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Location of project:	Lincolnshire, Suffolk and Kent
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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

Headline

Pre-harvest calcium spray programmes on cabbage increase the weight of harvested heads; increased head size reduces the firmness of internal leaves.

Calcium spray programmes on swede increase calcium content in roots and reduce the rate of tissue browning.

Post-harvest application of the biological control agent Serenade reduced the rate of storage rots caused by Botrytis.

Background

Significant losses in winter cabbage and swedes occur after harvest with up to 30-40% wastage during storage, due to fungal decay and physiological breakdown. A number of post-harvest strategies that combine treatments to improve crop health and lower fungal load were tested to determine their effectiveness in reducing wastage. Pre-harvest nutrient sprays containing calcium and boron have been shown to improve firmness, reduce the rate of senescence and delay the onset of disease of harvested crops.

Additional treatments during storage such as ethylene removal on broccoli and ozone treatments on cucurbits have been reported to reduce water loss in stored products thereby improving the financial return on the saleable crop coming out of store.

The amount of ethylene removal required to provide significant effect on the quality of cabbage is unknown. Previous studies in broccoli stores (FV 395, WRAP) found ethylene accumulating (100-600 ppb) in stores where regular forklift (propane fuelled) activity occurred. Identifying threshold concentrations of ethylene that effect the storage quality of white winter cabbage will determine whether ethylene scrubbing technologies are appropriate for improving the storage quality of stored cabbage. Ozone has been trialled on a range of crops (cucumbers, courgettes, tomatoes) to reduce the incidence of disease and lower moisture loss. Identifying an effective dose of ozone, that lowers disease and water loss of cabbage and swede without discolouring cut surfaces has yet to be determined.

Alternative disease control techniques including advances in the development of bio-control agents such as Serenade (Bayer) afford the possibility to lower disease spread during storage caused by Botrytis. The combination of calcium sprays and post-harvest dipping with biological control agents may provide a viable alternative to current post-harvest fungicide application.

Summary

A series of trials were initiated to investigate the effect of pre-harvest calcium/nutrients and post-harvest treatments to reduce the onset of disease in white cabbage and swedes.

In year 1, a field site for white winter cabbage cv. Cilion, planted on the 14th May 2014 was kindly provided by Naylor Farms, Lincolnshire, and for swede cv. Tweed; A W Mortier, Cedar Farm, Suffolk provided a field site. A randomised plot trial design using four replicate-plots per treatment and was managed by the Allium and Brassica Agronomy Ltd.

The four treatments were as follows: Untreated control, InCa (Plant Impact) – 1L/ha, Brassitrel Pro (Yara) – 4L/ha and Carnival (Headland) – 5L/ha. All sprays applied in 200L/ha water with 02F110 nozzles using a 2m spray boom.

A total of eight sprays were applied at two weekly intervals by the Allium and Brassica Agronomy Ltd starting in July and finishing in mid-October. Cabbages were hand harvested on the 5/6th November 2014 and swedes were hand harvested on 23rd October 2014. Cabbages and swedes were immediately transported to the Produce Quality Centre at East Malling Research where they were placed in a 1°C air store to remove field heat. Cabbages were stored subsequently under controlled atmosphere conditions of 5% CO_2, 3% O_2 (1°C). Swedes were air-stored (1°C, 98% RH).

In the second year, a field site provided by Paul Freeman, John Sauls Farm, Boston, for a trial on white winter cabbage cv. Expect planted on the 13th June 2015. Two treatments were applied, an untreated control, and InCa (Plant Impact) – 1L/ha. All sprays were applied in 200L/ha water with 02F110 nozzles using a 2m spray boom. Treatments were applied later in the growing season on 1st, 15th and 28th September and the 7th October 2015. Cabbages were harvested on the 21st November 2015 and transferred to the Produce Quality Centre and stored in wooden bins in air at 1°C. Weather data for the two growing seasons is in the Appendix.

Post-harvest treatments

Cabbages: Disease control

In Year 1, cabbages were dipped in 200 L of solution in the following treatments;

Water, Serenade (Bayer) 30 mL L^{-1}, F233 1 g L^{-1}, + Bond sticker (1 mL L^{-1}) and Rovral WG (BASF) 0.67g L^{-1} /SL567A 0.104 mL L^{-1}.

In year 2 cabbages were dipped in 200 L of solution in the following treatments;

Water, InCa (1 mL L^{-1}), Serenade (Bayer) 30 mL L^{-1}/InCa 1 mL L^{-1}, Rovral WG (BASF) 0.67g L^{-1} /SL567A 0.104 mL L^{-1}.

Bins were transferred to a 1°C air store.

Cabbages: Ethylene -trial

White winter cabbages (4-5 kg/head) were placed in 500 kg storage containers with a constant flow of air (1 L kg^{-1} h^{-1}) amended with 0, 50, 100 or 150 ppb ethylene (BOC, UK).

Cabbages/Swede:Ozone-trial

Cabbages and swedes were exposed to ozone (10 ppm) for 30 or 90 minutes. Treatments were repeated after two and four months of storage.

Swedes: Hydrogen peroxide trial

In year one, Swedes were treated with hydrogen peroxide solution (StoreFresh 7 % H_2O_2) using a hoselock spray applicator applied at 100 mL t^{-1} or 200 mL t^{-1}. Treatments were repeated every six weeks. In year two, dry-fogging of hydrogen peroxide was applied using a compressed air ultrasonic nozzle inside storage chambers delivering the equivalent of 100 mL t^{-1} or 200 mL t^{-1}. Treatments were applied in December, January and March. An additional treatment of dry fogging calcium (InCa 420 mL t^{-1}) was included.

Results

Cabbage- Year 1

Pre-harvest application of InCa significantly increased the amount of calcium present in cabbage (Table 1) while Brassitrel Pro and Carnival increased the weight of cabbage heads (Table 2). The firmness of cabbages measured using a penetrometer showed a reduction in firmness in the tissue around the base of the stalk (heart) where calcium products were applied. Penetrometer testing of cabbages found the outer leaves (Table 2) of InCa and Carnival-treated cabbages were firmer.

All three calcium spray products are formulated with incorporation of nitrogen: Brassitrel Pro (6.9 % N w/w), Carnival (14.9 % N w/w) and InCa (4.5% N w/v). The combination of calcium and nitrogen increased the size of cabbages through encouraging tissue expansion causing a reduction in the density and compactness of central leaves. In general, application of calcium/nutrient sprays reduced weight loss in CA stored cabbage by ~1% over the first 3 months of storage.

On removal from CA storage after nine months cabbages were destructively sampled. The amount of wastage removed from cabbages was between 27.7-33.0% (Table 3), *Botrytis* infections made up the largest proportion of infections (20-22.8%) with a smaller amount of *Phytophthora* infections (7-10%) entering through the stems (Table 3). No treatment effects of pre-harvest application of calcium were observed.

Cabbage –Year 2

The concentration of calcium in untreated cabbage averaged 33.4 mg $100g^{-1}$ and was raised to 39.7 mg $100g^{-1}$ by the InCa spray programme applied between September-October (Table 4). A similar increment in calcium content observed in year 1 (38.1 mg $100g^{-1}$) where an 8 treatment spray programme was implemented.

The proportion of infected tissue in air-stored cabbage (untreated) averaged 17.7% after 7 months storage in air (1°C); predominately caused by *Botrytis cinerea* (Table 13). Cabbages treated pre-harvest with InCa averaged 13.6% infected tissue. Post-harvest drenching with Serenade/InCa (9% rots) was as effective as Rovral/SL567A (6.5% rots) in reducing rotting caused by *Botrytis* (Table 13). Post-harvest application of InCa (14.6 %) failed to reduce the incidence of rotting compared to dipping in water (13.6%).

Swede – year 1

All calcium spray programmes tested increased the calcium content of roots. Whether the resultant increase in calcium was the movement of calcium from leaves to roots is unknown. In addition to calcium, Brassitrel Pro increased iron, phosphate and manganese; InCa application increased potassium and phosphate and Carnival led to raised iron content in the roots. Interestingly, no increase in boron was observed in swedes even though Brassitrel Pro and Carnival are formulated with boron as a minor element.

No effect on yield or size distributions were observed between treatments and no increase in nitrogen or dry matter content in roots was recorded. Application of Carnival increased the resistance to splitting/crack formation after harvest when tested using a wedge fracture test. All calcium treatments reduced the rate of tissue browning in swedes cut after harvest.

Botrytis rots developed on the leaves and petioles with a large amount of visible sporulation, disease spread to the stem and in severe cases infection progressed to the main root. Initial experiments with hydrogen peroxide and ozone treatments to reduce inoculum load showed no reduction in stem or root rotting. There was no effect of calcium sprays controlling disease spread on leaves and no significant treatment effects were observed.

Table 1. Mineral content of cabbages sprayed with InCa, Brassitrel Pro and Carnival

Minerals	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
mg $100g^{-1}$					
N	161.5	180.2	150.2	175.8	30.2
Ca	32.62	**38.12**	31.6	36.85	4.5
K	210.5	218.5	202.8	**234.8**	19.6
mg kg^{-1}					
B	1.22	**1.53**	1.22	**1.44**	0.15
% Dry Mat.	8.9	8.6	8.5	8.9	0.31
Ca/DM	3.7	**4.3**	3.6	**4.2**	0.41

Table 2. Weight and firmness of cabbages sprayed with calcium products InCa, Brassitrel-Pro and Carnival

Treatment	Position	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
Weight (kg)		3.6	3.8	**4.4**	**4.3**	0.21
Firmness (N)	Heart	101.1	**86.4**	**92.1**	**88.1**	3.72
Firmness (N)	Outer Cortex	94.8	**105.0**	**83.7**	**104.6**	3.72

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 3. The incidence of disease and weight loss in cabbage after nine months CA storage (5% CO_2, 3% O_2 at 1°C) treated pre-harvest with calcium/nutrient sprays.

Storage time	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
% Total wastage (wt)	29.1	33.0	27.7	30.8	10.84
% *Botrytis* (wt)	21.1	20.0	20.6	22.8	6.81

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 4. Mineral content of swedes sprayed with InCa, Brassitrel Pro and Carnival

Minerals	Control	InCa	Brassitrel-Pro	Carnival	$LSD_{0.05}$
mg $100g^{-1}$					
N	88.8	111.2	104.5	102.8	31.57
Ca	36.25	**40.15**	**42**	**41.52**	3.65
K	261	**297.5**	287.5	272.8	31.28
mg kg^{-1}					
B	1.97	1.94	2.01	2.01	0.2
%Dry Mat.	11.3	11.0	11.2	11.3	0.92
Ca/DM	4.1	4.5	**4.8**	**4.7**	0.41

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 5. Mineral analysis of cabbages (Year 2) treated pre-harvest with InCa

mg $100g^{-1}$	InCa	Control	$LSD_{0.05}$	F prob
N	**209.9**	181.0	14.28	0.002
Ca	39.7	34.3	7.88	0.152
K	288.6	284.4	6.84	0.556
mg kg^{-1}				
Cu	**0.23**	0.19	0.01	0.002
Zn	**1.38**	1.18	0.06	<.001
B	1.57	1.57	0.13	0.966

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 6. Harvest quality of cabbages (Year 2) subject to four late season applications of InCa

Cabbage	InCa	Control	$LSD_{0.05}$	F prob
Firmness (N)				
Inner cortex	90.4	**94.5**	3.86	0.003
Outer cortex	59.9	**72.3**		
Yield per head				
Weight (kg)	**4.5**	4.2	0.14	<.001
Leaf Colour				
Colour L	71.1	72.6	1.38	0.032
Colour a	**-16.7**	-15.2	0.43	<.001
Colour b	**31.4**	29.5	1.41	0.009

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 7. The incidence of wastage caused by Botrytis infection in cabbages treated with pre- or post-harvest calcium (InCa) application or post-harvest application of Rovral/SL567A and combination of InCa/Serenade

Post-harvest Dipping trial				Pre-harvest Spray trial		Combined analysis	
InCa/Serenade	Rov/SL567A	Water	InCa	Control	InCa-Spray	$LSD_{0.05}$ on 18 df	F pr.
9.0	**6.5**	13.6	14.6	17.7	13.6	4.20	<.001
LSD (4.31 on 12 df)				LSD (4.99 on 6df)			

N.B. Results in bold are significantly different (P<0.05) from the control within the same row

Table 8. The incidence of Botrytis *(B. cinerea)* infection on Swedes treated with a dry fog of hydrogen peroxide (StoreFresh 7% v/v H_20_2) or InCa, air-stored for six months (1°C)

	% Stem Infection		Stem severity (Max 60)		% Side rots	
	Stalks		Stalks			
Treatment	**Trimmed**	**Untrimmed**	**Trimmed**	**Untrimmed**	**Trimmed**	**Untrimmed**
Water	0.6	67.0	0.4	29.5	2.0	4.6
Calcium	0.7	75.6	0.1	32.8	5.5	10.2
100 ml/t H_2O_2	2.6	76.8	1.4	34.9	8.1	5.0
200 ml/t H_2O_2	2.0	72.5	0.7	31.8	4.6	5.9
LSD	2.89	20.14	1.46	9.84	5.08	6.09

Financial Benefits

The potential financial benefits of this project are that growers may be able in future to use biological control agents such as Serenade to help combat *Botrytis* infections developing in winter cabbage during storage.

Action Points

- Pre-harvest sprays of calcium formulated with nitrogen increased the weight of cabbages
- Larger cabbages tended to have softer centres - managing head development will be important in determining the crispness of leaves
- Application of InCa and Carnival increased the sucrose content of cabbages
- Post-harvest application of Serenade reduced post-harvest application of Botrytis
- Calcium sprays increased calcium content of swedes, reduced the onset of tissue browning and increased the sucrose content.
- Removing leaf and petiole material from the stalks of swedes reduced significantly the rate of disease development during storage
- Neither ozone or hydrogen perioxide applied at harvest nor a repeat application during storage reduced the rate of Botrytis infection of swedes.

SCIENCE SECTION

Introduction

Significant losses in winter cabbage and swedes occur after harvest with up to 30-40% wastage during storage, due to fungal decay and physiological breakdown. Strategies that control physiological breakdown and the incidence of post-harvest disease require further investigation. It is hypothesised that a number of post-harvest strategies that combine treatments to improve crop health and lower fungal load will help reduce wastage.

Calcium is an important regulator of plant cell health, strengthening cell walls, preventing localised tissue death and slowing the ingress of disease. Increasing the uptake and translocation of calcium into the head of cabbage and roots of swede is expected to increase the storage life of the crop. Newer formulations of calcium and zinc (InCa™) and a calcium/boron formulation (Carnival, Brassitrel Pro) tested recently on apple have shown improved uptake of calcium into tissue and may provide a valuable method to strengthen tissue (TF 200). Boron deficiency in swedes has been linked to brown heart and low boron and is often associated with increased tissue browning (Fadel 2014).

Additional treatments during storage, such as humidification, ethylene removal and ozone treatments are also beneficial in reducing water loss, and thereby improving the financial return on the saleable crop coming out of store. Ethylene removal from the storage environment using catalytic scrubbers has proved a successful method of extending the storage life of broccoli (FV 395) by reducing the rate of senescence and water loss. To date, the threshold of ethylene removal required for effective reduction in water loss and senescence/decay in cabbage has yet to be determined and requires further investigation. Recent trials with ozone (NRI) on cucurbits led to reduced water loss via increased stomatal closure on the skin surface, and lowered disease development. Earlier trials on cabbage with higher concentrations of ozone led to surface pitting and browning. Identifying an effective dose of ozone, that both lowers disease and water loss of both crops without discolouring cut surfaces has yet to be determined.

Moreover, advances in the formulation of bio-control agents (Serenade ASO) against Botrytis may provide longer-term protection during storage diseases in cabbage. The efficacy of biocontrol agents is often enhanced by pre-harvest treatment with calcium (Wang *et al* 2010).

Materials and Methods

Pre-harvest calcium spray trial - Year 1

Year 1: Two sites were located in East Anglia for calcium spray trials. For white winter cabbage (var. Cilion) a field site was kindly provided by Naylor Farms, Fosdyke, Lincolnshire, the crop was planted on the 14th May 2014, and for swede (var. Tweed) A W Mortier provided a site at Cedar Farm, Alderton, Woodbridge, Suffolk.

A randomised plot design trial was used with four foliar calcium products applied in four replicated plots per treatment. The four treatments were as follows:

1. Untreated control

2. InCa (Plant Impact) – 1L/ha: N: (4.5% w/w), CaO (7% w/w) of which Ca (5% w/w), Zinc (Zn) (0.8% w/w)

3. Brassitrel Pro (Yara) – 4L/ha: CaO (12.5% w/v) of which Ca (8.9% w/v), MgO (11.8% w/v) of which Mg (7.0% w/v), Mn (7.0% w/v), N- Urea (6.9% w/v), Boron (6.0% w/v), Mo (0.4% w/v)

4. Carnival (Headland) – 5L/ha: CaO (22.5% w/v), MgO (3% w/v), Zinc (300 ppm w/v), Boron (750 ppm w/v), Total nitrate Nitrogen (14.9% w/v).

All sprays were applied in 200L/ha water with 02F110 nozzles using a 2 m spray boom. Sprays were applied at 2 weekly intervals by Allium and Brassica Agronomy Limited starting in July and terminating in mid-October. A total of 8 sprays were applied. Swedes were sprayed through protective netting.

Harvesting Year 1

Cabbages were hand harvested on the 5/6th November 2014 and swedes were hand harvested on 23rd October 2014. After harvest, cabbages and swedes were transported immediately to the Produce Quality Centre at East Malling Research where they were placed in a 1°C store to remove field heat. In Year 1 Cabbages pre-treated with calcium, were transferred to nets (3 per net) and placed into four 500 kg CA chambers. Each treatment was replicated across all four chambers. Controlled atmospheres were established by N_2 flushing and the addition of CO_2 to achieve a CA atmosphere of 5% CO_2, 3% O_2 (1°C), with the balance nitrogen. Atmospheres were monitored every 3 hours using the ICA 66 system with automatic injection of air, N_2 or CO_2 with the additional manual supplementation of N_2 when required.

Swedes that were part of the spray trial were distributed to plastic storage crates, with 12/13 roots per crate on arrival to EMR. Field replicates were maintained during storage. Swedes

were stored in crates in air at 1°C +-0.2°C. Humidity was kept high by frequent wetting of the store floor.

Post-harvest treatments Year 1

Cabbages: Biological control of post-harvest diseases

Cabbages (4-5 kg head size) were placed in nets, with 21 cabbages per replicate and four replicates per treatment. Cabbages were transferred to the Pesticide Handling Unit at East Malling Research (EMR) where they were dipped in 200 L of solution in the following treatments;

1. Control: Water
2. Serenade ASO (Bayer) 30 mL L^{-1}
3. F233 1 g L^{-1}, + Bond sticker (1 mL L^{-1}),
4. Rovral WG (BASF) 0.67g L^{-1} /SL567A (Syngenta) 0.104 mL L^{-1}.

Nets were immersed fully for 2 minutes with constant agitation. Nets were then removed and allowed to drip dry before transfer to separate wooden bins. Bins were transferred to a 1°C store where they were stored in air as increased by frequent wetting of the floor

Cabbages: Ethylene supplementation trial - Year 1

In order to ascertain the effectiveness of ethylene scrubbing technologies on the storage potential of white cabbages, trials were conducted on 4-5 kg cabbages placed into metal boxes and stored in 500 kg storage containers with a constant flow of air (1 L kg^{-1} h^{-1}) amended with 0, 50, 100 or 150 ppb ethylene (BOC, UK). Return flows were scrubbed of ethylene by way of a potassium permanganate scrubber. Ethylene concentrations and air flows were regulated using a series of in-line gas regulators and needle valves. Ethylene concentration was measured using a GC-FID (Agilent 6890).

Cabbages/Swede: Ozone trial - Year 1

To determine effectiveness of short bursts of ozone (~10 ppm) to disinfest swede and cabbage was determined. Swedes were placed in a 300 L plastic container and ozone was applied using an ozone generator (Model ES 215A, Onnic, UK) and the concentration of ozone was measured using an ozone monitor: L-106 Ozone Monitor (2B Technologies, US);

1. 30 minute exposure to ozone
2. 90 minute exposure to ozone

Cabbages were exposed only to the longer 90 minute exposure. Untreated cabbages and swedes were included as controls. Treatments were repeated after 2 and 4 months of storage.

Pre-harvest calcium spray trial - Year 2

Cabbages (var. Expect) planted on the 13th May 2015, were subject to a pre-harvest spray programme using InCa (Plant Impact) on John Sauls farm, Boston using a replicated plot design, with application rates of 1L/ha, applied on four occasions directed towards late season head development on the 1st 15th and 28th September and the 7th October 2015. Cabbages were harvested on the 21st November 2015 and transported to East Malling Research, where they were placed immediately in a 1°C air store to remove field heat. Samples were placed into nets (2 heads per net), four replicates per treatment with 10 nets per replicate.

Cabbage: Post-harvest treatments - Year 2

Cabbages (4-5 kg) were treated as in year 1 and were dipped in 200 L of the following treatments for 2 minutes. Water temperature was taken at the beginning and end of each treatment.

1. Control: Water
2. Serenade ASO (30 mL L^{-1}) + InCa (1 mL L^{-1})
3. InCa (1 mL L^{-1})
4. Rovral WG (BASF) 0.67g L^{-1} /SL567A (Syngenta) 0.104 mL L^{-1}.

In Year 2 cabbages treated pre-harvest with calcium were stored in air (1°C) for 8 months with inspections of head quality in March and May 2016 for disease development. The overall amount of wastage was determined by weighing whole heads and then removing infected leaves until reaching the first clean-leaf, cabbage heads were reweighed and a % wastage total was calculated.

Swedes: Post-harvest application - Year 1

On arrival to EMR swedes were randomly distributed to plastic storage crates, with 12/13 roots per crate. Leaves and petioles were removed from half the swedes while the other half retained their leaves. Swedes were stored in crates in air at 1°C +-0.2°C. Humidity was kept high by frequent wetting of the store floor.

Swedes: Hydrogen peroxide trial - Year 1

Swedes (var. Tweed), either trimmed to leave a bare stalk removing petiole and leaves or swedes where the leaves were retained, were treated with the following treatments:

1. Hydrogen peroxide (10% H_2O_2) solution (~100 mL/t)
2. Hydrogen peroxide (10% H_2O_2) solution (~200 mL/t)

Solutions were applied using a hand held atomiser - (Hoselock). Swedes were packed into crates (25 roots/ crate; ~10 kg) and sprayed for 20 seconds per crate delivering 33 ml/crate (0.5 mL ai/100 mL) or a double dose (1 mL ai 100 mL^{-1}), equivalent to 100 mL t^{-1} and 200 mL t^{-1} Swedes were allowed to air dry before returning to store. Treatments were repeated every 6 weeks, water control and untreated roots were included as controls.

Swedes: Hydrogen peroxide trial - Year 2

Unwashed swedes (var. Tweed) were divided into roots where the stalks retained leaf and petioles and those which had been trimmed down to the bare stalk.

Roots (25 per replicate) were placed into plastic crates, 6 replicates (150 roots) per treatment. Treatments were applied using a modified misting device, incorporating an ultrasonic (JD ultrasonic) compressed air operated (2 psi) nozzle and delivery system designed to operate within small scale CA-chambers ~360 L. Fogging of H_20_2 (BioFresh 7% H_2O_2 ai) was applied at two rates, the standard rate of 100 mL t^{-1} and a double rate of 200 mL t^{-1}. At each application, 6 crates of ~70kg of roots were treated for 42 seconds with a standard dose or 2 applications of 2 x 42 seconds to achieve the higher application rate.

An additional treatment using the calcium product InCa (8mL L^{-1}), was used in a post-harvest application using the fogging system, each 70 kg consignment was subject to 3 minute exposure to calcium fog (30 mls InCa 70 kg)

Chambers were left for 30 minutes after each treatment before the lids were removed. Boxes were stored outside at ambient to air dry before being placed in an air-store 1°C. Treatments were applied in December 2015 and re-applied in March 2016.

Quality Assessments

Harvest Quality Assessments: Spray trial - Years 1 & 2

At harvest, 20 cabbages per treatment (spray trial) were taken for assessment of quality. Outer leaves were pulled back and measurements taken on an undamaged leaf. Leaf colour was recorded using a Minolta colour meter. Chlorophyll fluorescence measurements were taken as a measure of chloroplast and tissue health using a Handy Pea Fluorimeter (Hansatech Instruments).

The internal flesh colour of swedes was measured immediately after cutting using the Minolta colour meter and the rate of browning was reassessed after exposing the cut surface to air for 1 hour.

Sugar, Mineral and Dry Matter Assessment

A 2 cm thick segment was cut longitudinally through each of 20 cabbages per replicate (320 in total) with a saw and from this section a further V shaped section was cut from the outer edge towards the stalk.

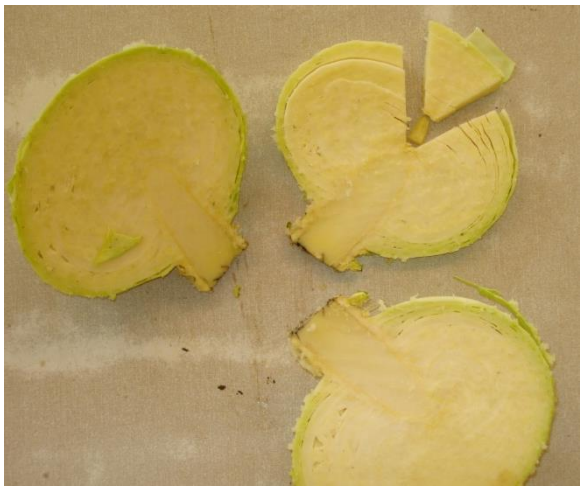

Figure 1. Section through cabbage, a 'V' shaped segment was taken for mineral and sugar analysis

Sub-samples of cabbage leaves were cut into 0.5 cm sections and material was mixed thoroughly before sampling and freezing (-20°C) with later sugar and dry matter assessment. Sections were pooled across all 20 cabbages per replicate for mineral analysis (FAST Ltd). For swedes, the process was repeated with the exception that roots were sectioned equatorially.

Before freezing, fresh weights of tissue destined for dry matter assessments were taken followed by storage at -20°C. Dry weights were estimated from oven dried (70°C) samples removed after 48 hours of drying, and % dry matter content was calculated.

Samples for sugar analysis were freeze dried for 48 hours before grinding to a powder in a pestle and mortar; 200 mg of powdered tissue was extracted in 1.6 mL of 80% ethanol for 2 hours in a shaking water bath (70°C). Samples were vortexed every 30 minutes. The supernatant was decanted after samples were centrifuged (13,000 g for 2 minutes) and filtered through a 0.45 µM syringe filter, into 1 mL glass HPLC vials. Vials were stored at -80°C before analysis.

Cortex Firmness

Firmness readings of cabbage were taken on the cut surface, two in the heart of the cabbage either side of the stalk and two towards the outer circumference (Figure 2), using an 8 mm probe attached to a penetrometer (Lloyd Instruments).

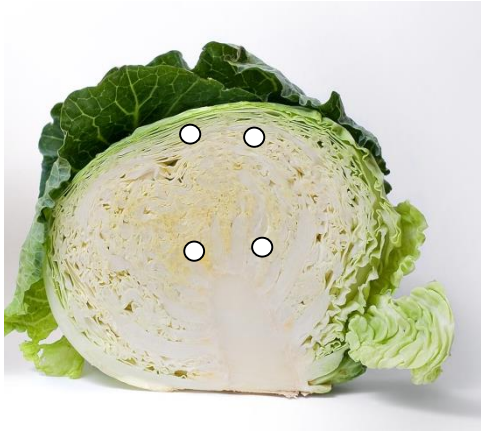

Figure 2. Location of sampling points for the penetrometer

The firmness of swedes was measured using a wedge fracture technique. A 1 cm equatorial section was cut from each of five roots per replicate. Sections were further scored with a double bladed knife (blades spaced 1 cm apart) and a 1 cm "chip" section was cut across the equatorial section. Maintaining the orientation of tissue, two 1 cm sections were cut from the "chip" ending up with 2 x 1cm^3 of tissues. The firmness and elasticity of cubes of tissue were assessed by driving (2 mm min^{-1}) a stainless steel wedge (Lloyd Instruments) through the tissue and recording the deformation characteristics using Nexygen software.

Data was analysed using ANOVA with Genstat version 18.

Results and Discussion

Year 1 Cabbage - Calcium spray programme

Quality at harvest

Cabbages treated with InCa during the growing season had elevated calcium content at harvest. The calcium content of cabbages treated with Carnival was raised but just failed to reach significance at $p<0.05$.

All cabbages subject to the calcium spray programme were higher in nitrogen (Table 1) due to fact that all of the calcium products trialled in this project were co-formulated with nitrogen in the form of nitrate or urea. The combination of nitrogen and calcium increased the size and weight of harvested heads in all three nutrient spray products. In general, calcium/nutrient treatments increased the size of cabbages, most likely through cell expansion, a process which resulted in cabbages having less dense centres. Increasing head size led to reduced firmness of the inner cortex (heart tissue) of cabbage (Table 2). However, two products InCa and Carnival also increased the strength of the outer leaves (Table 2).

The sampling strategy of tissue employed for mineral analysis is critical in determining the overall results. Calcium is immobile in plant tissues and movement is restricted to the xylem elements within plants. For this reason, foliar applied calcium does not move far from the point of deposition. It is probable that the majority of the applied calcium was been incorporated into the outer leaves where increased firmness was observed.

The dry matter content of cabbages was similar across all treatments (Table 1), suggesting there was no effect on cell density or the increased incorporation of photosynthates into cell walls.

Potassium and magnesium have an antagonistic effect on calcium, displacing calcium from active sites within the cell wall and cell membranes. A higher potassium content of cabbages treated with Carnival was observed even though the formulation contained no potassium. The ratio of potassium to calcium was sufficiently low across all treatments to suggest that antagonistic interactions were limited; in apple a ratio of above 30 is considered problematic. Calcium/nutrient treatments failed to increase the magnesium content of cabbage even though Brassitrel Pro and Carnival contain magnesium oxide as part of the formulation.

Cabbages treated with Brassitrel Pro treated cabbage resulted in darker green (Minolta–a) leaves at harvest (Table 2).

Table 1. Mineral analysis of winter white cabbage subject to pre-harvest sprays of calcium/nutrient compounds. Cabbages sampled at harvest - A composite sample of 20 heads per plot; four replicates per treatment ($LSD_{0.05}$ on 12 df).

Minerals	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
mg $100g^{-1}$					
N	161.5	180.2	150.2	175.8	30.21
Ca	32.6	**38.1**	31.6	36.9	4.50
K	210.5	218.5	202.8	**234.8**	19.55
Mg	12.9	13.0	12.6	13.4	1.35
P	15.4	16.6	15.1	16.9	2.16
mg kg^{-1}					
Cu	0.20	**0.15**	**0.16**	0.19	0.05
Fe	3.66	3.58	3.94	3.57	0.49
Mn	1.06	1.04	1.00	1.05	0.12
Zn	1.21	1.18	1.19	1.22	0.14
B	1.22	**1.53**	1.22	**1.44**	0.15
% Dry Mat.	8.9	8.6	8.5	8.9	0.31
Ca/DM	3.7	**4.3**	3.6	**4.2**	0.41
K/Ca	6.5	**5.7**	6.4	6.4	0.75
K+Mg/Ca	6.9	**6.1**	6.8	6.8	0.77

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row.

Table 2. Harvest firmness and leaf colour of white winter cabbage treated pre-harvest with a calcium/nutrient spray programme.

Treatment	Position	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
Firmness (N)	Heart	101.1	**86.4**	**92.2**	**88.1**	3.72
Firmness (N)	Outer Cortex	94.8	**105.0**	**83.7**	**104.6**	3.72
Colour L	Outer Leaves	72.2	**75.4**	71.9	72.5	1.25
Colour a	Outer Leaves	-17.3	**-16.2**	**-18.0**	-17.1	0.68
Colour b	Outer Leaves	32.1	31.3	**33.7**	31.8	1.11

On removal from CA storage after 9 months there was a significant incidence of decay covering the outer leaves of all cabbages. Cabbages were segregated into those heads infected with *Phytophthora* or where heads were infected with *Botrytis,* where the disease penetrated from the outer leaves either through direct infection, through wounds in the surface leaves or developed ahead of earlier infections caused by light leaf spot, dark leaf spot or ringspot.

Cabbages were destructively sampled, to estimate of the weight of infected tissue presence on each cabbage. The total amount of wastage removed from cabbages coming out of CA store in June 2015 was between 27.7-33.0% (Table 4), *Botrytis* infections made up the largest proportion of infections with a smaller amount of *Phytophthora* infections entering the stems. The amount of tissue wastage associated with *Botrytis* infections was between 20-22.8%. No treatment effects of pre-harvest application of calcium were observed.

Table 4. The incidence of disease and weight loss in cabbage after 3 and 9 months CA storage (5% CO_2, 3% O_2 at 1°C) treated pre-harvest with calcium/nutrient sprays.

Storage time	Control	InCa	Brassitrel	Carnival	$LSD_{0.05}$
3 months					
% Wt loss	3.05	2.69	**2.01**	**2.11**	0.542
% *Botrytis (Number)*	57.5	**73.8**	59.8	**85.9**	16.15
% *Phytophthora (Number)*	14.0	23.3	18.8	**32.1**	13.13
9 months					
% Total wastage (wt)	29.1	33.0	27.7	30.8	10.84
% *Botrytis* (wt)	21.1	20.0	20.6	22.8	6.81

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Changes in firmness and colour during storage

After removal from storage of the outside leaves colour measurements revealed a significant reduction in green colour of leaves occurred during the storage period. Cabbages at harvest averaged background green colour (a values) values of -17.1 (across treatments) dropping to -14.6 after three months CA storage and ending up at -7.2 after 9 months storage. While cabbages treated with Brassitrel Pro at harvest were greener than other cabbages, treatment differences were lost during storage (Table 5). The firmness of cabbage heads were measured at the end of storage. The inner cortex of cabbages were less firm in calcium/nitrogen treated heads due to increased head expansion, while the firmness of outer leaves were higher in cabbages treated with InCa and Carnival (Figure 3), where tissue analysis indicated a higher calcium content.

Table 5. Colour (Lab) of cabbage after 3 months CA storage (5% CO_2, 3% O_2, 1°C) treated pre-harvest with calcium/nutrient sprays.

Storage time	Control	InCa	Brassitrel	Carnival	$LSD_{0.05}$
3 months					
Colour L	75.2	74.1	74.0	75.7	1.18
Colour a	-14.6	-14.3	-15.0	-14.6	0.36
Colour b	28.6	28.2	28.9	28.9	1.22
9 months					
Colour L	86.2	85.9	87.0	87.5	1.35
Colour a	-7.6	-7.9	**-6.3**	**-6.8**	0.56
Colour b	23.5	22.9	20.5	22.6	2.26

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

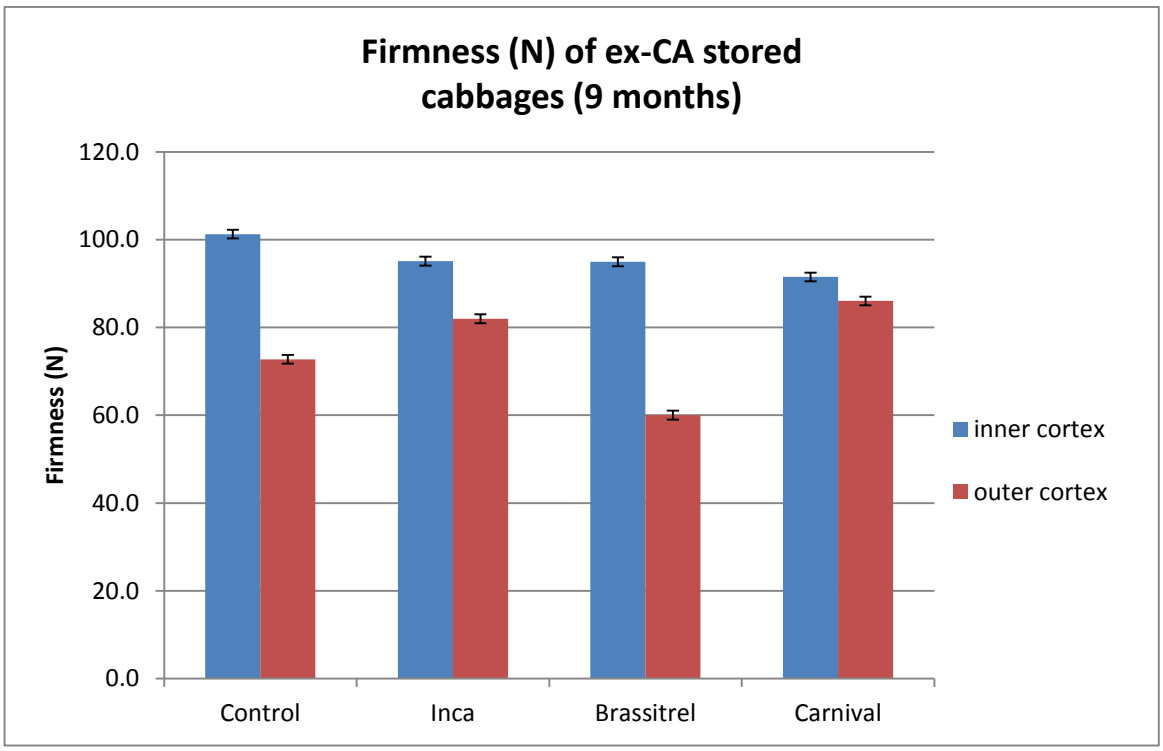

Figure 3. Firmness of cabbage across the inner and outer cortex measured using a Lloyd penetrometer (8 mm probe).

Cabbage: Post-harvest dipping trial - Year 1

Initial assessment after 3 months storage of the incidence of *Botrytis* infection of cabbages dipped in biological control agents Serenade ASO and F233 reduced infection by over half compared to the control and were as effective as Rovral WG in reducing *Botrytis* (Table 6). No *Phytophthora* infections were observed in this trial.

Post-harvest treatment with Serenade ASO or Rovral WG/SL567A were equally as effective at reducing the ingress of infection caused by *Botrytis* compared to controls dipped in water.

Table 6. The incidence (% numbers infected) of Botrytis disease in white cabbage stored in air at 1°C for 3 months.

Water	Rovral WG/SL567A	Serenade ASO	F233	$LSD_{0.05}$
36.6	**14.8**	**19**	**15.3**	14.32

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Final Inspection (7 months air storage 1°C) Year 1

At the end of the 7 month air-storage trial, cabbages were removed from air storage and weighed, the incidence of infection was estimated by the weight of leaves removed due to infection and the % wastage was estimated. Serenade ASO was as effective as the standard Rovral WG/SL567A treatment for control of *Botrytis* infections (Table 7). In this case no *Phytophthora* stem infections were observed.

Table 7. The incidence of wastage caused by *Botrytis* in air stored cabbage at 1°C treated at harvest with BGA (F233, Serenade ASO or Rovral WG)

F233	Rovral WG/SL567A	Serenade ASO	Water	$LSD_{0.05}$	Fprob
17.3	**9.8**	**7.4**	13.4	3.89	<0.001

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Ozone

Short bursts (90 minutes) of ozone treatment (~10 ppm) applied after harvest and after 3 months storage caused deterioration in the brightness (L value) and background green colour (a value) along with a reduction in background yellow (b value). A higher incidence of wastage was observed in ozone treated cabbages caused by a discolouration of the leaves and the mid-rib of leaves attached to the central stalk, where ozone had permeated into the head of the cabbage (Table 8).

Table 8. Colour profile of ozone-treated cabbages after 7 months air-storage

	Control	Ozone	F pr.	$LSD_{0.05}$
Colour L	80.6	**69.4**	<.001	1.93
Colour a	-12.6	**-4.7**	<.001	1.39
Colour b	29.2	**21.6**	<.001	1.86
% Wastage	12.2	**20.8**	0.07	8.48

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Ethylene

In order to understand the importance of ethylene removal within cabbage stores, it was necessary to determine the long-term effect of ethylene exposure on the storage quality of cabbage. Supplementation of air flowing into cabbage storage containers with ethylene at 0, 50, 100 and 150 ppb stored at 1°C found that higher concentrations of ethylene affected cabbage quality. A drop in background green colour (Colour a) of cabbage heads was observed where cabbages were exposed to concentrations of ethylene between 100-150 ppb (Table 9). However, no effect on the firmness of the inner or outer cortex of cabbages, or on the incidence of disease was recorded.

Table 9. The overall effects of ethylene on firmness (N), colour and the proportion of wastage of air-stored (1°C) cabbage amended with 0, 50, 100 and 150 ppb ethylene**.**

Ethylene	0 ppb	50 ppb	100 ppb	150 ppb	F pr.	$LSD_{0.05}$
Firmness	97.0	98.5	94.9	95.2	0.20	3.78
Colour L	84.8	84.3	85.8	83.4	<.001	1.09
Colour a	-12.9	-13.3	**-11.6**	**-11.1**	<.001	0.80
Colour b	27.2	27.9	26.9	26.6	0.19	1.28
% Wastage	9.3	11.6	11.3	9.7	0.47	3.46

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row.

Pre-harvest treatment of Cabbage - Year 2

Application of InCa later in the growing season (September-October) increased calcium concentrations within the head of cabbage to 39.7 mg 100 g^{-1} (Table 10) and was a similar increment in calcium content observed in Year 1 (38.1 mg $100g^{-1}$). However, the increase in calcium content of cabbages in Year 2 failed to reach significance (P<0.05) due to the higher calcium content found within the untreated cabbage heads in Year 2 (34.3 mg 100). An increase in the amount of nitrogen in the InCa treated cabbage along with elevated amounts of copper and zinc (Table 10). InCa, is a co-formulation of (Ca) 6% w/v, Nitrogen (N) 5.4% w/v and Zinc (Zn) 1% w/v.

Table 10. Mineral analysis of cabbages treated pre-harvest with InCa, the data is a mean of 4 replicates each replicate contained 5 cabbages.

Minerals	InCa	Control	$LSD_{0.05}$	F pr.
mg $100g^{-1}$				
N	**209.9**	181.0	14.28	0.002
Ca	39.7	34.3	7.88	0.152
K	288.6	284.4	6.84	0.556
Mg	12.6	11.9	1.55	0.376
P	29.7	29.8	1.56	0.852
mg kg^{-1}				
Cu	**0.23**	0.19	0.01	0.002
Fe	4.25	4.26	0.54	0.954
Mn	1.51	1.49	0.03	0.519
Zn	**1.38**	1.18	0.06	<.001
B	1.57	1.57	0.13	0.966
Ratio				
K/Ca	7.4	8.5	0.61	0.117
N/Ca	5.4	5.4	0.81	0.953
K+Mg/Ca	7.7	8.8	1.45	0.115

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Harvest Quality of Cabbages Treated Pre-harvest with Calcium (InCa) - Year 2

Application of InCa increased the weight of harvested cabbage heads by ~9% from 4.15 kg in untreated to 4.49 kg in calcium-treated cabbage (Table 11). The increase in head size led to a softening, of the outer leaves compared to untreated cabbage. The difference was less pronounced in the inner cortex. The change in tissue strength did not impact on the incidence of wastage (see below) but whether such difference in leaf strength impacts on processing quality is unknown.

Application of InCa increased the background green colour (Colour a) of the outer leaves caused by the elevated nitrogen content (Table 11). In the second year of the trial, the positive effect of calcium sprays on sucrose accumulation was not observed (Table 11).

Table 11. Harvest quality of cabbages subject to late season treatment InCa (4 applications)

Cabbage	InCa	Control	$LSD_{0.05}$	F prob
Firmness (N)				
Inner cortex	90.4	**94.5**	3.86	0.003
Outer cortex	59.9	**72.3**		
Yield per head				
Weight kg	**4493.5**	4155.5	142.4	<.001
Leaf Colour				
Colour L	71.1	72.6	1.38	0.032
Colour a	**-16.7**	-15.2	0.43	<.001
Colour b	**31.4**	29.5	1.41	0.009
Sugars µL/µL				
Fructose	20.2	19.8	1.38	0.54
Glucose	33.3	33.6	1.37	0.66
Sucrose	3.6	4.1	1.17	0.36

N.B. Results highlighted in bold are significantly different (P<0.05) from the control within the same row

Post-harvest Quality of Cabbages following 7 Months Storage in Air (1°C): Spray trial - Year 2

After 7 months air storage (1°C), cabbages were assessed for the incidence of disease and assessed for internal quality (firmness and presence of internal defects). The firmness of the outer cortex of all cabbages had dropped, due in part to moisture loss, while the strength of the inner cortex remained similar to samples taken at harvest (Table 12). When averaged over all treatments, the inner cortex tissue was significantly firmer (91.1 N) compared to the outer cortex (61.6N). The inner cortex of cabbages treated pre-harvest with InCa were slightly softer (88 N) compared to untreated cabbages (94.1 N), while no treatment differences in the strength of the outer leaves was observed. No changes in internal visual quality were observed, and no signs of ‘cigar burn’ were recorded.

Table 12. Firmness (N) of cabbage leaves treated with Calcium (InCa)

Position	Outer cortex	Inner cortex	$LSD_{0.05}$	Fprob
Position	61.6	**91.1**	3.01	<.001
	InCa	Control		
Treatment	74.6	**78.1**	3.01	0.02
Interaction	InCa	Control		
Inner cortex	88	**94.1**		
Outer cortex	61.1	62.1	4.25	0.096

Control of post-harvest disease in Cabbage - Year 2

Finding alternatives to the standard post-harvest fungicides application of Rovral WG/SL567A for controlling disease spread is becoming increasingly important. Losses in air-stored cabbage that received no post-harvest treatment averaged 17.7% after 7 months storage in air (1°C); this was predominately caused by *Botrytis cinerea* (Table 13). Cabbages that received four pre-harvest sprays of InCa had a lower incidence of rotting (13.6%) at the end of storage but the magnitude of the reduction failed to reach significance at P<0.05.

The use of post-harvest drenching with Serenade ASO/InCa (9% rots) was as effective as Rovral WG/SL567A (6.5% rots) in reducing rotting caused by *Botrytis* (Table 13). Post-harvest application of InCa (14.6 %) alone was no better than water (13.6%) for reducing rotting. The act of dipping (washing) cabbages in water (13.6 % rots) tended to lower the rot potential of cabbages going into store, compared to untreated control samples (17.7%) but the size of the difference failed to reach significance at P <0.05 (Table 13).

Table 13. The incidence of wastage caused by Botrytis infection in cabbages treated with pre- or post-harvest calcium application or post-harvest application of Rovral WG/SL567A and combination of InCa/Serenade ASO.

Post-harvest Dipping trial				Pre-harvest Spray trial		Combined analysis	
InCa/Serenade	Rov/SL567A	Water	InCa	Control	InCa-Spray	$LSD_{0.05}$ on 18 df	F pr.
9.0	**6.5**	13.6	14.6	17.7	13.6	4.2	<.001
LSD (4.312 on 12 df)				LSD (4.99 on 6df)			

Reducing Post-harvest diseases in Swedes

Swede: Calcium spray trial

Quality at harvest Year 1

Spray applications of calcium products resulted in a small but significant increase in calcium content within the roots (Table 14). Interestingly, there was no increase in magnesium or boron content of roots treated with Brassitrel Pro and Carnival even though both are formulated with MgO and boron (Brassitrel Pro: 11.8% MgO, B: 6 % w/v; Carnival MgO 3% w/v, Boron 750 ppm w/v). The incorporation of zinc within the InCa formulation led to an increase in zinc in InCa-treated swedes. Calcium mobility is mostly limited to the xylem vessels and movement within the plant is controlled by the rate of transpiration. InCa formulated with CAT technology is reported to offer a degree of phloem mobility. All calcium products tested in this trial led to a small increase in calcium content in swede roots, this may be the result of the combined effect of calcium and nitrogen within the formulations increasing the rate of canopy establishment and larger leaf size (not measured). The potential improvement in canopy structure may increase the transpiration rate and the pull of nutrients from the rhizosphere into the roots. The size distribution of swedes from the different plots was variable and no significant shift in size was seen in the different classes of root size (Table 15). The largest impact of increasing the calcium content within roots was a reduced rate of tissue browning observed across all calcium treatments (Table 18). Untreated swedes were significantly ($P<0.05$) discoloured after an hour's exposure to air compared to the three calcium/nutrient treated crops. Commercially, swedes are retailed as whole roots, half-roots where sections are shrink wrapped or as diced root pieces within freshly prepared vegetable packs, in the latter two cases reduced rates of tissue discolouration may provide a commercial advantage.

There was no improvement in the firmness and biomechanical properties of treated swedes tested at harvest (Table 16) with the exception that the amount of force (N) required to generate a crack in cubes of swede tissue was higher in the Carnival treated crop.

Table 14. Mineral analysis of swedes (var. Tweed) subject to pre-harvest sprays of calcium/nutrient compounds. Swedes were sampled at harvest - A composite sample of 20 roots per plot; four replicates per treatment ($LSD_{0.05}$ on 12 df).

Minerals	Control	InCa	Brassitrel-Pro	Carnival	$LSD_{0.05}$
mg/100g					
N	88.8	111.2	104.5	102.8	31.57
Ca	36.3	**40.2**	**42.0**	**41.5**	3.65
K	261.0	**297.5**	287.5	272.8	31.28
Mg	8.9	9.6	9.8	9.0	1.05
P	41.9	**44.1**	**44.1**	38.7	1.87
mg/kg					
Cu	0.3	0.2	0.3	0.2	0.03
Fe	15.0	15.1	**18.1**	**16.8**	1.25
Mn	1.1	1.1	**1.4**	1.3	0.25
Zn	1.2	**1.4**	1.3	1.2	0.15
B	2.0	1.9	2.0	2.0	0.20
%Dry Mat.	11.3	11	11.2	11.3	0.92
Ca/DM	4.1	4.5	**4.8**	**4.7**	0.41
K/Ca	7.2	7.4	6.9	**6.6**	0.51
K+Mg/Ca	7.5	7.6	7.1	**6.8**	0.50

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row.

Table 15. Size distribution and weight (g) of swedes at harvest subject to pre-harvest calcium sprays

	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
>100 mm	49.9	54.0	39.7	45.5	21.0
100-85 mm	32.5	23.9	31.0	29.5	10.76
< 85 mm	17.6	22.1	29.2	22.4	21.7
Weight per tubers (g)	233.7	213.0	242.5	224.1	42.77

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Table 16. The effect of calcium treatments on the biomechanical properties of swede (wedge fracture test) at harvest

Treatment	Control	InCa	Brassitrel - Pro	Carnival	$LSD_{0.05}$
Ext. at Max Load (mm)	2.6	2.3	3.1	3.1	0.60
Load first fail (N)	12.8	**8.6**	11.0	13.7	1.96
Load at Crack (N)	8.8	8.8	9.3	**10.1**	1.07
Dist first fail (mm)	2.1	**1.3**	1.9	2.2	0.63

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Analysis of the sugar content of swedes at harvest found that Carnival-treated swedes were higher in fructose and glucose content (Table 17), while swedes treated with InCa and Carnival were higher in sucrose. The change in sugar profile in calcium sprayed swedes may have resulted from the nutrient spray programme encouraging rapid canopy establishment and/or delaying leaf senescence leading to a greater accumulation in photosynthate into the roots. Alternatively, elevated calcium in roots has facilitated increase sucrose loading into cells.

Table 17. Sugar (sucrose, glucose and fructose) profiles of swedes treated with calcium

Treatment	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
Fructose µL/µL	14.6	14.8	14.9	**15.3**	0.40
Glucose µL/µL	17.4	17.5	17.9	**18.6**	0.50
Sucrose µL/µL	3.0	**3.4**	3.2	**3.7**	0.24

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Table 18. Changes in Minolta colour a values (green-blue spectrum) on the cut surface of swedes measured immediately after cutting and after 60 minutes exposure to air

Treatment	Time	T 0	T 60	Δ T0-T60
Control		-2.38	**-1.43**	**0.95**
InCa		-2.89	-2.67	0.22
Brassitrel		-2.63	-2.31	0.32
Carnival		-2.61	-2.06	0.56
$LSD_{0.05}$ (df 24)		0.535		0.56

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Disease incidence in swedes - Year 1

The incidence of disease was most prevalent on the leaves and petioles infected with *Botrytis spp*, with a large amount of visible sporulation. Infection migrated down to the stem and in some cases infection progressed to the main root. Disease of the root not associated with the direct ingress from the stem was less frequently observed. Root infection were associated with sporulating leaf debris stuck to the side of the root or cross infection from adjacent swedes, or where infection had developed around a lesion or wound. There was no effect of calcium sprays controlling disease spread on leaves and the low frequency of direct root infections meant no significant treatment effects were observed (Table 19).

Table 19. The incidence of *Botrytis* infection of swedes treated pre-harvest with calcium products and assessed after two months storage in air 1°C (96-100% RH)

Treatment	Control	InCa	Brassitrel Pro	Carnival	$LSD_{0.05}$
% Leaf/petiole Infection	75.8	85.5	86.3	85.6	29.35
% Stem infection	1.0	0.0	0.5	0.0	1.18
Leaf + Stem Disease Severity Index (Max 60)	15.7	17.0	17.4	16.4	6.42
% Root rots	1.95	0.50	0.0	0.0	3.10

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Post-harvest Application of Hydrogen Peroxide

Initial assessment of treatments of trimmed (all leaf and petioles removed) and untrimmed (leaf material remaining) with hydrogen peroxide solution applied using a lab based atomiser found no reduction in the incidence of leaf and stem infections (Table 20). With untrimmed swedes hydrogen peroxide (100 mL t^{-1}) tended reduced the incidence of leaf/petiole rots compared to untreated controls but failed to reach significance P<0.05, but was able to reduce the severity of infection. The mode of application may have influenced the effectiveness of this treatment. An alternative dry fogging application of hydrogen peroxide using a miniature

fogging device was developed and tested in Year 2. The biggest source of infection of stored swedes comes from infection of the leaves and petioles with *Botrytis* spores in the field which leads to disease spread and sporulation during storage. Removal of leaves prior to storage reduces the inoculum load going into store.

Table 20. The incidence of Botrytis (*B. cinerea)* infection of swedes where stalks had leaves and petioles removed (trimmed) or left attached (untrimmed). Swedes were treated after harvest with Hydrogen Peroxide (7% v/v H_2O_2) solution and assessed after three and six months storage in air 1°C (96-100% RH) Year 1.

	H_2O_2	H_2O_2	Control	$LSD_{0.05}$
	100 mL t^{-1}	200 mL t^{-1}	Water	
Untrimmed- 3 months				
% Stalk+ leaf infection	32.7	23.40	32.1	27.8
% Side rot	15.70	8.6	5.6	10.4
Severity index (max 60)	6.5	6.1	6.8	4.6
Trimmed- 3 months				
% Stalk infection	22.0	X	40.0	46.6
% Side rot	6.0	X	2.4	9.9
Severity index (max 60)	8.2	X	12.3	2.6
Untrimmed- 6 months				
% Stalk + leaf infection	19.9	29.6	21.4	15.1
% Side rot	18.5	17.6	16.9	6.9
Severity index (max 60)	9.6	17.6	16.9	13.8

N.B. Results highlighted in bold are significantly different ($P<0.05$) from the control in the same row

Post-harvest Application of Ozone

Treatment with ozone for either 30 or 90 minutes failed to reduce the incidence or severity of disease in stem and stalk infections, over 90 % of swedes showed signs of mycelial infection with sporulation present (Table 21). Interestingly, ozone increased the susceptibility of side rots developing on swedes. The thin epidermis has been damaged by the concentration of ozone and exposure time used. Similar patterns associated with an increase in damage have been observed in ozone-treated sweet potato (NRI-unpublished data). After six months storage in air (1°C) there was a slight reduction in the severity of stem infections where roots had been subject to multiple 30 min exposure to ozone (Table 21) however, the index of severity of infection was high in all treatments (38-45).

Table 21. The incidence of Botrytis infection of swedes (untrimmed swedes) treated after harvest with ozone and assessed after three and six months storage in air 1°C

	Control	Ozone	Ozone	$LSD_{0.05}$
		90 min	30 min	
3 months storage				
% Stem	96.2	95.5	92.6	5.89
% Side rot	3.9	18.6	15.8	9.18
Severity index (max 60)	28.8	27.3	24.8	3.48
6 months storage				
% Stem	97.7	96.7	93.0	4.64
% Side rot	47.3	50.0	42.2	13.15
Severity index (max 60)	42.1	45.1	**38.1**	2.55

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Hydrogen Peroxide - Dry Fogging Year 2

Application of hydrogen peroxide delivered as a dry fog caused an increase in the incidence and severity of infections of trimmed stalks (Table 22), possibly through damage to the cut stem-surface. No difference in the incidence or severity of infection was observed when hydrogen peroxide was used on untrimmed stems. Removing all petiole and leaf material from swedes prior to storage significantly reduced the severity of *Botrytis* infection during storage. More than a 25 fold reduction in % stem infections was observed after 3 months storage where the leaves and petioles had been removed (trimmed) from stems compared to where they had been left attached (untrimmed) in the controls. Fogging swedes with hydrogen peroxide or calcium did not reduce stem infections or the incidence of root rots after 3 months storage. After 6 months storage, some of the infections found on trimmed stalks appeared to 'dry up' possible helped by retreatment with H_20_2 and calcium (Table 23). While the spread of disease in 'untrimmed' swedes progressed and often spreading down the stem into the root, increasing the severity of the infection.

Table 22. The incidence of Botrytis (*B.cinerea*) infection after 3 months storage in air (1°C) on swedes treated with Calcium (InCa) or hydrogen peroxide (Store Fresh 7% v/v H_20_2).

	% Stem infection		Stem infection severity (Max 60)		% Side rots	
	Stalks		Stalks		Stalks	
Treatment	Trimmed	Untrimmed	Trimmed	Untrimmed	Trimmed	Untrimmed
Water	2.3	58.4	0.5	16.1	0.0	3.6
InCa 420 mL t^{-1}	3.4	50.1	0.7	12.3	0.0	5.5
H_2O_2 100 mL t^{-1}	**10.3**	43.0	**2.8**	14.9	1.3	2.1
H_2O_2 200 mL t^{-1}	**12.8**	50.7	**3.0**	17.3	**2.7**	3.3
$LSD_{0.05}$	6.06	18.42	1.54	7.03	2.60	4.80
F-Prob	0.002	0.42	0.001	0.72	0.12	0.26
$LSD_{0.05}$	14.29		5.17		3.88	
F-Prob	0.11		0.68		0.23	

N.B. Results highlighted in bold are significantly different (P<0.05) from the control in the same row

Table 23. The incidence of Botrytis *(B.cinerea)* infection on swedes treated with calcium (InCa) or hydrogen peroxide (StoreFresh 7% v/v H_20_2), stored for 6 months in air at 1°C

	% Stem Infection		Stem severity (Max 60)		% Side rots	
	Stalks		Stalks		Stalks	
Treatment	Trimmed	Untrimmed	Trimmed	Untrimmed	Trimmed	Untrimmed
Water	0.6	67	0.4	29.5	2.0	4.6
Calcium	0.7	75.6	0.1	32.8	5.5	10.2
H_2O_2 100 mL t^{-1}	2.6	76.8	1.4	34.9	8.1	5.0
H_2O_2 200 mL t^{-1}	2.0	72.5	0.7	31.8	4.6	5.9
F.Prob	0.44	0.76	0.34	0.74	0.13	0.23
$LSD_{0.05}$	2.89	20.14	1.46	9.84	5.08	6.09
F.Prob Trimmed x	0.82		0.83		0.24	
Untrimmed						
$LSD_{0.05}$	14.1		6.89		5.52	

Conclusions

Cabbages

- Pre-harvest spray programme of InCa increased calcium content of cabbage
- Calcium and nitrogen application increased yield of cabbages
- Larger cabbages recorded a lower firmness in the centre (heart) of the cabbage at harvest
- Sprays of InCa and Carnival increased the firmness of outer leaves
- Calcium spray applications in general reduced the rate of weight loss in CA stored cabbage (reduction of 1% weight over 3 months)
- Brassitrel Pro treated cabbage were greener (Minolta a value) at harvest treatment differences were lost during storage
- Calcium sprays had no impact on dry matter accumulation
- Initial inspection has shown no benefit of calcium spray programmes on the incidence of disease
- Post-harvest application of Serenade ASO reduced post-harvest Botrytis.

Swedes

- Calcium sprays increased calcium content of swedes, reduced the onset of tissue browning and increased the sucrose content
- Removing leaf and petiole material from the stalks of swedes significantly reduced the rate of disease development during storage
- Neither ozone or hydrogen peroxide applied at harvest and a repeat application during storage reduced the rate of Botrytis infection of swedes
- Increased calcium content of swedes did not affect yield, size distribution or dry matter content
- Carnival increased the resistance to splitting/crack formation after harvest
- Sucrose content of swedes was increased by InCa and Carnival treatments. Glucose and fructose content was raised in Carnival treated swedes.

Knowledge and Technology Transfer

Brief project summary presented in HDC News (2016).

References

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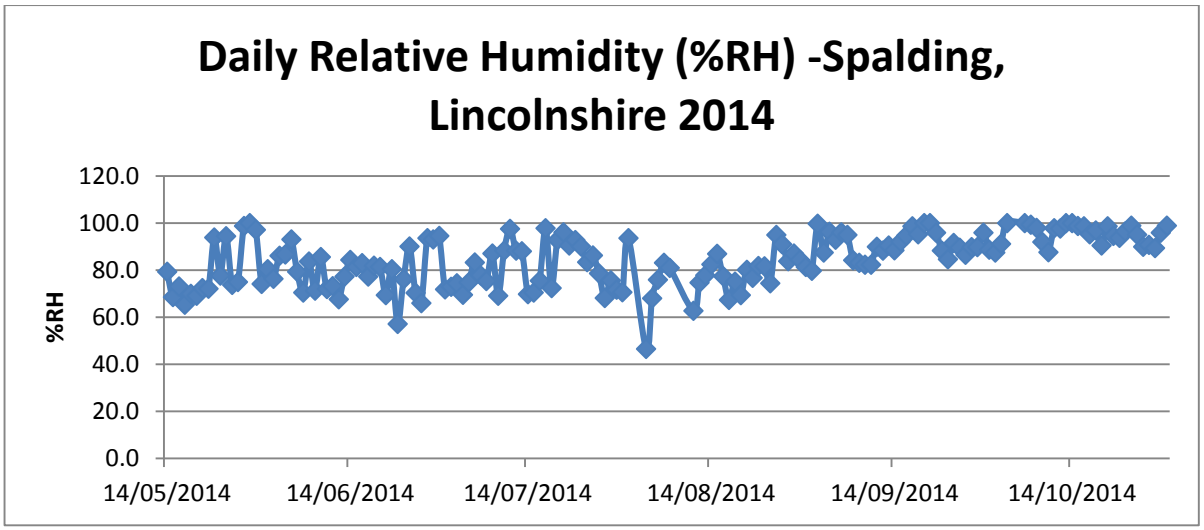
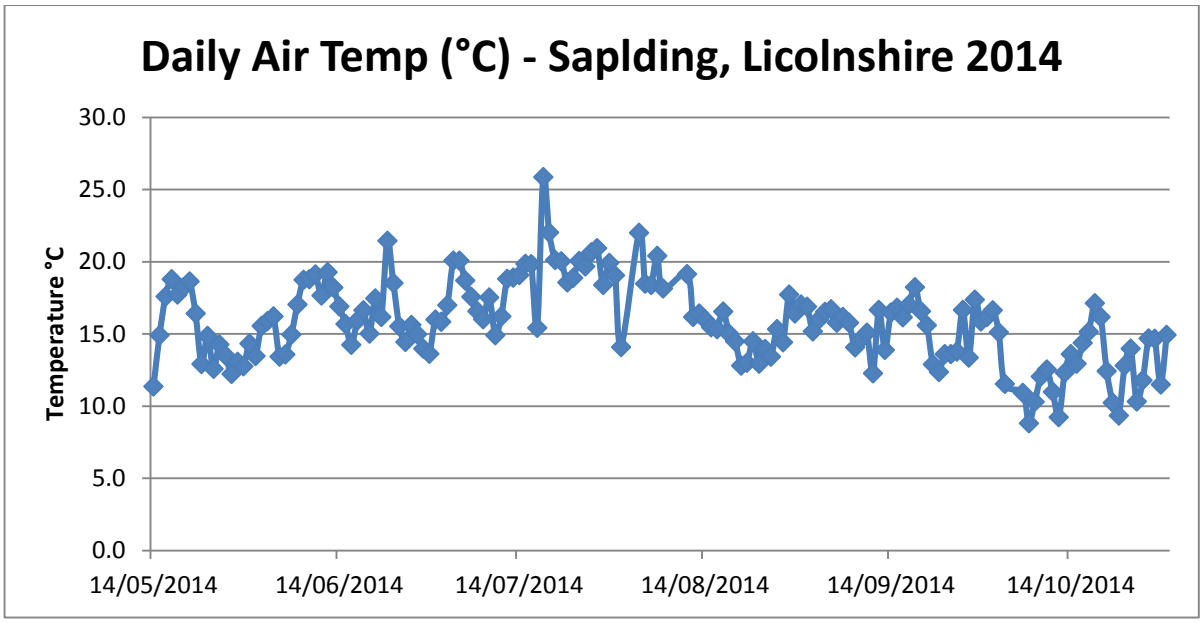
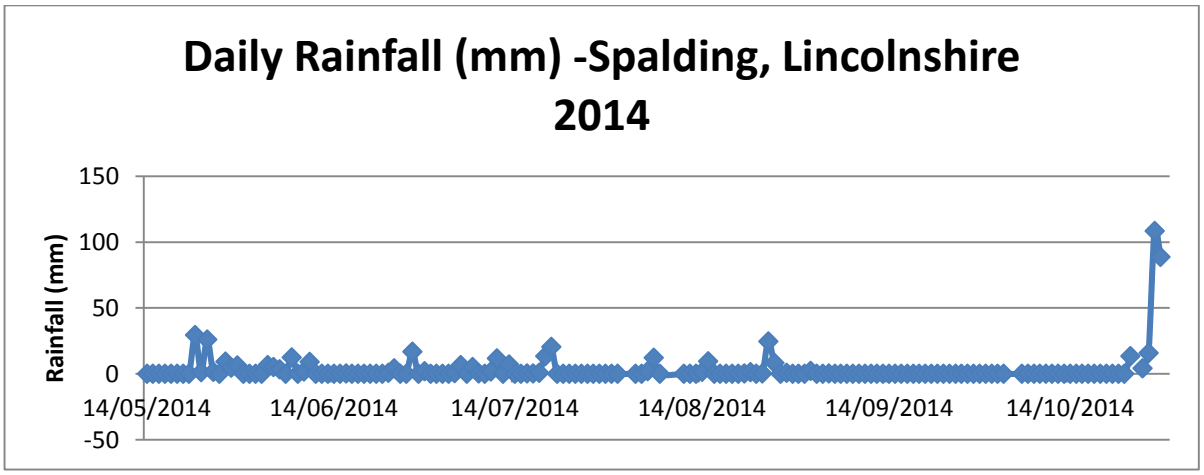
Appendix

Weather data for Spalding Lincolnshire 2014 –Year 1.







Weather data (partial) for Spalding Lincolnshire 2015 –Year 2.