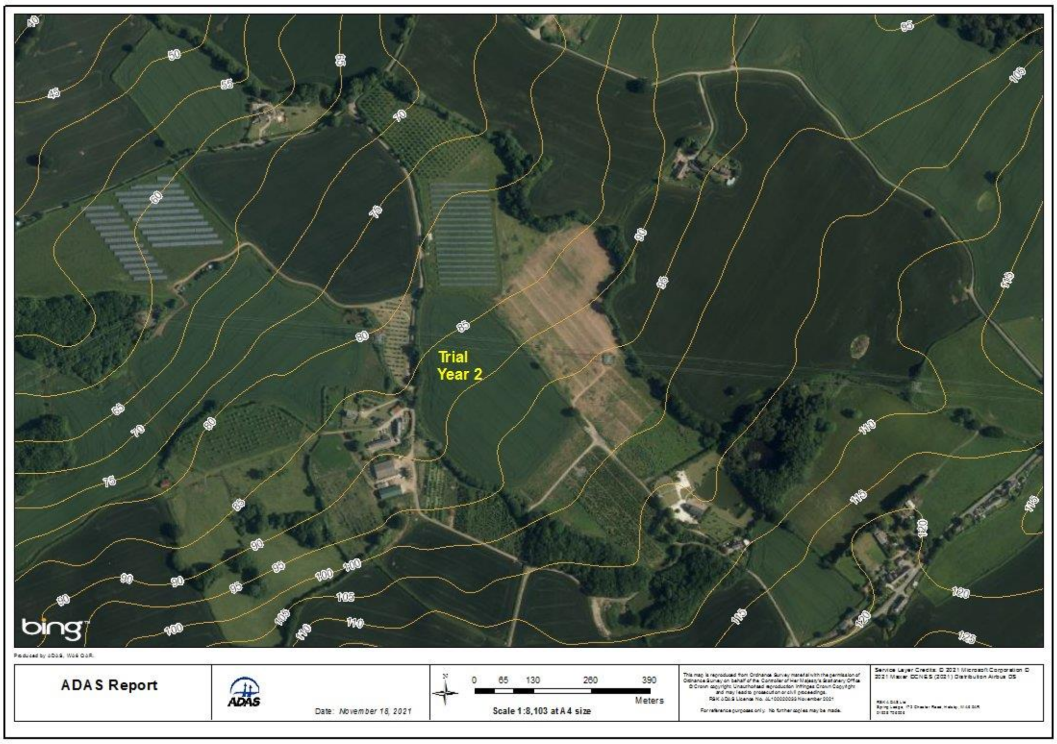

Figure 4. Aerial imagery of Farm showing topography.

2 METHODOLOGY

2.1 Experimental Design

The experimental design and implementation was led by the ADAS Horticulture Team, procured in line with Welsh Government (WG) protocols in conjunction with the host farmers.

The plan involved carrying out field-scale trials over two seasons at commercial grower sites. BER rot risk can vary significantly between seasons and sites, so the use of multiple sites over multiple seasons provided a more robust test of the potential benefits of supplementary calcium provision. Due to commercial pressures, it was not possible to carry out trials at Gelynos for the second season, and so Clearwell farm was identified as an alternative site – it was particularly beneficial that both Clearwell and Aberbran grew for the PYO market to provide the most robust test of this approach as products would be left in the field for the maximum amount of time before retail, rather than earlier harvest for wholesale.

Up to five commercially available foliar feed products were trialed at each grower site in comparison with an untreated (water spray) control plot. Initial planning meetings at the start of each season between the host grower, project mentor and project actors were used to identify which products would be utilized, and to agree an application schedule for each product. On-label recommendations for application and dose were followed, although products were selected with comparable application requirements to facilitate trials work. Technical aspects of application (e.g., frequency of application, appropriate nozzles and water volume) were identified through consultation with project actors/mentor and manufacturers/distributors of the relevant products. Identification of the trial site, and soil sampling to determine current nutritional status, also supported this process.

Whilst it would have been preferable to select a single variety for trial use (e.g., cv. Harvest Moon), this was not possible (especially in the second trial year) as the grower sites grew a wide variety of pumpkin cultivars in mixed cultivation. This is reflective of common PYO practice where multiple varieties are grown together to achieve a range of pumpkin types for customers including a wide range of pumpkin sizes (e.g., monster to mini munchkin), rind types (e.g., smooth or warted) or colours (orange or white). Edible varieties tend to be of similar size and agronomic need as standard size orange pumpkins, and so the evidence collected here will be directly translatable to edible pumpkin production. Assessments were suitably scaled to ensure scientifically valid results were produced whilst allowing for secondary testing of the interaction between cultivar type and treatment. While other cucurbit lineages are equally susceptible to BER (e.g., marrow) these are of considerably smaller market value compared with PYO pumpkins. In addition, PYO pumpkins were left in the field as opposed to harvesting and storage. This meant than sub-optimal storage conditions significantly increased the risk of post-harvest rots reducing marketable yield. Furthermore, unpredictable weather conditions and early fruit maturation before the narrow market window around Halloween meant that fruit was left in unideal conditions for extended period of times.

A selection of up to five products was utilized in the trial alongside an untreated control. A range of products were selected to achieve a good representation of the main categories of foliar feed (Ca alone, Ca with N, Ca with micronutrients, Ca with chelators and an organic calcium product). This selection also represented a good spread of products from commercial companies. This product range was developed with inputs from Chris Creed and Angela Huckle (independent agronomists from RSK ADAS Ltd.) and with reference to the AHDB calcium in cucurbit review. Products were applied at the manufacturer's recommended rate. This resulted in varying net calcium applications to the trial crops, but this was unavoidable given different chemistries between the selected products. Indeed, equal application of calcium would not necessarily correspond with equal absorption by the crop (particularly given the use of chelates which promote uptake). In order to accommodate this the calcium content of leaf/fruit tissue was assessed during the project so that total biological calcium was assessed – statistical analysis allowed testing of any relationship between total tissue Ca and BER development. Project outputs refer to the different products by a Code with reference to active ingredient, as opposed to commercial name.

The trial plan adopted at each site is given in Figure 5 below. Each treatment was applied to three replicate blocks, with each block consisting of 10m lengths of four rows. For assessments each border row was discounted to cover the impact of overspray, with the central two rows utilized for assessment. Likewise, the first fruit at the start and end of each row was left unassessed. Assuming a target density of 1 fruit per plant/1 plant per m^2, this made 16 fruit/plot available for assessment.

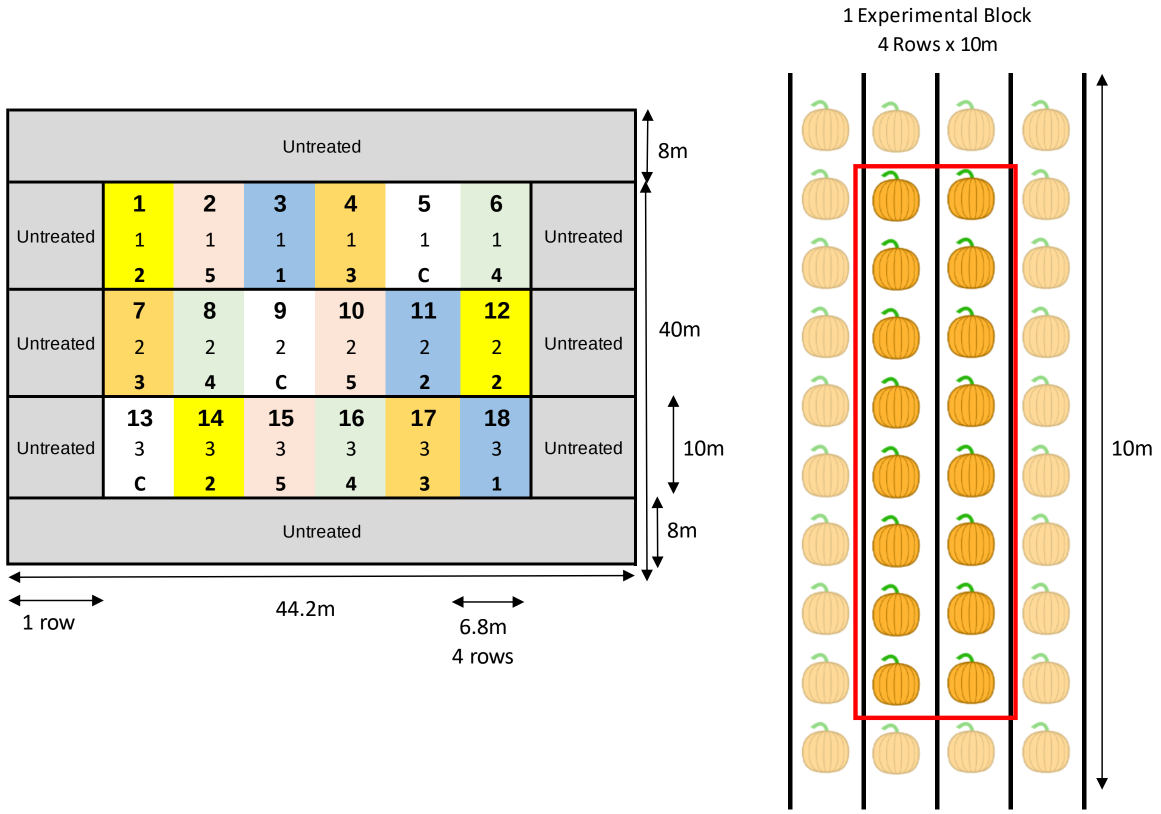

Figure 5. Trial plan at each site. Each treatment was applied over three replicate blocks, with each block comprised of 10m lengths of four rows. The first and last row, and first and last pumpkin plant in each block was excluded from assessments to minimise overspray effects.

2.2 Implementation of BER Management Options and Mentoring

A range of products were selected for inclusion in the trial (Table 1). Rates were based on manufacturers recommendations or extrapolated from comparable crops where these were absent. As a result, some variation was seen in the achieved g/Ha of calcium after application, although the reported benefits of some formulations are that calcium availability to the plant increased through enhanced penetration of the product. Product 3 was included as a general organic foliar feed (rather than a specific calcium product) to test for organic-compatible products. Application rates are given below (Table 1), with each product diluted in 200L of water, and applied at sufficient rates to achieve leaf runoff. All products were applied every 14 days from the onset of flowering, starting from 16 July 2020 until harvest, although logistical issues in year two reduced this frequency to once a month. Samples were taken on 28 – 30 September 2020 in the week preceding the start of marketing in the run up to Halloween.

Table 1. Foliar spray products utilised in the trial.

Product Code	Formulation	Rate (L/Ha)	Calcium Content			Achieved g/Ha
			w/w	w/v	g/l	
N/A	Untreated	0				
2	CaO in a propriety formulation including AXM to promote calcium uptake in periods of low metabolic activity.	2	14.5	21.8	218	436
3	CaO-based organic growth stimulant containing concentrated extract of kelp species *Ecklonia maxima*. Approved as an unrestricted input by the Soil Association.	3			0.8	2.4
4	Calcium formulation including amino acids ($Ca_5H_4N_{12}O_{33}$), plant sugars, lignates and surfactants	3	13.8		138	138
5	Soluble calcium formulation with 30 g/L MgO, 149 g/L N and 300 ppm Zn	5			225	1125
6	Liquid micronutrient fertiliser (calcium chloride solution) for foliar application	5			224	1120

2.2.1 Year 1

Site 1 (Aberbran) had a pH of 5.8 on a sandy silt loam soil with 915 mg/L available calcium, while Site 2 (Gelynos) had a pH of 6.6 on a sandy silt loam/sandy loam with 1035 mg/L available calcium before the start of the trial. Pumpkin cultivation was new to site 1 which had been previously used for fodder swedes for sheep grazing, compared with site 2 which had been used for pumpkins in 2019 following longer term grassland cultivation. Following soil analysis, fertiliser applications and lime were applied in line with RB209 to ensure nutrients were not limiting factors – although slightly less N than that recommended by RB209 was applied (a base dressing of 50 kg N/Ha) as is standard for pumpkin. Standard weed control measures were applied, alongside standard pest/disease management. This included sprays for powdery mildew treatment (e.g., 3 – 4 sprays of Signum, potassium bicarb or Tallius). This was supplemented by hoeing for weed control at Site 1 and Site 2.

Plants for both sites were raised by the same propagator (Cae Melwr, Llanrwst) and were planted at the same time. Pumpkins can either be direct drilled or raised in advance from propagators – both need to be planted around a similar time, although propagated plants can give more even establishment although time will need to be allowed for plants to be ordered and raised in advance. Pumpkins can be established by direct drilling, although this requires a good seed bed and low weed burden. Both growers are relatively inexperienced with the crop and are growing in a cool climate, so propagated plants were considered the easiest route to establishment. Treatments were applied to three replicate plots at each site of 10m lengths of two rows width per site. Plots were separated by 1 row gap, or a 1m buffer strip between plots to prevent overspray (Figure 6). At the target density of 1 plant/m^2, with typical yields of 1 fruit per plant, this layout achieved 1620 fruit per plot for assessment. Fruit numbers were less than would typically be utilised in trials of this nature, but the large fruit size and low density would make larger-scale trials unfeasible.

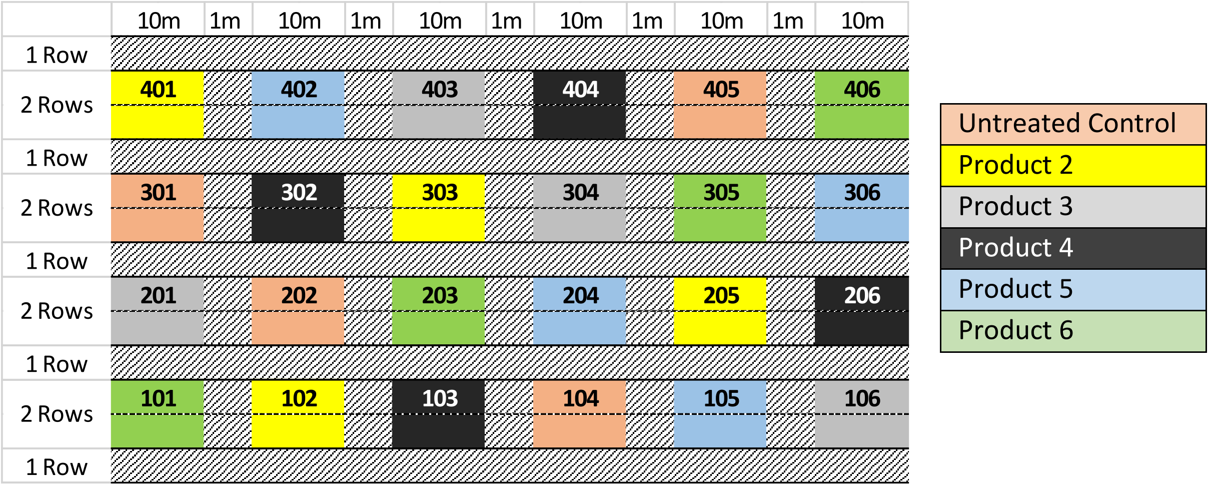

Figure 6. Trial layout replicated at each site. Plot numbers correspond to replicate blocking pattern.

Plots were assessed for flower (male and female) and fruit number during cultivation, alongside healthy and rotted fruit at harvest, and fruit size and powdery mildew incidence on the foliage. At harvest two representative pumpkins from three plots at each site were sampled and stored in mock commercial conditions (20°C with a 12-hour light cycle). Fruit were surface sterilised before wounding and inoculation with *Fusarium* cultures previously isolated from pumpkin as a source material. Fruit were inoculated to ensure that all samples were subject to the same level of disease pressure, rather than relying on natural inoculum (which can show significant variation between different seasons and areas, even within fields) to test for the rate and severity of rot impact. This approach was made further necessary in pumpkin, given the large size of the fruit, giving small numbers per plot compared with other crops (e.g. soft fruit) which would accommodate natural variability due to larger sample sizes. Furthermore, pumpkin may be stored for many months under suitable conditions. Wounding and inoculation ensured that rot development could be studied on a realistic timescale rather that storing produce for far longer than would be seen in normal market conditions. The inoculations did not take, although sufficient disease pressure from natural sources was present to ensure sufficient levels of rot development occurred in storage. Fruit were assessed for rot incidence and severity up to four weeks after harvest.

2.2.2 Year 2

The methodology outlined above was followed into the second year of the project into the 2021 season following adaptation to Site 3 (Clearwell). The trial was established and the first application made on 4 August 2021 (Site 1) and 10 August 2021 (Site 3), with a second application on 9 September 2021 (Site 1) and 15 September 2021 (Site 2). Logistical issues (including the impact of the ongoing covid-19 outbreak) prevented a third application between these dates which would have been preferable. Different varieties were also grown compared with year 1 – site 1 grew Cargo and Ghost (a white pumpkin), while site 3 grew Spitfire.

3 RESULTS

3.1 General Crop Development

Cultivation of crops at all sites was in accordance with commercial norms in both 2020 and 2021, with yields largely in line with grower expectations. Weed development can be a significant problem for pumpkin during early establishment, especially if there are delays in planting the crop due to unsuitable weather conditions in the early season, or where a suitably clean sterile seed bed has not been created before planting. Weed cover was 54% and 51% of ground at harvest in 2020 (sites 1 and 2 respectively) and 54% and 51% in 2021 (site 1 and 3 respectively). Weed cover can be detrimental for the crop through competition for nutrients, water and light, whilst also posing a barrier for customers during PYO marketing. However, weed cover at these sites was within commercial norms, and showed no correlation with treatment as no significant differences were seen in weed cover between treatments in 2021.

The primary disease problem was powdery mildew with 32% and 52% mean incidence in the canopy in 2021 at sites 1 and 3 respectively. However, late season powdery mildew growth is in general left uncontrolled as it can help the canopy to die back to promote fruit development in advance of harvest, and these levels were not outside of typical thresholds. There was also no significant correlation between powdery mildew incidence and treatment in 2021.

3.2 Flowering

Flowering, and the proportion of male and female flowers was assessed at each site over the growing season. Plants which have high nutrient availability are more likely to form unproductive male flowers, reducing the overall production of fruit (**Figure 7**). In 2020 the number of female flowers at site 1 was greatest in the first assessment, although a later flush of female flowers at the site 2 meant there was no overall difference in flower number either between site or between treatment (Table 2). Similarly, in 2021 there were no significant differences between treatments for female flower number at either site. Female flowers are typically formed early in July, which are pollinated and produce fruit over the summer months. Male flowers may be formed over a longer period, especially when formed on supplementary suckers.

Figure 7. Female (left) and male (right) pumpkin flowers.

Table 2. Average flower count at each site (2020 and 2021).

		Flower	Site	Average count per plot					
2020	16/07	Female	1	2.0	2.3	1.0	1.5	2.3	1.0
			2	2.3	2.6	2.3	2.7	3.1	3.1
		Male	1	8.0	9.0	6.3	11.0	8.0	6.3
			2	1.2	0.9	0.9	1.0	1.2	1.0
	30/07	Female	1	2.3	2	1.6	1.9	2.3	1.9
			2	0.5	0.6	0.1	0.5	0.3	0.6
		Male	1	2.0	1.4	1.0	1.8	1.8	1.8
			2	0.4	0.5	0.1	0.1	0.1	0.5
2021	04/08	Female	1	2.0	2.3	1.0	1.5	2.3	1.0
			3	2.5	2.8	2.3	1.0	3.0	1.3
		Male	1	8.0	9.0	6.3	11.0	8.0	6.3
			3	7.3	10.0	8.3	8.0	5.5	7.0.0
	09/09	Female	1	0.0	0.0	0.0	0.0	0.0	0.0
			3	0.0	0.0	0.0	0.0	0.0	0.0
		Male	1	2.5	8.0	4.3	3.0	5.0	3.0
			3	0.0	3.0	2.5	4.0	1.0	2.0

3.3 Fruiting

In 2020 there were no significant differences in pumpkin number between site, or between treatments. However, significant differences were seen between treatments and sites so these are presented separately below (Figure 8). Overall, fruit at Site 2 were marginally smaller in diameter, although there were minor but significant differences between treatments with the treated fruit showing greater diameter than the untreated controls. At Site 1 treatment fruit were marginally larger, particularly treatments 5 and 6 compared with the control. At Site 2 the control fruit were smaller than those seen in the treatments, although no significant differences were seen between the treatments.

In 2021 fruit sizes were much more consistent between treatments, and between sites. Overall fruit sizes were larger in 2021 compared to 2020. Whilst it is difficult to determine the cause of this it is most likely to be due to differences between local climate, season and cultivar grown. It is noteworthy, however, that a small but significant increase in fruit size was seen in treatments 5 and 6 compared with the other treatments, particularly at site 1. Whilst this difference is not significant it may indicate a potential uplift in overall productivity compared with the other treatments – this would correspond to the presence of nitrogen and other nutrients in these treatments rather than calcium alone. In 2021 fruit number was increased at site 3 compared with site 1, but there were no significant differences between treatments at each site (Figure 9).

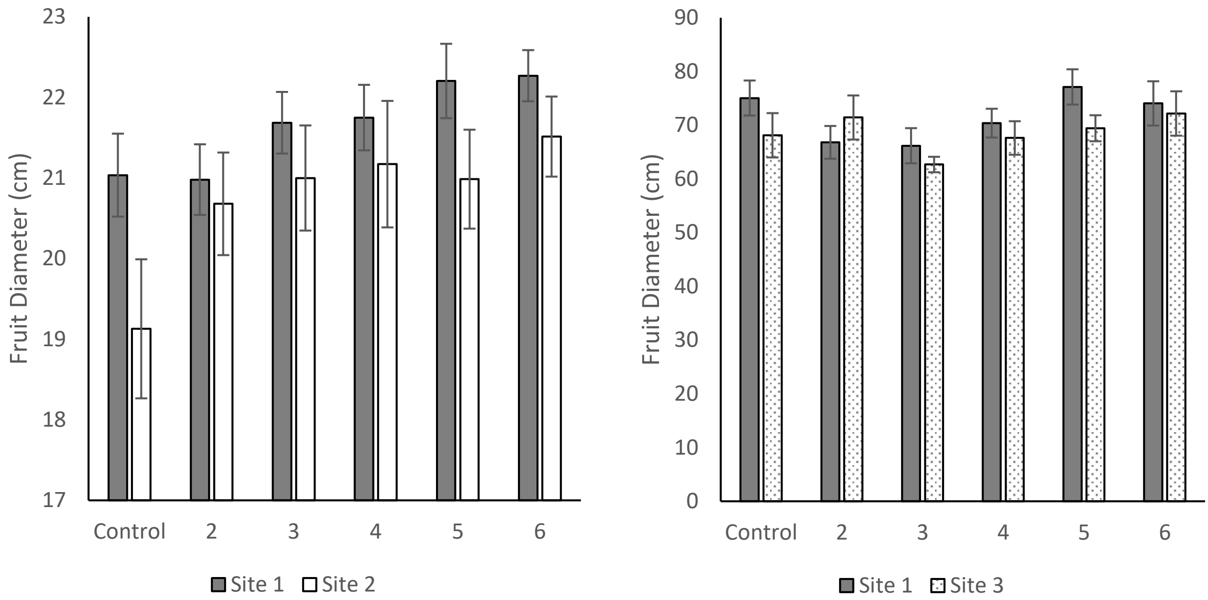

Figure 8. Average fruit size at harvest in 2020 (left) and 2021 (right). Average fruit weight was not recorded in 2021 as it is mostly influenced by variety choice.

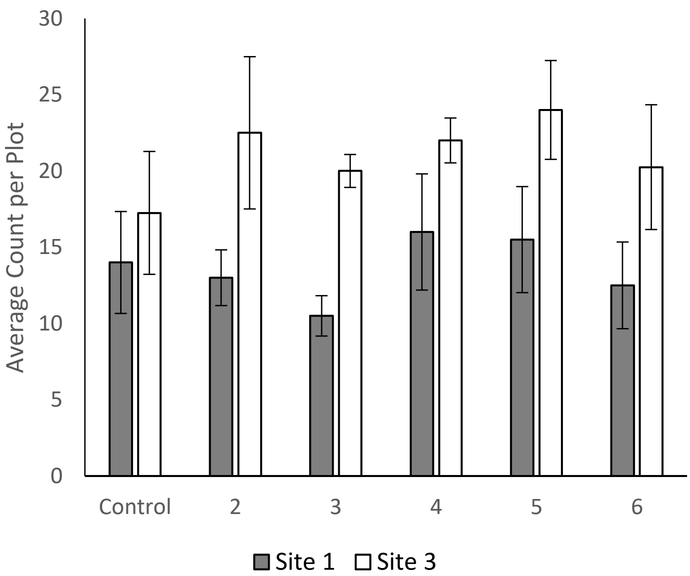

Figure 9. Average fruit number per plot from harvests in 2021.

3.4 Postharvest Rot Development

Disease development from natural inoculation can be highly variable between seasons, sites and locations in a field. Furthermore, the longevity of pumpkins means that pumpkins may need to be stored for a long period of time making it difficult to separate true rots from opportunistic rots developing from natural senescence. Therefore, to avoid variability between treatments and to ensure that sufficient disease pressure was available to ensure a consistency between treatments, fruit were wounded and inoculated as outlined above. Inoculations in 2020 were not effective, (rots did not show sufficient development at wounding sites) although sufficient native disease pressure was present from harvest that natural internal rots could be assessed. Pumpkins sampled from Site 1 showed lower rot incidence in treatments 2, 3, 5 and 6 (most significantly in treatments 5 and 6). Pumpkins sampled from Site 2 showed high level of rot development except for treatment 5 (Figure 10).

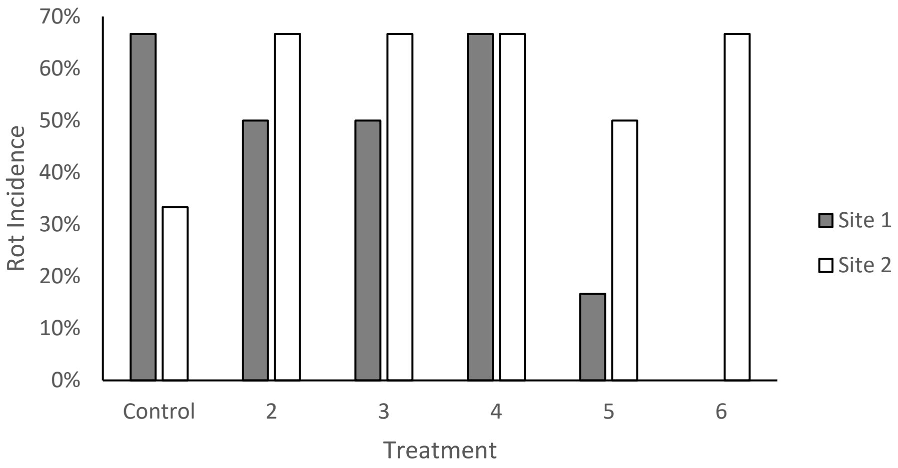

Figure 10. Incidence of postharvest rot development in pumpkin, meaned per treatment in 2020.

In 2021 inoculations were considerably more successful, allowing assessment of lesion size over a period of several weeks (Figure 11). There was a significant difference in lesion development, with fruit from site 1 showing considerably greater rot development compared with site 3. At site 1 treatment 6 gave significantly smaller lesion size development compared with the other treatments, with lesion size only a quarter of that seen in fruit from other treatment. Treatments 2, 4 and 5 also showed reduced lesion size compared with the control, although these were not significantly different. Average lesion size was considerably smaller at site 3, although all treatments showed significantly reduced lesion size compared with the untreated control, except for the final assessment.

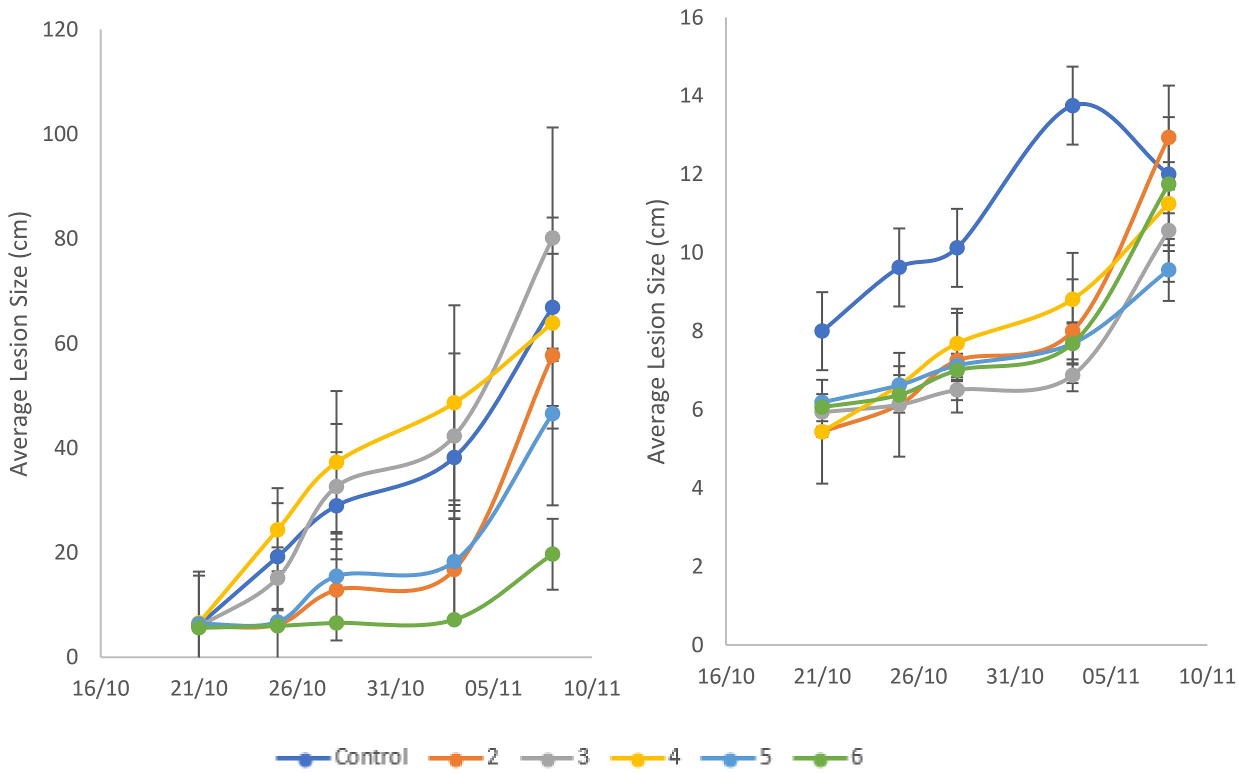

Figure 11. Average lesion size following fruit inoculation after harvest at site 1 (left), site 3 (right).

4 DISCUSSION

This project set out to test the potential for calcium foliar feeding to reduce the impact of rots in pumpkin production. A key issue in this problem is the relatively niche and nebulous nature of this problem – PYO pumpkin production represents a tiny fraction of overall production, so the availability of evidence to support the use of new nutritional approaches is likely to be unavailable. The combination of factors – large fruit which require significant nutritional investment during growth which are left in the field beyond maturity – is also highly unique to the crop. Furthermore, the incidence of BER in pumpkin can be highly variable and is likely to be subject to a range of risk factors including climate, disease pressure, growing conditions (e.g., weed density), nutrition and cultivar choice. Disease incidence is unlikely to follow any clear-cut relationship with any of these factors either in combination or in isolation. It is against this background that the results of this project are best viewed.

The variable onset of BER symptoms, and difficulties achieving effective inoculation in the lab, has impacted the ability of this project to draw clear conclusions from the results obtained. However, there are some significant indications that the use of calcium foliar feeds can reduce the incidence or development of rots when used in the field. Postharvest rot development was significantly reduced with treatments 5 and 6 at site 1 in 2020, with comparable results for the progression of lesion development in at site 1 in 2021. It is also noteworthy that all treatments at site 3 had a positive impact on lesion development in 2021 despite relatively low levels of overall lesion growth. The overall benefits of foliar calcium application are difficult to define based on the results of this project, although there is a general indication that the use of calcium foliar feeds can have a positive impact on the development of fruit rots.

It is noteworthy that the overall greatest response is implied in treatments 5 and 6, despite these products having a similar calcium content compared with product 2. This corresponds with the suggestion that calcium product formulation (and the presence of additional nutrients such as nitrogen) may have an impact on the ability of the plants to absorb and utilise the calcium provided through foliar application. Therefore, growers should not assume that all foliar calcium products are equivalent to each other, and they should base their choice of feed product on all available information rather than on pure calcium content alone.

A secondary finding of this project is that the use of foliar calcium feeds does not create any negative impacts for wider production. There were no significant increases in foliar disease incidence (e.g., powdery mildew development) nor were there any shifts in the proportion of productive female flower formation. This means that their wider utilisation for disease control will not be at the expense of the other aspects of production that were monitored.

A key piece of grower feedback was a concern that biweekly application of foliar feeds may be difficult to justify from a labour cost and availability perspective, especially when the benefits of their use may be variable and difficult to define. Growers' feedback also indicated that spraying would not be feasible as the crop matures due to high canopy coverage making accessing the crop difficult, with an increased risk of damage to fruit in the field. However, it is common practice for growers to continue to spray crops for powdery mildew control until early/mid August, and so foliar applications could continue over this timescale. It is common for wide spectrum fungicides to be used, but growers will still be constrained by on-label (and EAMU) regulations for pesticide use as a food crop. Given that some growers have been producing food products from their pumpkins (e.g. pumpkin soup) to further monetise their offering there is extra justification to ensure compliance. Whilst it was not an objective of this project, the reduced frequency of application in 2021 (two applications rather than three or more) enabled this aspect to be examined in greater detail. Given that positive impacts on disease development were seen in the 2021 trials, it may be implied that beneficial effects of foliar feed application may be seen with less frequent applications. Alternatively, it may be possible that application of the feeds at key times can still achieve comparable effects on rot reduction compared with routine application during fruit development. For example, targeting applications to periods of dry weather (where uptake of calcium from the soil will be reduced) may be of greatest benefit. Alternatively, targeting applications to particular points in the fruit development cycle may be of greatest benefit – for example, targeting more mature fruits in the run up to ripening may be of benefit in ensuring availability of calcium across the fruit compared with early fruit development where soil-derived calcium may be sufficient due to comparatively short transport distances within the fruit compared with fruit closer to maturation. Further work could better explore the relationship between dose, timing and frequency of applications to better link application practice with crop needs.

To a larger extent, the outcomes of this project are similar to the use of foliar nutrient sprays in general. These are widely seen as effective measures of directly addressing specific deficiencies within the crop – or to provide a short-term boost to growth – but remain secondary in effect to other growing inputs such as soil nutrition management. When combined with the variable risk of BER development, the benefits of foliar nutrient application are likely to be further variable in their identifiable benefit under standard conditions. Therefore, growers may not see a specific direct benefit from their use within a single year. However, under conditions of adverse stress (e.g., poor early establishment, dry summers, high disease pressure that is difficult to control with conventional fungicides etc.) it is likely that foliar calcium feeds could provide a worthwhile mitigating measure to aid growers in the control of this disease.

APPENDIX 1 FULL RESULTS TABLE FROM SECTION 3.2

The results below in (Table 3) show the average flower count at each site in year one and two (as discussed in section 3.2) and include the mean variation for each count.

Table 3. Average flower count at each site, including the mean variation.

Year	Date	Flower	Site	Average Count per Plot					
2020	16/07	Female	1	2 ± 0.3	2.3 ± 0.2	1 ± 0.2	1.5 ± 0.2	2.3 ± 0.3	1 ± 0.2
			3	2.3 ± 0.3	2.6 ± 0.3	2.3 ± 0.2	2.7 ± 0.2	3.1 ± 0.3	3.1 ± 0.3
		Male	1	8.0 ± 0.2	9.0 ± 0.1	6.3 ± 0.2	11 ± 0.1	8.0 ± 0.2	6.3 ± .00.1
			3	1.2 ± 0.2	0.9 ± 0.1	0.9 ± 0.1	1 ± 0.1	1.2 ± 0.1	1.0 ± 0.1
	30/07	Female	1	2.3 ± 0.3	2 ± 0.2	1.6 ± 0.2	1.9 ± 0.2	2.3 ± 0.3	1.9 ± 0.2
			3	0.5 ± 0.1	0.6 ± 0.2	0.1 ± 0.1	0.5 ± 0.2	0.3 ± 0.1	0.6 ± 0.2
		Male	1	2.0 ± 0.4	1.4 ± 0.3	1.0 ± 0.0	1.8 ± 0.2	1.8 ± 0.3	1.8 ± 0.2
			3	0.4 ± 0.1	0.5 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.5 ± 0.2
2021	04/08	Female	1	2.0 ± 0.6	2.3 ± 0.6	1.0 ± 0.3	1.5 ± 0.5	2.3 ± 0.6	1 ± 0.3
			3	2.5 ± 0.9	2.8 ± 0.3	2.3 ± 0.6	1 ± 0.3	3 ± 0.9	1.3 ± 0.4
		Male	1	8.0 ± 2.1	9.0 ± 2.9	6.3 ± 2.1	11 ± 3.7	8 ± 1.2	6.3 ± 1.3
			3	7.3 ± 1.5	10.0 ± 1	8.3 ± 1.4	8 ± 1.9	5.5 ± 0.5	7.0.0 ± 1.2
	09/09	Female	1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
			3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
		Male	1	2.5 ± 0.0	8.0 ± 0.0	4.3 ± 0.0	3.0 ± 0.0	5.0 ± 0.0	3.0 ± 0.0
			3	0.0 ± 0.0	3.0 ± 0.0	2.5 ± 0.0	4.0 ± 0.0	1.0 ± 0.0	2.0 ± 0.0

APPENDIX 2 REFERENCES

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