Project title:	Efficacy of treatments against Botrytis development during storage of Dutch white cabbage
Project number:	FV 462
Project leader:	Angela Huckle
Report:	Annual report, November 2022
Previous report:	none
Key staff:	Angela Huckle Callum Burgess Dr Erika Wedgwood
Location of project:	Boston, LINCS. UK
Industry Representative:	AHDB Horticulture
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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.

Name **Dr Erika Wedgwood**

Position **Plant pathologist**

Organisation **RSK ADAS Ltd.**

Signature E.F. Wedgwood Date 16/12/2022

Report authorised by:

[Name] Dr Catherine Eyre

[Position] Associate Director

[Organisation] RSK ADAS Ltd.

Signature .... Date ......16/12/22...............................

[Name]

[Position]

[Organisation]

Signature .... Date ....

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GROWER SUMMARY

Headline

No phytotoxicity arose from post-harvest application of chemical or microbial products experimentally to white cabbage, with no difference in marketable weights post-storage. Product efficacy against Botrytis was unable to be shown as neither untreated nor treated stored heads developed the rot.

Background

This trial sought to evaluate bioprotectants (biopesticides, both microbial and chemical) and conventional chemical plant protection products for control of grey mould (*Botrytis cinerea*) in stored Dutch white cabbage and reduce the amount of wastage occurring during storage.

Replacements for the post-harvest fungicide application of metalaxyl-M for *Phytophthora* spp. control and iprodione for *B. cinerea* control are required following their withdrawal from use.

Summary

Nine products were applied once to crate-sections of cabbage heads directly after harvest in November 2020. Water was sprayed as an untreated control for the tenth treatment. There were four conventional chemical products, two other products with chemical active ingredients and three microbial products, with four replicate “plots” of 30 heads per crate-section (Table 1). All but one product are registered fungicides. Heads were weighed before and after storage for 26 weeks after which rots were assessed, and heads trimmed to obtain marketable weights. No significant differences were found between any of the treatments and the untreated heads in yield or disease measures (Table 1).

Head weight was a mean 4 kg each at harvest, with on average a 9.6% weight loss for crate-sections due to dehydration during storage. Following trimming, to remove leaves to produce a marketable head post-storage, the mean weight per replicate crate-section was reduced from 87.2 Kg to 67.7 Kg, i.e., a mean 70% of the harvested weight. There was no phytotoxicity from any of the products. No maximum residue level results were obtained due to difficulties with analytical laboratory services due to covid precautions in place at the time of the trial.

No Botrytis developed in the stored heads and so this trial was not a good test of product efficacy against *Botrytis cinerea* grey mould. Phoma (canker) lesions were found in 21 of the 40 crate-sections, being present across all treatments, principally causing only slight damage. Phytophthora rot was absent from the treatments AHDB9817 (conventional fungicide), AHDB9767 (conventional fungicide), AHDB9852 (organic fungicide: plant derived protein) and AHDB9737 (plant flavonoid), but only nine heads were affected across the whole trial when the heads were cut open (resulting in a final mean marketable weight of 66.9 Kg per crate-section across the trial).

Table 1. Mean results pre- and post-storage for white cabbage heads treated in crates in November 2020 and processed in May 2021. (Calculations based on revised weight column)

Treatment	Total initial stored weight (kg)	Mean head weight (kg)	Revised weight excluding samples for MRL (kg)	Total weight ex store (kg)	% Dehydration	Total trimmed weight - marketable (kg)	% Marketable weight	Trimmed Marketable weight ex. Phytophthora	% Marketable weight (excluding Phytophthora)	Phytophthora (kg)	Canker (0-5 index)
Water	95.84	3.85	92.24	83.6	9.35	63.22	68.51	61.4	66.55	1.82	0.25
AHDB9817	97.03	3.85	93.43	84.04	10.05	67.91	72.69	67.91	72.69	0.00	1.50
AHDB9816	105.39	4.23	101.79	92.75	8.83	70.42	69.28	69.53	68.42	0.88	1.75
AHDB9936	98.02	3.93	94.42	86.01	8.90	68.09	72.15	67.26	71.25	0.83	0.50
AHDB9891	102.24	4.10	98.64	88.26	10.5	68.46	69.72	66.72	67.96	1.74	0.50
AHDB9815	100.32	4.03	96.72	88.71	8.10	69.38	71.67	68.79	70.97	0.59	1.75
AHDB9939	95.78	3.83	92.18	84.35	8.50	65.07	70.59	63.19	68.56	1.88	1.75
AHDB9767	104.48	4.18	100.88	91.27	9.55	72.41	71.76	72.41	71.76	0.00	0.75
AHDB9852	97.56	3.90	93.96	85.95	8.50	68.2	72.58	68.2	72.58	0.00	1.00
AHDB9737	105.09	4.20	101.49	87.44	13.38	63.98	63.43	63.98	63.43	0.00	1.50
Grand Mean	100.17	4.01	96.57	87.24	9.57	67.71	70.24	66.94	69.42	0.77	1.12
F- Probability value	0.172	0.152	0.172	0.078	0.212	0.162	0.087	0.185	0.172	0.47	0.687
Least significant difference	8.904	0.356	8.904	6.284	3.671	6.563	5.802	7.649	6.889	2.319	2.027

Financial Benefits

Benefit from the use of products in the form of processed marketable yield will differ widely depending on the incidence and severity of rots that could have developed had they remained untreated. With labour shortages, any reduction from treatment application after harvest in post-storage trimming due to rots could be of significance financially as untreated heads with external disease symptoms may remain untrimmed and so unmarketable.

Action Points

- Harvest in dry conditions, when possible, to reduce the chance of Botrytis and Phytophthora spore splash and spore germination success and so achieve a lower incidence of storage rotting.
- Where microbial products are available, recognise that their activity against pathogens is likely to be much slower than conventional chemical products. AHDB9936 can be used under an EAMU for post-harvest drench application to outdoor cabbage.
- Read label instructions and supporting technical information when selecting biocontrol products as they can have differing modes of action and optimum operating conditions.

SCIENCE SECTION

Introduction

This study was conducted to compare fungicides of differing modes of action for crop safety and efficacy in the prevention of storage rots of Dutch white cabbage. Storage rots, caused by grey mould (*Botrytis cinerea*) and other pathogens, are a major problem in all stored vegetables and can lead to yield loss, and quality reduction. *B. cinerea* can survive as a saprophyte on plant debris such as dead and decaying lower leaves, as well as causing primary damage to a wide range of crops and weeds. Iprodione (Rovral WG) was previously available for field application. Abundant grey mould spores are produced under conditions of high humidity and can infest cabbage heads directly or during crop handling without necessarily initially developing any necrosis. Once trimmed, cabbages are placed in store and the humid conditions (typically 90% relative humidity or higher) that are provided to prevent moisture loss favour infection. Although storage is targeted to be around 0°C, warmer temperatures occur and favour the development of grey mould growth. A soft brown rot develops which can penetrate deeply into the head. The spores can spread throughout storage boxes through run-off in droplets.

Fungi and bacteria other than grey mould can also cause spoilage (Red Tractor, 2015) including *Alternaria*, *Mycosphaerella*, *Phoma* and *Phytophthora* spp. which can cause lesions that lead to secondary invasion by *B. cinerea*. Phytophthora rot (*P. megasperma*) can infest from the soil during wet harvesting conditions to spread rapidly up the stem and cause whole head loss. Post-harvest fungicide application (metalaxyl-M for *Phytophthora* spp. control and iprodione for *B. cinerea* control) has been used to reduce the amount of wastage occurring during storage. Fungicide treatment is carried out by either dipping (immersion) of the storage boxes, or by overhead drenching when it should be ensured that all surfaces of every cabbage are covered in fungicide. However, a final use date for Rovral WG was set for 5 June 2018. The maximum residue level for metalaxyl-M has been lowered to a point that exceedance of residue levels would be possible after use on harvested heads and from 21 January 2018 in-crop foliar use was only possible. There are no current replacements for these products and so alternative plant protection products are required for use on stored cabbage heads. Potential chemical and biological products were therefore evaluated in this project for phytotoxicity, efficacy and the quality/marketability of treated white cabbage heads after 26 weeks storage.

Materials and methods

The trial was sited in a commercial standard cold store at the Allium & Brassica Centre, Boston, storing Dutch white cabbage (cv. Ancoma). Cabbage heads of 3 kg to 4 kg were harvested in the week beginning 16 November 2020 from a commercial field crop with standard management and placed into crates sectioned vertically into four compartments by ply-wood sheets. All trial treatments were applied once post-harvest on 23 November 2020, directly onto the cabbage. Treatments were applied to the heads in their storage crates using a water volume of 200 L/ha by hand-lance using a gas-assisted AZO sprayer (see Application Table). Spray volume was calculated on a pro-rata basis of average crop weight based upon 20 L water per tonne cabbage. With 30 heads per plot, and heads of 3.5 kg, each plot contained around 105 kg. The sprayer was filled with 2.5 L of spray volume per plot and sprayed evenly over the cabbage until the sprayer was empty.

A randomized block design was used for the trial layout, with four replicates of 10 treatments, including an untreated control. Each of the 40 crate-section plots measured 0.5 m wide x 1 m long and 0.9 m high (half the crate depth, to ensure the sprays were contained within each plot). The plywood dividers prevented any cross-contamination. Some heads were removed after treatment applications to send away for laboratory analysis of maximum residue levels.

Table 1. Treatment numbers, with their associated applications showing the rates that were used for the single application to cabbage heads post-harvest before storage.

	Timing 1 – applied post-harvest directly to cabbage heads	
Treatment Number	**Product**	**Rate (L/ha** or **kg/ha)**
1	Untreated	-
2	AHDB9817	0.5
3	AHDB9816	0.5
4	AHDB9936	3% *
5	AHDB9891	2.5
6	AHDB9815	2.5
7	AHDB9939	0.6
8	AHDB9767	0.2 + 1
9	AHDB9852	2.75
10	AHDB9737	150 ml / 20 L

* Rate of AHDB9936 adjusted from per hectare to % volume / volume (after consultation with chemical company representatives)

Table 2. Products and active ingredients applied to cabbage heads pre-storage with chemical products' active ingredient concentrations, or colony forming units in microbial products

Product	Active ingredient (a.i.)	Concentration of a.i. or colony forming unit (cfu) in product
AHDB9817	Conventional fungicide	50% w/w
AHDB9816	Conventional fungicide	500 g/kg
AHDB9936	*Bacillus sp.*	1015.1 g/L
AHDB9891	*Bacillus sp.*	250 g/kg (5 x 10^{13} cfu/kg)
AHDB9815	*Pythium sp.*	1 x 10^{6} cfu/g
AHDB9939	Conventional fungicide	250 g/L
AHDB9767	Conventional fungicide	100 g/L
AHDB9852	Organic fungicide – plant derived protein	20%
AHDB9737	Natural plant flavonoids	Unspecified

Application details

	Application A
Application date	23/11/2020
Time of day	Not recorded
Crop growth stage (Max, min average BBCH)	Heads of harvested crop (to go into in store)
Crop height (cm)	N/A
Crop coverage (%)	N/A
Application Method	Spray
Application Placement	On harvested crop
Application equipment	Modified AZO compressed air backpack sprayer except for AHDB9815 where a hand-held fogging machine was used.
Nozzle pressure (bar)	2.0 (AZO)
Nozzle type	Flat Fan (AZO)
Nozzle size	03-F110 single nozzle (AZO)

Application water volume (L/ha)	1000 L per 50 tonnes cabbage
Temperature of air - shade (°C)	Not recorded
Relative humidity (%)	N/A
Wind speed range (kph)	N/A (indoors)
Dew presence	N/A
Temperature of soil - 2-5 cm (°C)	N/A
Wetness of soil - 2-5 cm	N/A
Cloud cover (%)	N/A

After product application, the bins were drained and after drying the boxes were put into store 24 November 2020, 18-24 hours after treatment. The bins were placed into a commercial store for refrigeration down to 1°C at approximately 95% relative humidity.

Refrigerated store roof									
Column 1				Column 2					
207 5	208 3	209 4	210 10	407 8	408 6	409 3	410 5		Refrigerated store wall
203 2	204 7	205 9	206 6	403 4	404 1	405 7	406 2		
109 10	110 3	201 8	202 1	309 7	310 1	401 9	402 10		
105 4	106 9	107 1	108 6	305 3	306 8	307 10	308 9		
101 7	102 2	103 5	104 8	301 6	302 4	303 5	304 2		
Refrigerated store floor									

Logger in column 1, 4th stack up

Logger in column 1, 2nd stack up

Figure 1. Trial layout of crates in cold store in 2020/2021

Figure 1 shows the arrangement of crates with cabbage heads in the cold store in 2020/21. Cabbages were stacked into wooden storage boxes divided by plywood sheets to create plots, with four plots per box e.g., 101, 102, 103 104 are in a box on the floor level.

The plots were assessed on 28 May 2021 following 26 weeks storage, focusing on fungal species presence and damage causing losses in weight and marketability. Photographs were taken of each crate-section.

All crop base inputs in the field such as fertiliser, watering regimes, pesticides, and pest netting were applied by the grower as standard. Harvest, packing, and storage conditions were typical for industry standards.

Assessment details

Evaluation date	Evaluation timing after application	Crop Growth Stage (BBCH)	Evaluation type	Assessment type
23/11/2020	Before	Harvested, pre-storage	Quality	Initial total weight per plot of 30 heads (kg)
28/05/2021	26 weeks	Harvested, in storage	Quality	Ex-storage total weight per plot (kg)
28/05/2021	26 weeks	Harvested, in storage	Quality	Ex-trimmed total weight per plot (kg)
28/05/2021	26 weeks	Harvested, in storage	Phytotoxicity	Scale 0-10, 10 = totally destroyed as described below
28/05/2021	26 weeks	Harvested, in storage	Efficacy	*Botrytis* sp. Scale 0-3 as described below
28/05/2021	26 weeks	Harvested, in storage	Efficacy	*Phytophthora* sp. affected per plot (kg)
28/05/2021	26 weeks	Harvested, in storage	Efficacy	*Sclerotinia* sp. affected per plot (kg)
28/05/2021	26 weeks	Harvested, in storage	Efficacy	*Phoma* sp. 0-5 canker index as described below
28/05/2021	26 weeks	Harvested, in storage	Quality	Marketable weight of plot after trimming (kg)
28/05/2021	26 weeks	Harvested, in storage	Quality	Calculation of the percentage marketable yield. The proportion of cabbage that was not lost to trimming or Phytophthora.

Efficacy

Phoma canker Index	**Description**
0	None
1	Low
2	Low-moderate
3	Moderate
4	Moderate-high
5	High

Botrytis rot Index	**Description**
0	No evidence of Botrytis (Marketable)
1	Low level, no more than 10% coverage, penetrating no more than 1-2 wrapper leaves (Marketable)
2	Low level, no more than 10% coverage, penetrating no more than 1-2 wrapper leaves (Marketable)
3	Severe, affecting more than 50% of surface area, penetrating deep into head tissue. (Unmarketable)

Phytotoxicity

A head tolerance 0-10 index was used, and its equivalence in % head damage due to phytotoxicity is shown in the table below.

Head tolerance index	**Head damage extent**
0	0% (*no damage*)
1	10%
2*	20%
3	30%
5	50%
7	70%
9	90%
10	100% (*complete destruction*)

* ≤2 = Damage considered acceptable to the farmer, i.e., damage unlikely to reduce marketable yield

Results

The conditions at harvest were dry, thus resulting in relatively low levels of rot in store.

Analysis by ANOVA using GENSTAT did not give any F probability values less than 0.05, thus showing there were no significant treatment differences at this probability level in any of the parameters measured (**Table 3**). A further statistical comparison of product rankings (Student-Newman-Keuls test) carried out also showed that all treatments ranked the same across the different assessment measures and calculation derived data.

Table 3. Summary table of mean fresh weight of cabbage heads in November 2020 and following storage with losses due to dehydration and rots by May 2021 with Analysis of Variance (27 d.f.) showing no significant treatment differences

Treatment	Total initial stored weight (kg)	Mean head weight (kg)	Revised weight excluding samples for MRL (kg)	Total weight ex store (kg)	% Dehydration	Total trimmed weight - marketable (kg)	% Marketable weight	Trimmed Marketable weight ex. Phytophthora	% Marketable weight (excluding Phytophthora)	Phytophthora (kg)	Canker (0-5 index)
Water	95.84	3.85	92.24	83.6	9.35	63.22	68.51	61.4	66.55	1.82	0.25
AHDB9817	97.03	3.85	93.43	84.04	10.05	67.91	72.69	67.91	72.69	0.00	1.50
AHDB9816	105.39	4.23	101.79	92.75	8.83	70.42	69.28	69.53	68.42	0.88	1.75
AHDB9936	98.02	3.93	94.42	86.01	8.90	68.09	72.15	67.26	71.25	0.83	0.50
AHDB9891	102.24	4.10	98.64	88.26	10.5	68.46	69.72	66.72	67.96	1.74	0.50
AHDB9815	100.32	4.03	96.72	88.71	8.10	69.38	71.67	68.79	70.97	0.59	1.75
AHDB9939	95.78	3.83	92.18	84.35	8.50	65.07	70.59	63.19	68.56	1.88	1.75
AHDB9767	104.48	4.18	100.88	91.27	9.55	72.41	71.76	72.41	71.76	0.00	0.75
AHDB9852	97.56	3.90	93.96	85.95	8.50	68.2	72.58	68.2	72.58	0.00	1.00
AHDB9737	105.09	4.20	101.49	87.44	13.38	63.98	63.43	63.98	63.43	0.00	1.50
Grand Mean	100.17	4.01	96.57	87.24	9.57	67.71	70.24	66.94	69.42	0.77	1.12
F- Probability value	0.172	0.152	0.172	0.078	0.212	0.162	0.087	0.185	0.172	0.47	0.687
Least significant difference	8.904	0.356	8.904	6.284	3.671	6.563	5.802	7.649	6.889	2.319	2.027

No heads developed Botrytis. Nine heads (across eight plots of various treatments – see Appendix Table) had Phytophthora infection causing softening into the heads making them unmarketable. Sclerotinia was only present in one plot. No phytotoxicity developed from any of the treatments.

Chemical residue level results were unable to be obtained for the heads held back after treatment as this experiment took place when covid-19 restrictions impeded analysis laboratory functioning.

Bar charts are given in the section below to show the mean results for each treatment. Although bars vary in height there were no statistically significantly differences, there being replicate crate-sections with values higher than others so showing a high residual in the ANOVA.

At the start of storage there were some non-significant differences in the mean plot weights owing to random slight difference in the individual weights of the same number of heads in each crate-section (**Fig. 2**). The lowest weight, 92.2 Kg, was for heads receiving **AHDB9939** and **AHDB9816** applied to plots with highest mean fresh weight, of 101.8 Kg (L.s.d 8.90). These weights and further calculations exclude the heads taken away for residue testing following spraying.

After treatment and storage for 26 weeks, the highest mean plot fresh weight was still recorded for **AHDB9816** at 92.7 Kg (9.14 Kg heavier than the **untreated control),** however there were no still no statistically significant differences between the means (L.s.d. 6.28) (**Fig. 2**).

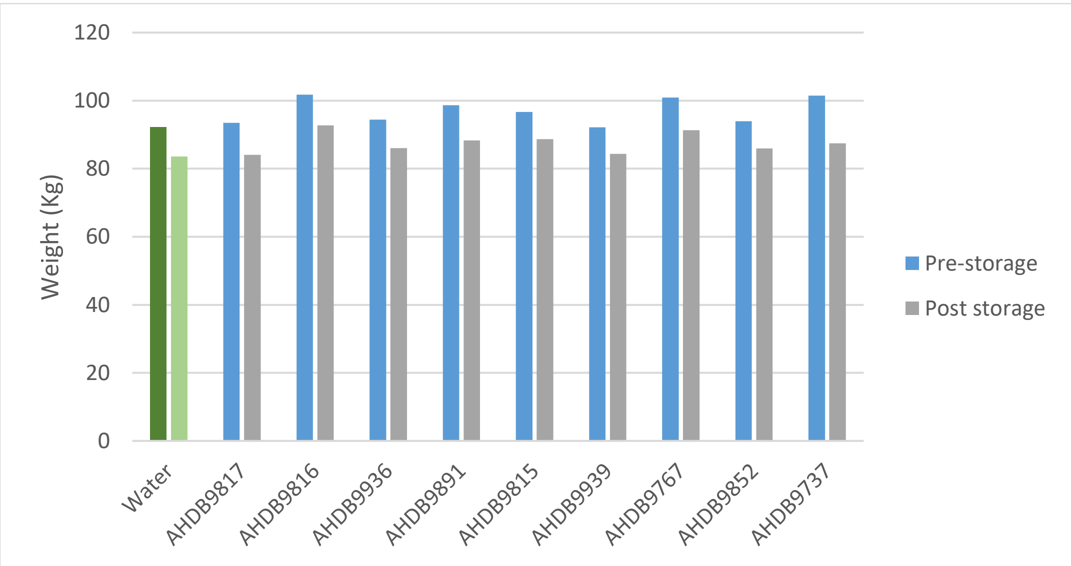

Figure 2. The average total fresh weight in Kg of a crate-section (plot of stored cabbage) for all 10 treatments at: Pre-storage – start of storage in November 2020, Post-storage – end of storage in May 2021, with the untreated controls shown in green. Note that this is pre-trimming and includes unmarketable material.

No significant differences were seen in percentage dehydration following storage. The highest mean loss, of 13.4%, was seen in **AHDB9737**, but this was statistically no greater than the 9.35% loss of moisture in the **untreated control** (L.s.d. 3.67) (**Fig. 3**). The mean for **AHDB9737** was raised by just one of the replicate plots (plot 9) with a value of 23.4% loss - this was highlighted by the ANOVA test as being out of line with the other three replicates of that treatment (see plot scores in **Appendix**). Similarly, the shorter bar for **AHDB9815** was due to a value of 4.4% in plot 8 that depressed the mean for that treatment to 8.1% but it not being statistically the lowest.

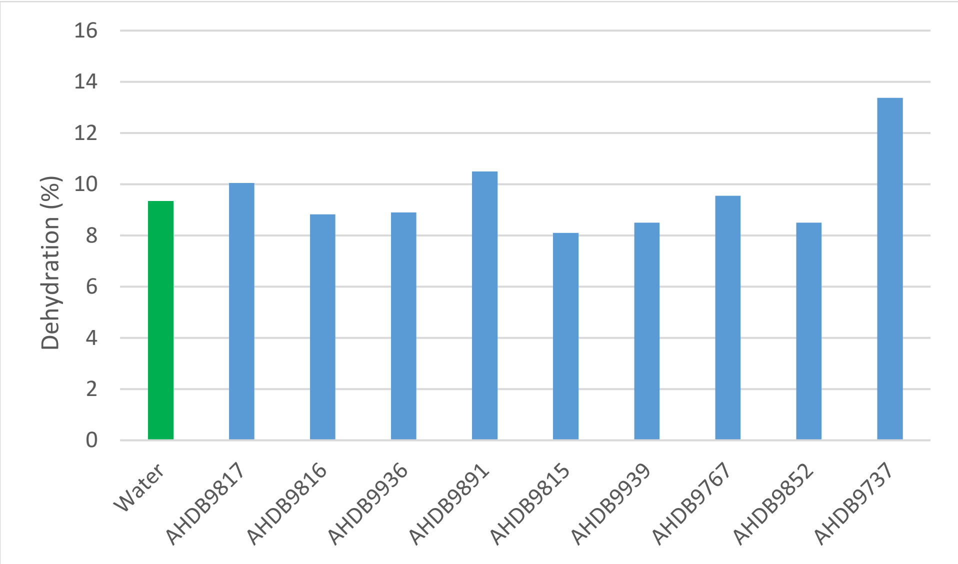

Figure 3. The average total percentage dehydration of a crate-section (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

There were no statistical differences in mean marketable net head weight after storage (**Fig. 4**). Although **AHDB9767** had a fresh weight of 72.4 Kg this was statistically similar to that of the lowest weight in the trial, 63.2 Kg, belonging to the **untreated control** (L.s.d. 6.56) and the treated head lowest mean weight belonging to **AHDB9737** at 63.99 Kg.

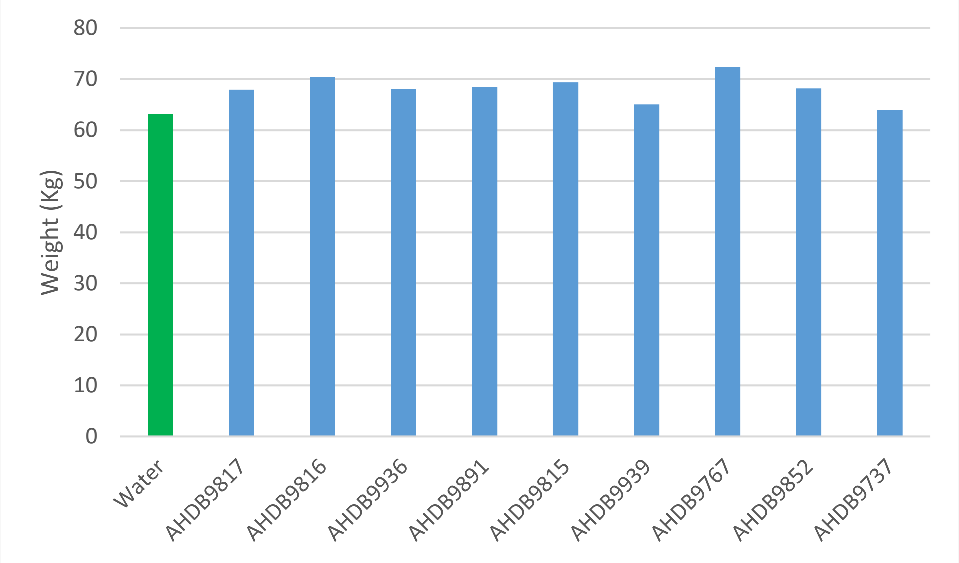

Figure 4. The average total head marketable net weight of a crate-section (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

There was no statistical difference between any treatments. The highest mean of 72.7% marketable weight compared with the starting weight for **AHDB9817** was only 4.2% above the **untreated control** and the lowest of **63.4%** for **AHDB9737** only 5.1% less (L.s.d. 5.80) (**Fig. 5**).

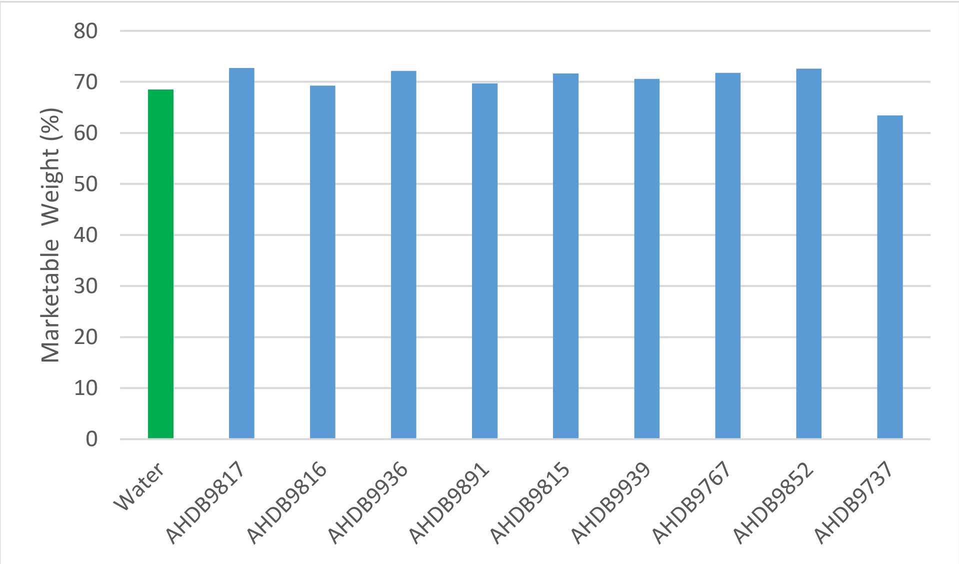

Figure 5. The mean % of starting weight that was marketable after post-storage trimming of a crate-section (plot) for all 10 treatments, with the untreated control shown in green.

The highest mean weight of heads infected with Phytophthora of 1.18 Kg was seen for **AHDB9939**, similar to the **untreated control** of 1.16 Kg (**Fig. 6**). Only nine heads were affected across the trial with none present in the **AHDB9737**, **AHDB9852**, **AHDB9767** and **AHDB9817** treated plots.

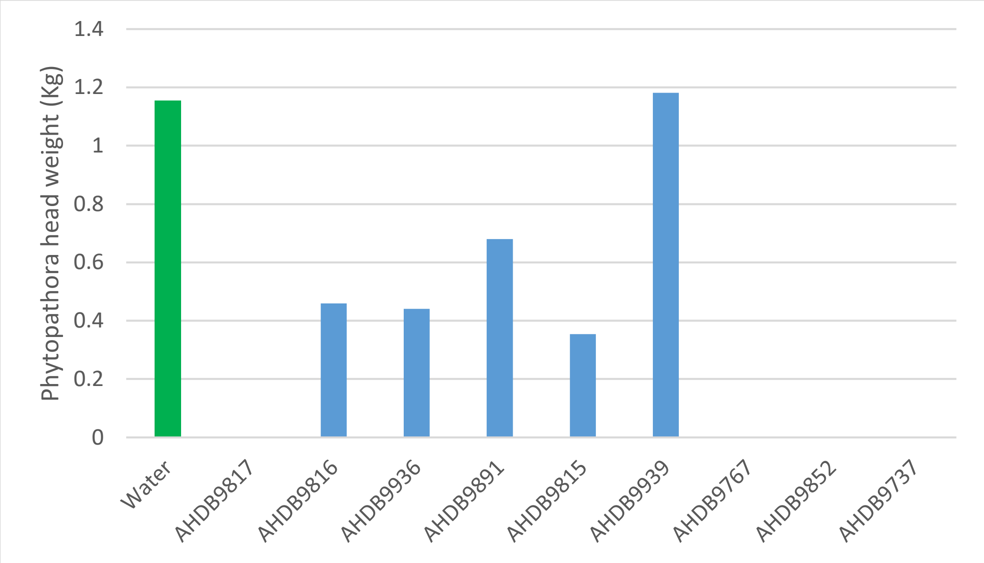

Figure 6. The average total weight of Phytophthora infected heads of a crate (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

Only one head had Sclerotinia, causing a mean weight loss for **AHDB9891** of 0.76 Kg (Fig. 7).

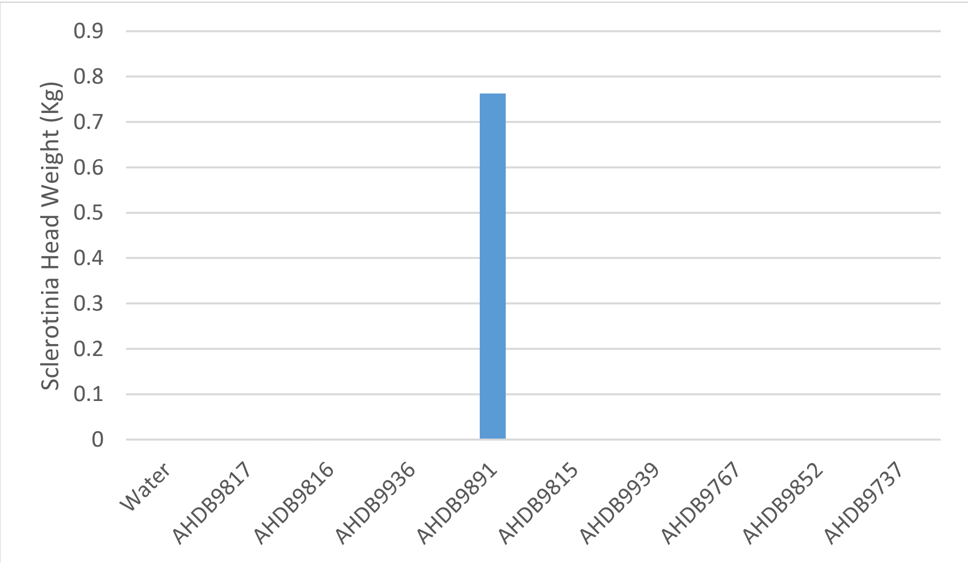

Figure 7. The average total weight of Sclerotinia infected heads of a crate (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

The highest, but not statistically significant, Phoma damage was seen for **AHDB9816** which had a low-medium mean damage index score of 1.7. This was only a mean 1.6 greater than the **untreated control** (L.s.d. 1.59) which had the lowest mean because only one crate-section had some damage. There was no obvious trend in how often a particular level of Phoma was seen within each of the four crate-section plots of each treatment (**Table 4**).

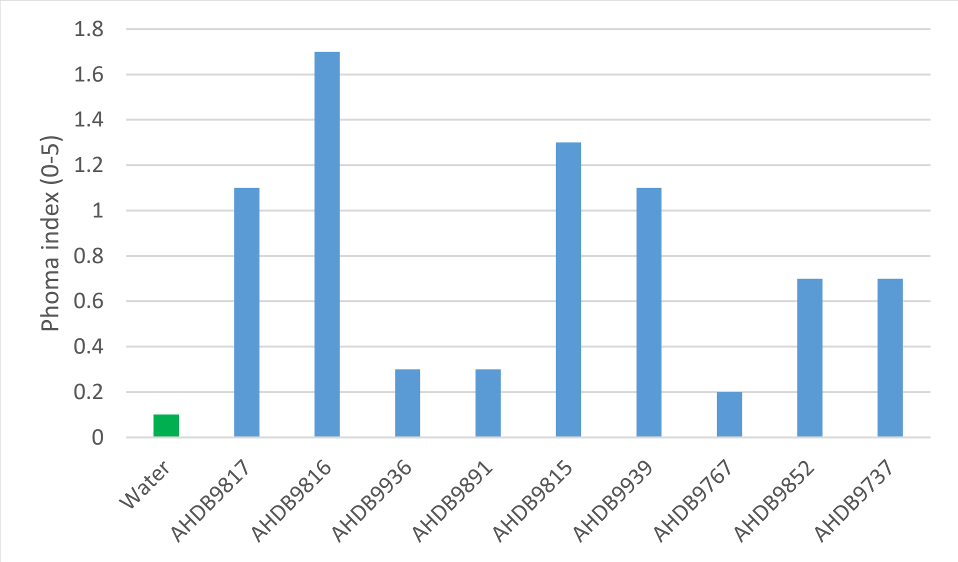

Figure 8. The average appearance of Phoma damage index of infected heads of a crate (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

Table 4. The number of times each Phoma canker index was recorded for each of the four crate-sections per treatment post-storage

		Phoma canker index 0 = nil to 5 = high				
No.	**Treatment**	**0**	**1**	**2**	**3**	**5**
1	Untreated	3	1	0	0	0
2	AHDB9817	1	1	1	1	0
3	AHDB9816	0	2	1	1	0
4	AHDB9936	2	2	0	0	0
5	AHDB9891	2	2	0	0	0
6	AHDB9815	1	0	2	1	0
7	AHDB9939	1	2	0	0	1
8	AHDB9767	3	0	0	1	0
9	AHDB9852	1	2	1	0	0
10	AHDB9737	2	1	0	0	1

The highest mean percentage processed marketable weight (i.e., heads post-trimming internally damaged by Phytophthora excluded) of 72.7% of the original weight was seen in **AHDB9817** but the 6.2% greater weight retention (L.s.d. 6.89) was not significantly better than the **untreated control.** The lowest % marketable weight compared with starting weight for a treatment was for **AHDB9737** with 63.4%, but this was only 3.12% less than the **untreated control**.

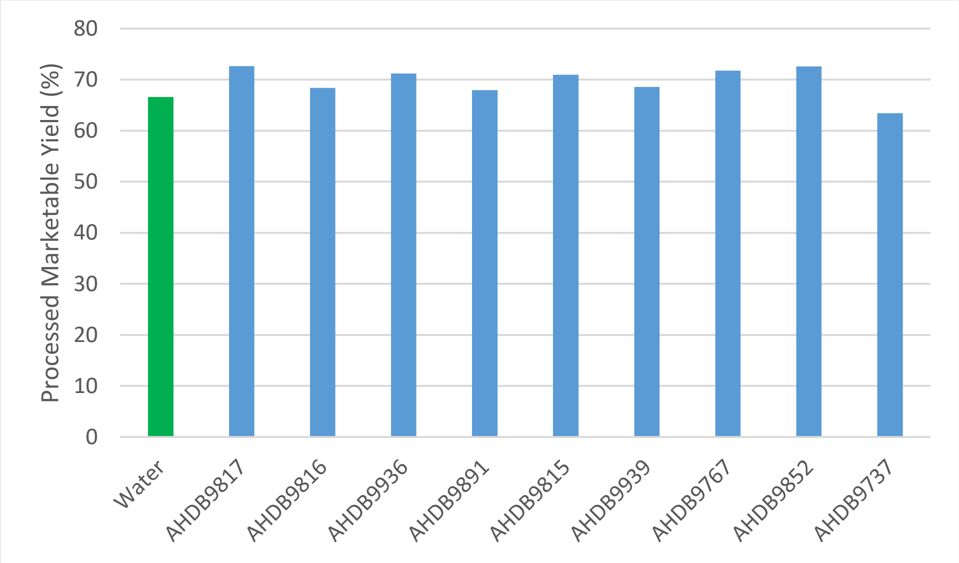

Figure 9. The average percentage of processed marketable yield of a total crate (plot) of stored cabbage for all 10 treatments at the end of storage, with the untreated control shown in green.

Throughout the storage period the crates were shown from the logger readings to have been held at around 1°C and 95% relative humidity (**Fig. 10**).

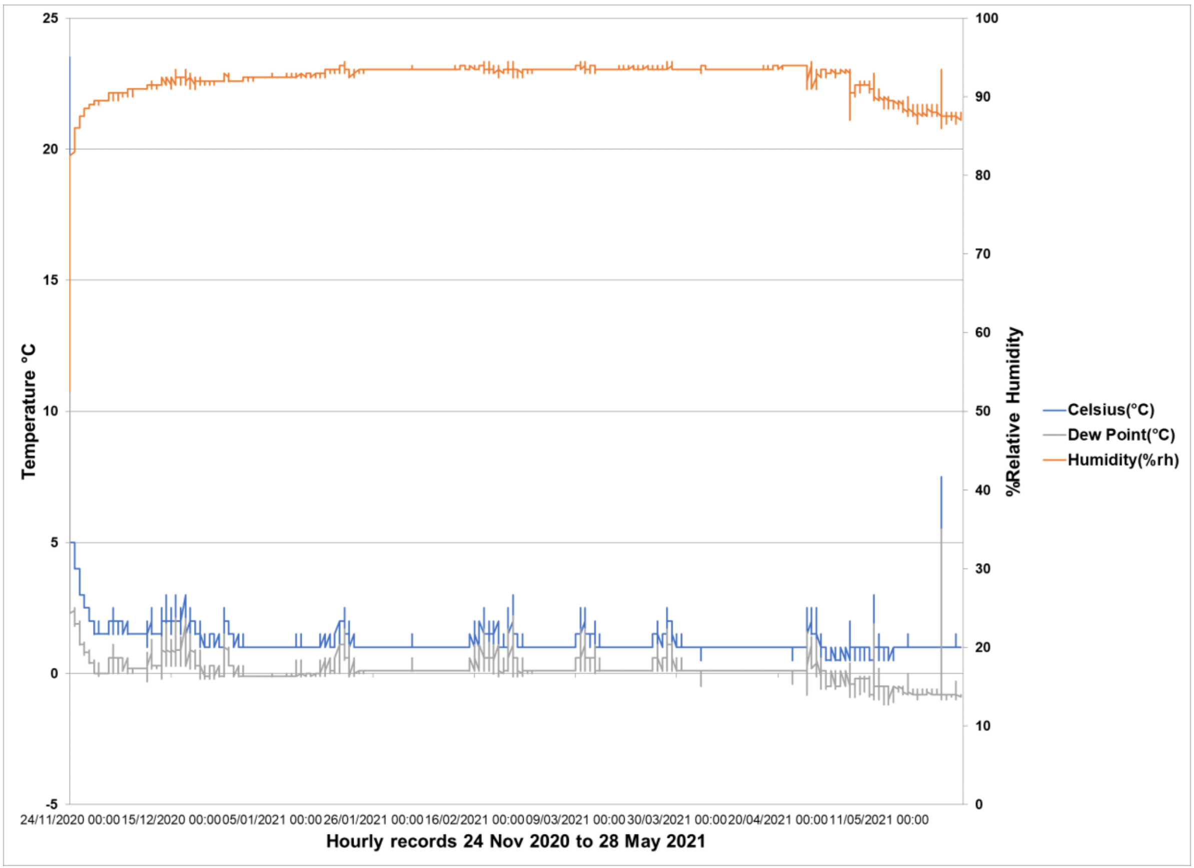

Figure 10. Store temperature between November 2020 and May 2021 for the cabbages of around 1°C with humidity around 95% RH. The second logger gave very similar readings.

Discussion

The most important variables of this study were processed marketable yield and disease presence as these determine the effectiveness and condition that the treatment left the cabbage heads in. No differences in disease presence and marketable yield were seen in this trial and so there was little observable effects of the treatments on disease and quality of the cabbage. Probably because of dry conditions at harvest, no Botrytis (a principal target for the products) developed during storage of untreated and treated heads and Phytophthora incidence was not high.

AHDB9817 and **AHDB9852** produced marketable yields of over the grand mean of 70% in all their replicates, with **AHDB9767 and AHDB9936** also having several plots over 70%. This might indicate some advantage to their use unrelated to dehydration and disease incidence.

All treatments showed incidences of Phoma canker, suggesting that it was a problem in the field they were grown, and that the pathogen was present on the plants when treated, this problem varied across treatments, but the severity across the treatments, including the untreated control was low, and so had little impact or relevance to the trial alone. Sclerotinia rot was only found in one treated plot, not in the untreated, and it was likely this was a result of sclerotia from a previous crop having dropped in that location only so it would be unwise to compare product efficacy against this pathogen.

AHDB9817 is a broad-spectrum fungicide that has been successfully used to prevent grey moulds, Sclerotinia and Phoma in stored products. It inhibits enzymatic activity of fungi and prevents spores from germination. It is persistent in the field and very persistent under controlled lab conditions. This persistence could explain the successful prevention of disease over the trial period, and the preventative nature of the active substance in germination inhibition can explain the absence of any disease on any of the treated plants.

Although this treatment was successful in producing a high processed marketable yield, the Phoma/canker leaf spot damage was a little (not significantly) higher than many of the other treatments which might either suggest a slightly weaker control of the disease or chance greater infection in the field of the heads used in its storage bins. The dehydration percentage for **AHDB9817** was also higher (not significantly) than most treatments, this could relate to the presence of Phoma damaging the leaves and respiring as it grows. **AHDB9817** itself has a low water solubility and has a pH of 5.5 and so was unlikely to have dehydrated the heads but could disrupt moisture exposure to the surface of the heads. The benefits from the use of this treatment at storage in marketable yield enhancement should be the main consideration.

AHDB9767 is a systemic broad-spectrum fungicide that is conventionally used as a seed treatment on vegetable crops for the control of oomycetes (such as Phytophthora and downy mildews) and is environmentally persistent. As Phytophthora is the main target of this treatment it could have contributed to the (not statistically) higher than average marketable yield, as no heads with this treatment were lost to this disease.

Of the other conventional chemical treatments, **AHDB9816** and **AHDB9939** performed marginally poorer (not statistically) than **AHDB9817** which had a processed marketable weight of 72.7%, with both at around 68.5% when the untreated control was 66.5%. Disease damage was relatively high (not statistically) in both treatments, with **AHDB9816** showing the highest mean Phoma index of 1.7 and **AHDB9939** showing the highest Phytophthora head weight of 1.88 Kg.

AHDB9852 is an organic fungicide that has contact action against chitin and can disrupt chitin production, reported to control grey moulds and a variety of other opportunistic fungi. **AHDB9852's** broad spectrum activity and effects on surface cell walls and membranes, could have disrupted any opportunistic pathogens on the surface of the cabbage reducing disease incidence during storage. **AHDB9852** treated heads had no Phytophthora or Sclerotinia and only a relatively moderate amount of Phoma. This low disease incidence could be attributed to the chitin and membrane disrupting abilities of **AHDB9852**, but differences from other treatments (and the untreated) were not statistically significant. **AHDB9852** has a variable half-life depending on the conditions in which it is applied but has the potential to cover long storage periods and reduce yield losses. **AHDB9852** had one of the lowest (not statistically) dehydration losses at 8.5%. The viscous nature of **AHDB9852** may create a film that could contain the moisture in the heads.

AHDB9737 was a natural plant-based flavonoid, which was supplied by an independent producer that has now ceased trading.

For the three biological products, **AHDB9936** and **AHDB9891** had slightly (not significantly) less Phoma than **AHDB9815** but were closely matched in other measures. The relative humidity of 95 % in the crates would have been favourable to the colonisation of the cabbage surfaces by each of these microbes. However, the cold temperature in the cold store is unlikely to have been optimum for their growth, although neither would it favour growth of the pathogens.

The products **AHDB9936** and **AHDB9891** are not curative but could act against any *Botrytis*, *Phoma* or *Phytophthora* spp. spores on the head surface that had not germinated and started infection. The bacteria disrupt growth, spore germination and pathogen attachment. Metabolites produced by the bacteria can also contribute to the control achieved by the by the living bacteria which compete for space and resources. Stimulation of plant defence mechanisms has also been reported (O'Neill & Gwynn, 2014), but this might not function in harvested heads. The Sclerotinia recorded only in a head treated with **AHDB9891** was likely to have been from a random occurrence of inoculum in the cabbage field.

AHDB9815 n which operates via plant auxin like production stimulating plant defences, competition for space and nutrients and mycoparasitism. It is possible that due to the heads of the cabbage being in a cold store and removed from the rest of the plant, the auxin like hormones produced by the product may have been unable to have much effect.

Conclusions

No significant differences post-storage in marketable yield, including the dehydrating effect of storage, were shown between nine different in-crate at-storage treatments and untreated cabbage heads. However, no Botrytis developed on the stored heads, and there was only a low incidence of Phytophthora and Phoma even in the storage crates of untreated heads, so it was impossible to give a strong indication of the ability of the products to manage storage rots. It was shown that no phytotoxicity resulted from any of the products.

Knowledge and Technology Transfer

Knowledge transfer from this project was impeded by the spread of covid-19 in the UK and the associated lock-down and group-gathering restrictions during 2020 and 2021.

References

Red Tractor Assurance for Farms (2015). Crop-specific Module: Cabbage. Effective 1st September 2015.

T. O'Neill & R. Gwynn (2014). Getting the best from biopesticides. HDC Factsheet 18/12.

EPPO Guidelines

PP1/152 (4) Design and analysis of efficacy evaluation trials
PP1/181(4) Conduct and reporting of efficacy evaluation trials including GEP
PP1/292 (1) Cleaning pesticide application equipment (PAE) - efficacy aspects
PP1/291(1) Evaluation of the influence of tank mix adjuvants on the efficacy of plant protection products.
PP1/223 (2) Introduction to the efficacy evaluation of plant protection products.
PP1/135 (4) Phytotoxicity assessment
PP1/276 (1) Principals of efficacy evaluation for microbial plant protection products.
PP1/224 (2) Principles of efficacy evaluation for minor uses.
PP1/054(3) *Botrytis* spp. on vegetables.

Appendices

Certificate of

Official Recognition of Efficacy Testing Facilities or Organisations in the United Kingdom

This certifies that

RSK ADAS Ltd

complies with the minimum standards laid down in Regulation (EC) 1107/2009 for efficacy testing.

The above Facility/Organisation has been officially recognised as being competent to carry out efficacy trials/tests in the United Kingdom in the following categories:

Agriculture/Horticulture
Stored Crops
Biologicals and Semiochemicals

Date of issue: 1 June 2018
Effective date: 18 March 2018
Expiry date: 17 March 2023

Signature Alison Richardson
Authorised signatory

Certification Number
ORETO 409

HSE Chemicals Regulation Division

Department of Agriculture and Rural Development

Appendix Table Data from 2020/21 efficacy trial of stored cabbage. Zero Botrytis seen.

Treatment numbers: T1 Untreated, T2 AHDB9817, T3 AHDB9816, T4 AHDB9936, T5 AHDB9891, T6 AHDB9815, T7 AHDB9939, T8 AHDB9767, T9 AHDB9852, T10 AHDB9737.

Plot number	Treatment number	Total initial stored weight (kg)	Mean head weight (kg)	Revised weight excluding samples for MRL (kg)	Total weight ex store (kg)	% Dehydration	Total trimmed weight - marketable (kg)	% Marketable weight	Trimmed Marketable weight ex. Phytophthora	% Marketable weight (excluding Phytophthora)	Phytophthora (kg)	Sclerotinia (kg)	Canker Index (0-5)
1	7	98.80	4.0	95.20	86.87	8.8	67.68	71.09	63.84	67.06	3.84	0.00	0
2	2	100.74	4.0	97.14	87.89	9.5	70.46	72.53	70.46	72.53	0.00	0.00	0
3	5	102.04	4.1	98.44	84.98	13.7	61.72	62.69	54.76	55.63	6.96	3.05	0
4	8	104.47	4.2	100.87	89.61	11.2	71.69	71.07	71.69	71.07	0.00	0.00	0
5	4	99.48	4.0	95.88	88.02	8.2	72.31	75.42	72.31	75.42	0.00	0.00	0
6	9	96.77	3.9	93.17	86.17	7.5	69.95	75.08	69.95	75.08	0.00	0.00	0
7	1	94.85	3.8	91.25	82.85	9.2	61.95	67.88	58.37	63.97	3.58	0.00	0
8	6	87.60	3.5	84.00	80.29	4.4	58.94	70.16	56.58	67.36	2.36	0.00	2
9	10	118.53	4.7	114.93	88.03	23.4	63.52	55.27	63.52	55.27	0.00	0.00	5
10	3	99.55	4.0	95.95	88.57	7.7	69.86	72.81	69.86	72.81	0.00	0.00	3
11	8	103.6	4.1	100	90.83	9.2	67.68	67.68	67.68	67.68	0.00	0.00	0
12	1	94.30	3.8	90.7	82.175	9.4	60.7	66.92	60.70	66.92	0.00	0.00	0
13	2	93.67	3.7	90.07	81.245	9.8	66.97	74.35	66.97	74.35	0.00	0.00	1
14	7	96.24	3.8	92.64	84.295	9.0	64.4	69.52	64.4	69.52	0.00	0.00	5
15	9	97.95	3.9	94.35	86.155	8.7	68.62	72.72	68.62	72.73	0.00	0.00	1
16	6	96.43	3.9	92.83	84.545	8.9	67.08	72.26	67.08	72.26	0.00	0.00	2
17	5	112.63	4.5	109.03	97.70	10.4	69.01	63.29	69.01	63.29	0.00	0.00	0
18	3	108.95	4.4	105.35	94.25	10.5	64.67	61.38	64.67	61.39	0.00	0.00	1
19	4	104.73	4.2	101.13	91.80	9.2	70.42	69.63	70.42	69.63	0.00	0.00	0
20	10	105.00	4.2	101.4	89.72	11.5	63.72	62.84	63.72	62.84	0.00	0.00	0
21	6	108.79	4.4	105.19	94.71	10.0	75.46	71.73	75.46	71.74	0.00	0.00	3
22	4	93.12	3.7	89.52	81.165	9.3	68.61	76.64	68.61	76.64	0.00	0.00	1
23	5	95.19	3.8	91.59	82.98	9.4	68.70	75.01	68.7	75.01	0.00	0.00	1
24	2	100.57	4.0	96.97	86.395	10.9	70.21	72.4	70.21	72.40	0.00	0.00	2
25	3	107.8	4.3	104.2	95.205	8.6	75.23	72.19	75.23	72.20	0.00	0.00	2
26	8	103.86	4.2	100.26	91.25	9.0	74.29	74.1	74.29	74.10	0.00	0.00	3
27	10	94.21	3.8	90.61	82.10	9.4	59.96	66.17	59.96	66.17	0.00	0.00	0
28	9	102.1	4.1	98.5	89.59	9.0	70.97	72.05	70.97	72.05	0.00	0.00	2
29	7	93.57	3.7	89.97	82.815	8.0	64.73	71.94	61.05	67.86	3.68	0.00	1
30	1	96.59	3.9	92.99	83.605	10.1	61.18	65.79	61.18	65.79	0.00	0.00	1
31	9	93.40	3.7	89.8	81.895	8.8	63.28	70.47	63.28	70.47	0.00	0.00	1
32	10	102.61	4.1	99.01	89.895	9.2	68.74	69.43	68.74	69.43	0.00	0.00	1
33	4	94.75	3.8	91.15	83.04	8.9	61.01	66.93	57.7	63.30	3.31	0.00	1
34	1	97.60	3.9	94.00	85.785	8.7	69.06	73.47	65.35	69.52	3.71	0.00	0
35	7	94.51	3.8	90.91	83.41	8.2	63.46	69.81	63.46	69.81	0.00	0.00	1
36	2	93.15	3.7	89.55	80.625	10	64.02	71.49	64.02	71.49	0.00	0.00	3

37	8	105.98	4.2	102.38	93.41	8.8	75.97	74.2	75.97	74.20	0.00	0.00	0
38	6	108.44	4.3	104.84	95.315	9.1	76.04	72.53	76.04	72.53	0.00	0.00	0
39	3	105.25	4.2	101.65	92.97	8.5	71.91	70.74	68.38	67.27	3.53	0.00	1
40	5	99.11	4.0	95.51	87.375	8.5	74.40	77.9	74.4	77.90	0.00	0.00	1
Plot number	**Treatment number**	**Total initial stored weight (kg)**	**Mean head weight (kg)**	**Revised weight excluding samples for MRL (kg)**	**Total weight ex store (kg)**	**% Dehydration**	**Total trimmed weight - marketable (kg)**	**% Marketable weight**	**Trimmed Marketable weight ex. Phytophthora**	**% Marketable weight (excluding Phytophthora)**	**Phytophthora (kg)**	**Sclerotinia (kg)**	**Canker (0-5)**

All storage calculations were based on the revised plot weight results after removal of heads for maximum residue tests.

