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

AUTHENTICATION

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

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GROWER SUMMARY

Headline

Calcium spray programmes on cabbage increase the weight of harvested heads; increased head size can lead to cabbages with softer centres.

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

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. Strategies that control physiological breakdown and the incidence of post-harvest disease require further investigation.

A number of post-harvest strategies that combine treatments to improve crop health and reduce fungal load will help reduce 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 and ozone treatments are also beneficial in reducing water loss, and 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 needs to be determined to provide threshold levels which growers can try and achieve in commercial stores. The use of ozone has been trialed on a range of crops to reduce the incidence of disease and lower moisture loss in a range of crops. 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.

Alternative disease control techniques including advances in the development of bio-control agents such as Serenade give the possibility of lowering the 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/nutrient trials and post-harvest treatments to reduce the onset of disease.

For white winter cabbage (*Brassica oleracea*), a field site was kindly provided by Naylor Farms, Fosdyke, Lincolnshire, and for Swede (*Brassica napus var. napobrassica*) A W Mortier, Cedar Farm, Alderton, Woodbridge, Suffolk provided a field site. A randomised plot trial design was created using four replicate plots per treatment.

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 2 weekly intervals by the Allium and Brassica Agronomy Limited 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 1°C to remove field heat. Cabbages were transferred to nets and placed into four 500 kg CA 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).

Post-harvest treatments

Cabbages: Disease control

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}. Bins were transferred to a 1°C store.

Cabbages: Ethylene - trial

To determine the effect of background ethylene on the storage potential of white cabbages, trials were conducted on 4-5 kg cabbages 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

In year 1, the effectiveness of ozone to disinfest swede and cabbage was determined. Cabbages and swedes were exposed to ozone for 30 or 90 minutes. Untreated cabbages and swedes were included as controls. Treatments were repeated after 2 and 4 months of storage.

Swedes: Hydrogen peroxide trial

Swedes were treated with hydrogen peroxides solution (~100 mL/t (x1) and ~200 ml/t (x2) of (hydrogen peroxide solution (10% H_2O_2) Treatments were repeated every 6 weeks, water control and untreated roots were included as controls.

Harvest Quality Assessments: Spray Trial.

Leaf colour of cabbages and the rate of discolouration of cut swedes were recorded using a Minolta colour meter. Sugar and mineral content and dry matter analysis were taken from a V shape sections removed from cabbages and a from an equatorial section removed from.. Firmness measurements of cabbage were taken on the cut surface, two in the centre of the cabbage either side of the stalk and two towards the outer circumference (Figure 1), using an 8 mm probe attached to a penetrometer (Llyod Instruments). The firmness and elasticity of swedes was measured using a wedge fracture technique, a 1 cm^3 sections of root

Results

Cabbage

Bassitrel Pro and Carnival significantly increased the size of cabbages compared to the control. However, InCa was the only product to significantly increase the amount of calcium present in cabbage. The firmness profiles of cabbages from all three calcium spray programmes showed a reduction in firmness in the tissue around the base of the stalk (Heart) compared to the controls. The outer leaves (Figure 1) of InCA and Carnival treated cabbages were firmer than the control.

All three calcium spray products are formulated with incorporation of nitrogen. Bassitrel Pro (6.9 % w/w) and Carnival (14.9 % w/w) have a larger nitrogen component in the formulation than InCa (4.5% w/v) the combination of calcium and nitrogen increased the size of cabbages, however, the central heart tissue was less firm. The increase in calcium present in the outer leaves of cabbage treated with InCA and Carnival suggests a localised incorporation of calcium in the outer leaves. Calcium spray treatments had no effect on the dry matter accumulation. In general, application of calcium/nutrient sprays reduced the amount of weight loss in CA stored cabbage from 3 % in the control to ~2% in the treated cabbage after 3 months storage. There was no evidence from initial inspections that calcium spray application reduced rotting. Only once destructive analysis is complete at the end of the trial (June) will it be possible to determine the overall impact of calcium on diseases spread. Assessments of leaf quality and incidence of disease on ozone and ethylene treated cabbage is underway.

Swede

All calcium sprays increased the calcium content of roots. Whether the resultant increase in calcium was the movement of calcium from leaves to roots is unknown. An alternative and more likely scenario is that calcium application to leaves has encouraged leaf canopy development and increased transpiration allowing for greater accumulation of calcium in the roots. 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. While none of the formulations contained potassium, phosphate or iron, the presence of increased calcium content can stimulate the uptake of other minerals from the rhizosphere. 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 dry matter content or yield or size distributions were observed between treatments and no increase in nitrogen content in roots was observed indicating foliar applied nitrogen had not moved into the root. Application of Carnival increased 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. Additional testing will be conducted at the end of the trial (April). Initial experiments with hydrogen peroxide and ozone treatments showed no reduction in stem or root rotting.

The incidence of rotting was most obvious on the leaves and petioles of the leaves infected with *Botrytis spp*, with a large amount of visible sporulation on the surface of leaves, the disease migrated onto the stem and in some severe cases infection progressed to the main root. Disease of the root not associated with the direct ingress from the stem was observed, but less frequently. Root diseases were associated with Botrytis sporulating on leaf debris stuck to the side of roots, 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 1. Mineral content of cabbages sprayed with InCa, Brassitrel Pro and Carnival

Minerals	Control	Inca	Brassitrel	Carnival	$LSD_{0.05}$
mg/100g					
N	161.5	180.2	150.2	175.8	30.21
Ca	32.62	**38.12**	31.6	36.85	4.50
K	210.5	218.5	202.8	**234.8**	19.55
Mg	12.93	12.97	12.55	13.35	1.35
P	15.38	16.55	15.1	16.85	2.16
mg/kg					
B	1.218	**1.525**	1.222	**1.44**	0.15
% Dry Mat.	8.85	8.64	8.54	8.92	0.31
Ca/DM	3.68	**4.322**	3.572	**4.178**	0.41
K/Ca	6.53	**5.73**	6.43	6.38	0.75
K+Mg/Ca	6.92	**6.07**	6.83	6.75	0.77

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

Treatment	Position	Control	Inca	Brassitrel	Carnival	$LSD_{0.05}$	df
Weight (g)		3631.2	3763.5	**4382.2**	**4266.2**	215.2	78
Firmness (N)	Heart	101.1	**86.43**	**92.08**	**88.11**	3.723	32
Firmness (N)	Outer Cortex	94.8	**104.96**	**83.67**	**104.64**	3.723	32

Table 3. Weight loss and the incidence of disease in incidence of CA (5% CO_2. 3% O_2)

	Control	Inca	Brassitrel	Carnival	LSD
% Wt loss	3.05	2.69	**2.01**	**2.11**	0.542
% Botrytis	57.5	**73.8**	59.8	**85.9**	16.15
% Phytophthora	14	23.3	18.8	**32.1**	13.13

N.B. Results highlighted 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					
N	88.80	111.20	104.50	102.80	31.57
Ca	36.25	**40.15**	**42.00**	**41.52**	3.65
K	261.00	**297.50**	287.50	272.80	31.28
Mg	8.88	9.60	9.80	9.00	1.05
P	41.88	**44.12**	**44.12**	38.67	1.87
mg/kg					
B	1.97	1.94	2.01	2.01	0.20
%Dry Mat.	11.29	10.96	11.21	11.34	0.92
Ca/DM	4.12	4.54	**4.76**	**4.71**	0.41
K/Ca	7.21	7.40	6.86	**6.57**	0.51
K+Mg/Ca	7.46	7.64	7.09	**6.79**	0.50

Financial Benefits

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. Any reduction in these losses will increase grower's financial margins.

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 firmness of cabbage outer leaves
- Biological control agents show some promise for control of Botrytis, in early assessments
- Calcium sprays increased calcium content of swedes and reduced the onset of tissue browning

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^{TM},) 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 (TF200) Boron deficiency in swedes has been linked to brown heart and low boron 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 (FV395) 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 spray trial

Two sites were located in East Anglia for calcium pray trials. For white winter cabbage a field site was kindly provided by Naylor Farms, Fosdyke, Lincolnshire, and for swede A W Mortier provided a site at Cedar Farm, Alderton, Woodbridge, Suffolk.

There was a randomised plot design trial 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 2m 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 under protective netting. 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.

Storage

Cabbages 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 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

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 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 -trial

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

The effectiveness of ozone to disinfest swede and cabbage was determined. Cabbages and swedes were placed in a 300 L plastic container with an ozone generator the following exposure times were implemented:

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

Untreated cabbages and swedes were included as controls. Treatments were repeated after 2 and 4 months of storage.

Swedes: Hydrogen peroxide trial

Swedes, both trimmed to the stalk removing petiole and leaves and in addition 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 33ml/crate (0.5 mL ai/100 mL) or a double dose (1 mL ai $100mL^{-1}$). 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.

Assessments

Harvest Quality Assessments: Spray Trial.

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.

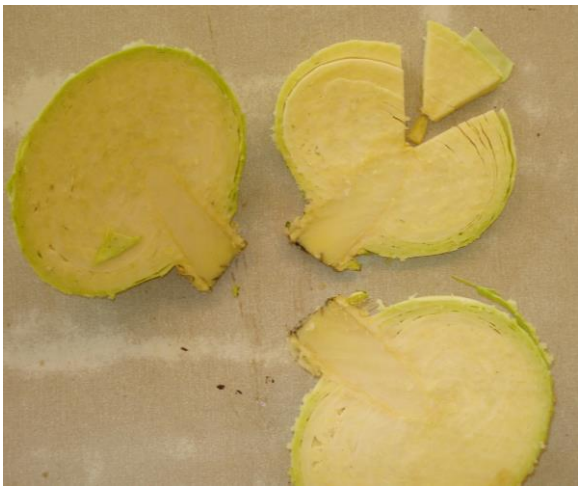

Figure 1.1: Section through cabbage, a ‘V’ shaped segment was taken for mineral and sugar analysis

Subsamples of cabbage leaves were cut into 0.5 cm sections and material was mixed thoroughly before sampling and freezing (-20°C) before later sugar and dry matter assessment. Sections were also pooled across all 20 cabbages per replicate for mineral analysis (FAST Ltd). For swedes, the process was the same except 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.

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 1), using an 8 mm probe attached to a penetrometer (Lloyd Instruments).

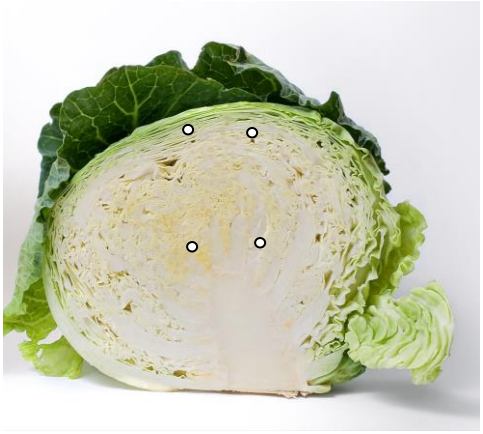

Figure 1.2 Location of sampling points for the penetrometer

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 (2mm min^{-1}) a stainless steel wedge through the tissue and recording the deformation characteristics using Nexygen software.

Data were analysed using ANOVA with Genstat version 13.

Results and Discussion

Cabbage – Calcium spray programme

Quality at harvest

All of the calcium products were formulated with other mineral elements including 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. All cabbages treated with calcium had softer centres than untreated cabbage (Table 2). 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. However, two products Inca and Carnival increased the strength of the outer leaves (Table 2). Interestingly these products also yielded the higher calcium content in tissue sampled for mineral analysis (Table 1). 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. Earlier

application of calcium in the development cycle of cabbage may aid incorporation of calcium at the cell division stage, affording better distribution of calcium.

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. The potassium content of cabbages treated with Carnival was higher 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.

Colour analysis of the leaves shrouding the head found small changes in green colour (Minolta –a) values with Brassitrel Pro treated cabbage having slightly darker green leaves at harvest.

Quality after Storage

After 3 months CA storage, cabbages were removed from 500 kg containers and inspected for colour, weight loss and the incidence of disease. Untreated control cabbages lost 3% weight loss over 3 months (Table 3) while, cabbages treated with Brassitrel Pro or Carnival lost 2% and 2.1% respectively.

Most of the outer leaves of cabbage had some form of infection, on visual examination it was not possible to determine extent of the ingress of the disease or estimate the proportion of wastage. Analysis of leaf colour after 3 months storage found no treatment difference in head colour (Table 4). Further inspections and a final destructive analysis are planned for later in the year. Samples for sugar analysis have been extracted and are in -80°C storage awaiting sucrose, fructose and glucose analysis by HPLC.

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	Carnival	$LSD_{0.05}$
mg/100g					
N	161.5	180.2	150.2	175.8	30.21
Ca	32.62	**38.12**	31.6	36.85	4.50
K	210.5	218.5	202.8	**234.8**	19.55
Mg	12.93	12.97	12.55	13.35	1.35
P	15.38	16.55	15.1	16.85	2.16
mg/kg					
Cu	0.195	**0.15**	**0.16**	0.19	0.05
Fe	3.655	3.575	3.942	3.57	0.49
Mn	1.062	1.038	1.002	1.045	0.12
Zn	1.212	1.175	1.188	1.218	0.14
B	1.218	**1.525**	1.222	**1.44**	0.15
% Dry Mat.	8.85	8.64	8.54	8.92	0.31
Ca/DM	3.68	**4.322**	3.572	**4.178**	0.41
K/Ca	6.53	**5.73**	6.43	6.38	0.75
K+Mg/Ca	6.92	**6.07**	6.83	6.75	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	Carnival	$LSD_{0.05}$	df
Firmness (N)	Heart	101.1	**86.43**	**92.08**	**88.11**	3.723	32
Firmness (N)	Outer Cortex	94.8	**104.96**	**83.67**	**104.64**	3.723	32
Colour L	Outer Leaves	72.16	**75.36**	71.92	72.51	1.246	284
Colour A	Outer Leaves	-17.26	**-16.23**	**-17.99**	-17.09	0.684	284
Colour B	Outer Leaves	32.14	31.25	**33.71**	31.82	1.112	284

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

Quality after Storage

After 3 months CA storage, cabbages were removed from 500 kg containers and inspected for colour, weight loss and the incidence of disease. Untreated control cabbages lost 3% weight loss over 3 months (Table 3) while, cabbages treated with Brassitrel Pro or Carnival lost 2% and 2.1% respectively.

Most of the outer leaves of cabbage had some form of infection, on visual examination it was not possible to determine extent of the ingress of the disease or estimate the proportion of wastage. Analysis of leaf colour after 3 months storage found no treatment difference in head colour (Table 4). Further inspections and a final destructive analysis are planned for later in the year. Samples for sugar analysis have been extracted and are in -80°C storage awaiting sucrose, fructose and glucose analysis by HPLC.

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

	Control	Inca	Brassitrel	Carnival	LSD
% Wt loss	3.05	2.69	**2.01**	**2.11**	0.542
% Botrytis	57.5	**73.8**	59.8	**85.9**	16.15
% Phytophthora	14	23.3	18.8	**32.1**	13.13

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

Table 4. Colour (Lab) of cabbage after 3 months CA storage (5% CO_2, 3% O_2,1°C) treated pre-harvest with calcium/nutrient sprays.

	Control	Inca	Brassitrel	Carnival	$LSD_{0.05}$	df
Colour L	75.2	74.1	74.0	75.7	1.177	78
Colour A	-14.6	-14.3	-15.0	-14.6	0.363	78
Colour B	28.6	28.2	28.9	28.9	1.221	78

Cabbage treated with biological control agents

Initial assessment of the incidence of Botrytis infection of cabbages dipped in biological control agents Serenade and F233 reduced infection by over half compared to the control and were as effective as Rovral in reducing *Botrytis* (Table 5). No *Phytophthora* infections were observed in this trial.

Table 5. The incidence (%) of Botrytis disease in white cabbage stored in air at 1°C

Water	Rovral/SL567A	Serenade	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

Swede: Calcium spray trial

Quality at harvest

Spray applications of calcium/nutrient sprays resulted in a small but significant increase in calcium content within the roots (Table 6). There was no increase in magnesium or boron content of roots. While calcium mobility is very much restricted to the xylem, foliar sprays of calcium products have been reported to increase calcium content of potatoes. While there was a small increase in calcium content in the swedes treated with calcium sprays- it is most likely that the calcium and nitrogen within the foliar application lead to improved 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 nitrogen content of swedes was higher in plots treated with Inca, Brassitrel Pro and Carnival as all 3 are formulated with nitrogen (4.5-14.9 % N). Interestingly, the phosphate content of swedes treated with Inca and Brassitrel Pro was higher than the control, even though the formulations contained no phosphate. The rate of tissue browning was reduced across all treatments, with the control (P<0.05) significantly more 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.

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 7). There was no improvement in the firmness and biomechanical properties of treated-Swedes tested at harvest (Table 8) 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. Nevertheless, further tests of swedes are scheduled for later in the storage season where treatment differences may develop.

Table 6. Mineral analysis of swedes 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	88.80	111.20	104.50	102.80	31.57
Ca	36.25	**40.15**	**42.00**	**41.52**	3.65
K	261.00	**297.50**	287.50	272.80	31.28
Mg	8.88	9.60	9.80	9.00	1.05
P	41.88	**44.12**	**44.12**	38.67	1.87
mg/kg					
Cu	0.25	0.22	0.25	0.22	0.03
Fe	15.01	15.12	**18.06**	**16.80**	1.25
Mn	1.06	1.06	**1.35**	1.25	0.25
Zn	1.24	**1.37**	1.33	1.21	0.15
B	1.97	1.94	2.01	2.01	0.20
%Dry Mat.	11.29	10.96	11.21	11.34	0.92
Ca/DM	4.12	4.54	**4.76**	**4.71**	0.41
K/Ca	7.21	7.40	6.86	**6.57**	0.51
K+Mg/Ca	7.46	7.64	7.09	**6.79**	0.50

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

Table 7. Size distribution of Swedes at harvest

	Control	Inca	Bassitrel	Headland	$LSD_{0.05}$
>100 mm	49.9	54	39.7	45.5	21
100-85 mm	32.5	23.9	31	29.5	10.76
< 85 mm	17.6	22.1	29.2	22.4	21.7

Table 8. The effect of calcium treatments on the biomechanical properties of swede (wedge fracture test)

Treatment	Control	Inca	Brassitrel	Carnival	$LSD_{0.05}$
Ext. at Max Load (mm)	2.6	2.33	3.1	3.13	0.601
Load first fail (N)	12.75	**8.62**	10.97	13.68	1.959
Load at Crack (N)	8.76	8.76	9.33	**10.13**	1.07
Dist first fail (mm)	2.12	**1.34**	1.88	2.25	0.633

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

Changes in the rate of tissue browning were measured at harvest, in roots that had been cut equatorially and measured at the start and after 60 minutes exposure to air. Swedes treated with calcium/nutrient products all resulted in a lower rate of tissue discolouration than the controls (Table 9).

Table 9. Changes in Minolta colour -a values (green-blue spectrum) on the cut surface of Swedes measured immediately after cutting and re-measured after 60 minutes exposure to air

Treatment Time	T 0	T 60 min	Δ T0-T60
Control	-2.377	**-1.430**	**0.95**
Inca	-2.893	-2.673	0.22
Brassitrel	-2.633	-2.308	0.32
Carnival	-2.612	-2.055	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,

The incidence of disease was most obvious on the leaves and petioles infected with *Botrytis spp*, with a large amount of visible sporulation on the leaf surface, infection migrated down to the stem and in some severe cases infection progressed to the main root. Disease of the root not associated with the direct ingress from the stem was observed, but less frequently. Root diseases were associated with sporulating leaf debris stuck to the side of the root, cross infection from adjacent swedes, showing signs of stalk infection 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 10).

Table 10. 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	0.5	0	1.18
Leaf+Stem Disease Severity Index (Max 60)	15.7	17	17.4	16.4	6.42
% Root rots	1.95	0.5	0	0	3.10
Weight 50 tubers	11687	10652	12126	11207	2138.60

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 did not reduce the incidence of leaf and stem infections (Table 11 & 12). The mode of application may have influenced the effectiveness of this treatment. Alternative application methods such a dry fogging of hydrogen peroxide are currently being tested commercially. Infection of the leaves and petioles with *Botrytis* spores in the field leads to disease spread and sporulation during storage with the potential for significant redistribution of spores and new infections developing in store. Removal of leaves prior to storage would reduce the inoculum load going into store.

Table 11. The incidence of Botrytis infection of swedes (trimmed) treated after harvest with Hydrogen Peroxide solution and assessed after two months storage in air 1°C (96-100% RH),

	H_2O_2 100 mL ai t^{-1}	H_2O_2 200 mL ai t^{-1}	Control Water	$LSD_{0.05}$
% Stalk	32.7	23.4	32.1	27.82
% Side rot	15.7	8.6	5.6	10.39
Severity index (max 60)	6.53	6.12	6.76	4.64

3 Replicates per treatment each replicate contained 50 swedes

Table 12. The incidence of *Botrytis* infection of swedes (untrimmed swedes) treated after harvest with Hydrogen Peroxide solution and assessed after two months storage in air 1°C (96-100% RH),

	H_2O_2 100 mL ai t^{-1}	Control Water	$LSD_{0.05}$
% Stalk	22	40	46.6
% Side rot	6	2.4	9.94
Severity index (max 60)	8.2	12.3	2.58

- 3 Replicates per treatment each replicate contained 50 swedes

Treatment with ozone for either 30 or 90 minutes did not reduce the incidence or severity of disease in stem and stalk infections, over 90 % of all swedes showed signs of mycelial infection with sporulation also present (Table 13). Interestingly, ozone appeared to increase the susceptibility of swedes to developing side rots where infection has started on the swollen root. The thin epidermis may be damaged by ozone.

Table 13. The incidence of Botrytis infection of swedes (untrimmed swedes) treated after harvest with ozone and assessed after three months storage in air 1°C (96-100% RH),

	Control	Ozone 90 min	Ozone 30 min	$LSD_{0.05}$
% Stem+Stalk	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

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- more detailed inspections to follow
- Ethylene and ozone trials ongoing

Swedes

- Calcium sprays increased calcium content in roots
- Inca increased potassium and phosphate content
- Brassitrel Pro increased phosphate, iron and manganese content
- Carnival increased Iron
- No effect on dry matter content
- No significant effect on yield or size distribution
- Firmness: Carnival increased the resistance to splitting/crack formation after harvest
- All calcium treatments reduced the rate of tissue browning after harvest
- Initial experiments with hydrogen peroxide and ozone treatments showed no reduction in stem or root rotting

Knowledge and Technology Transfer

None to date

References

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