FINAL REPORT

Blackheart - an emerging problem for the potato packing industry

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1. SUMMARY

Blackheart is a physiological disorder of potatoes where internal tissues become necrotic. Symptoms are not generally found in the field, or in store, and usually develop in-pack. The causes of blackheart are not understood and, because tubers appear otherwise sound, the defect is difficult to control and presents a challenge to the successful marketing of GB potatoes. Experimental work was carried out collaboratively with Cranfield University (CU) and the Fresh Potato Suppliers' Association (FPSA). This report summarises the work carried out at Sutton Bridge Crop Storage Research (SBCSR). The work carried out at CU is summarised in a separate report.

At SBCSR, studies were conducted on a range of commercial stocks, primarily cvs Maris Piper and Marfona. These were stored at 1.5°C and 3.5°C. Assessments were made prior to storage to try to evaluate blackheart risk.

Further assessments were made at intervals throughout the three seasons of the trial from storage and after packaging. Blackheart was not usually found within crops when they were in storage; it occurred most during shelf-life, following washing and packing.

Some proprietary methods of blackheart susceptibility testing were assessed but these did not produce any symptoms of blackheart early in storage. A new test was devised which gave good differentiation of blackheart susceptibility but generated some false positives and negatives.

This test enabled high- and low-susceptibility stocks to be identified for additional work on the detailed physiological/biochemical profile of these crops at CU.

This study identified the following factors as contributing to the risk of blackheart:

- Storage of susceptible varieties (although further data are needed on commonly used varieties within the fresh market sector)
- Long-term storage, especially at very low temperature (<3.5°C)
- Tuber size, with an increased prevalence for blackheart in tubers >60mm

No effect of respiration rate could be linked to the development of blackheart symptoms.

The adoption within industry of a more aggressive risk assessment methodology, such as the test used in this study, is recommended to enable high risk stocks to be more readily identified and blackheart risk to be managed more actively.

A review of literature relating to blackheart was undertaken by Professor Leon Terry at Cranfield University and this is provided as a separate document.

2. INTRODUCTION

Blackheart is a physiological disorder of potatoes that results in necrosis, and sometimes cavitation, of central tissues of tubers (see Fig. 1). Symptoms are usually dark brown to blue-black, with an irregular shape, but defined border. Affected tissue remains firm and without odour. The onset of the disorder is poorly understood but it is usually associated with oxygen depletion.

Symptoms of blackheart are typically absent in new crop and may become apparent during storage. Symptoms may also be absent in crops throughout storage yet become apparent only after washing and packing, during the subsequent shelf-life period or even when the produce has reached the consumer. This can cause retail and supply businesses significant reputational and financial difficulties if this results in consumer dissatisfaction or complaints and, of course, can also impact upon the likelihood of repeat business.

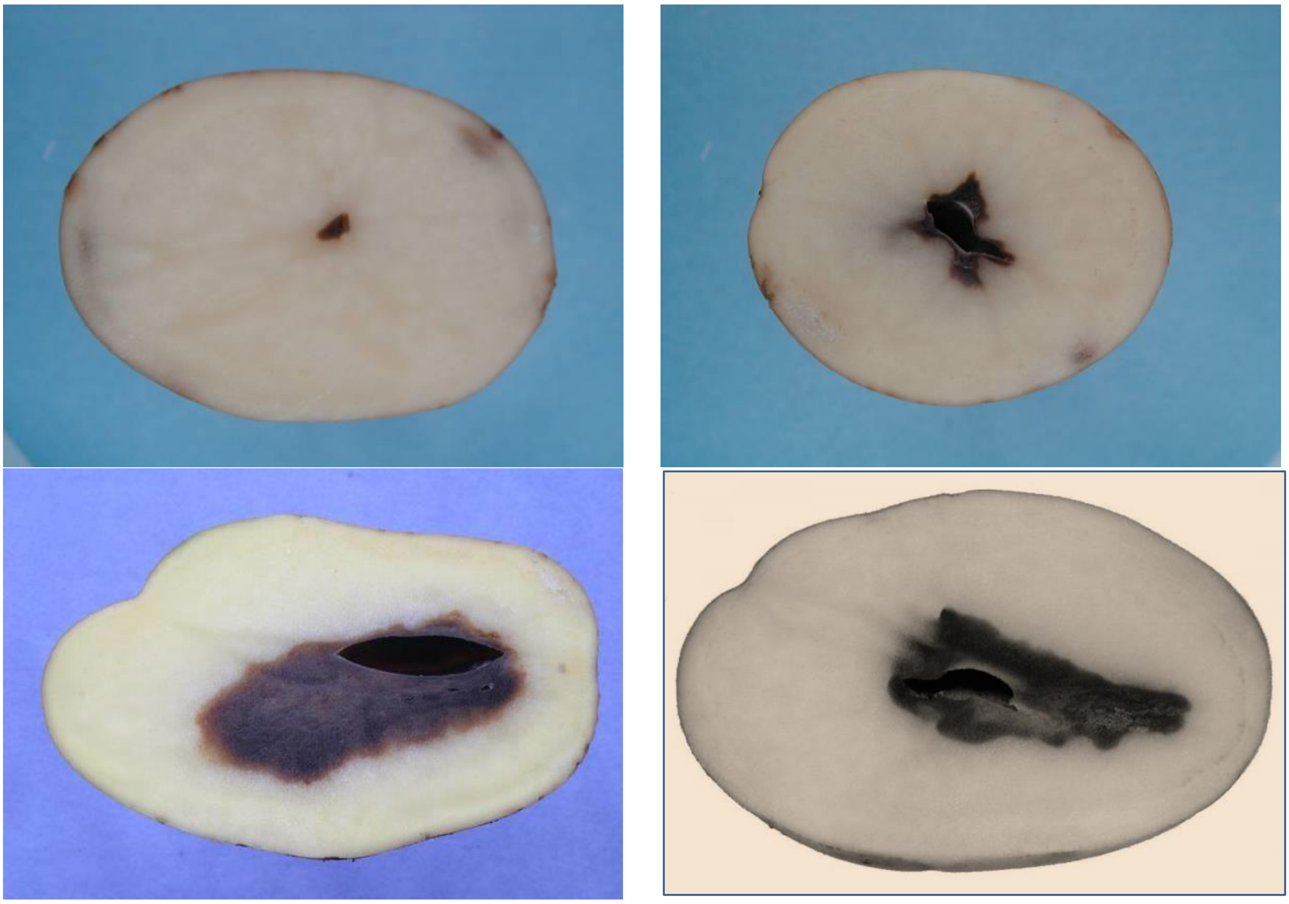


Fig. 1. Symptoms of blackheart in a range of tubers, showing discolouration and cavitation.

Blackheart is a particular problem for the fresh, packaged potato industry in Great Britain because of its reliance for supplies throughout much of the year on crop which has been stored. During the initiation of this project, discussions were held with members of the Fresh Potato Suppliers' Association (FPSA) to establish a baseline of understanding of the problem. Although there was only a limited amount of robust data available, FPSA members anecdotally associated blackheart with certain soil type (silts), waterlogging, cultivar (e.g. Maris Piper and Marfona were considered particularly susceptible), large tuber size and, in relation to shelf-life deterioration, the use of plastic packaging films. Although seasonal variations have been observed, the incidence of blackheart is reported to have increased in the last five years (David Walker, Chairman FPSA, personal communication). Blackheart is also extremely difficult to detect as typically only central tissues become necrotic. In all other respects tubers can appear healthy so crops may pass quality control checks and be marketed normally with the defects only becoming apparent to the consumer after preparation. Customer complaints from blackheart are reported to have increased in recent years (FPSA) and imported crops of critical cultivars (eg Maris Piper) could be sourced by some multiple retailers if blackheart cannot be effectively controlled in British crops.

This study aimed to address some of the key areas identified above although it was accepted that the range of factors which might impact upon blackheart risk was likely to be greater than could be addressed in a single project and one associated PhD. Experimental work on this study at SBCSR was carried out collaboratively with Cranfield University and the Fresh Potato Suppliers' Association. The trials were designed around the storage, and blackheart risk assessment, of a range of potato stocks, with three specific stocks being selected for additional storage and detailed physiological/biochemical analysis at Cranfield University. The collaborative work at Cranfield was carried out by Ms. Elsa Kiaitsi, under a PhD studentship funded by AHDB Potato Council and supervised by Professor Terry.

3. MATERIALS AND METHODS

In each year of this work, potatoes were supplied by member companies of the FPSA.

After delivery, stocks were transferred into half-tonne capacity boxes that were otherwise of a conventional design with solid sides and slatted bases. Storage took place in 12 or 16-tonne capacity stores at SBCSR. Stores used non-positive, overhead-throw ventilation similar to that used in stores throughout the fresh sector. Where necessary, sprouting was controlled by the application of spearmint oil [*Biox M*, Juno (Plant Protection) Ltd., Maidstone, ME15 6SL.

Throughout this trial, respiration rate was determined using a method based on carbon dioxide accumulation in hermetically sealed chambers, using a Vaisala carbon dioxide probe (Vaisala Oyj, Model GM-70, Helsinki, Finland). Between 2 and 3kg of tubers were placed in 9 litre capacity, hermetically sealable chambers. Carbon dioxide accumulation was measured by subtracting ambient carbon dioxide concentration (before sealing the chamber) from that after a timed interval (30-120 minutes) after sealing. The respiration rate of the sample is expressed as milligrams of carbon dioxide, per kilogram of potatoes, per hour (mg CO_2 kg^{-1} hr^{-1})

3.1. Method development and selection of stocks

A key element of this trial was the requirement to make some estimation of the relative risk of blackheart development across the range of potato stocks available. However, there is currently no widely-accepted, standard method for testing for, or inducing, blackheart so that susceptibility of stocks to the disorder can be estimated.

Proprietary methods have been developed by individual FPSA member companies, and two of these were used to test incoming stocks of cv Maris Piper in this trial. However, neither of the proprietary methods resulted in symptoms of blackheart in stocks during early storage.

In order for susceptibility to blackheart, and changes in susceptibility to blackheart to be estimated, a more challenging method was required that resulted in symptoms early in storage. This was also important for the design of the experiments, so that suitable stocks could be selected for the detailed biochemical/physiological analyses during storage at Cranfield University.

The proprietary methods for inducing blackheart both involved storage at an elevated temperature (25°C or 32°C) for up to 4 days. One method had an option to increase the severity of conditions by wetting tubers at the beginning of the test. Combinations of wetting (washing), incubation temperatures of 30 and 35°C and enclosure within chambers were assessed.

A broad range of responses were observed in stocks of cv. Maris Piper from sealing c. 20kg unwashed tubers in 30 litre capacity chambers (see Fig 2) and incubating these for 60 hours at 30°C in a three-tonne capacity Controlled Environment store.

This method was therefore adopted for inducing blackheart across all three seasons' work. It was used for selection of stocks for the detailed analyses at Cranfield University and also for the assessment of stocks for blackheart risk both before and during storage at SBCSR.

Fig. 2 Induction of blackheart was undertaken by sealing in a chamber and incubating at 30°C for 60 hours.

Blackheart symptoms were assessed after cutting tubers in half, longitudinally. Assessment of symptoms took place approximately 24 hours after cutting to maximise differentiation of symptoms.

3.2. Year 1: 2011-12 season

Selection of stocks

FPSA member companies supplied ten stocks of cv Marfona and fifteen stocks of cv Maris Piper between 1 September and 14 October 2011 from which samples for storage were taken. The remainder was held at 3.5°C and used for method development and initial selection of Maris Piper stocks for CU. One Maris Piper stock was discarded due to a high incidence of internal defects.

At store loading, all Maris Piper stocks were subjected to the blackheart induction method. This was used for selection of stocks for detailed analysis at Cranfield University. Two stocks showing susceptibility to blackheart and one stock not showing susceptibility to blackheart were supplied.

Storage trial

Crops were transferred into SBCSR half-tonne boxes and held at 3.5°C and 1.5°C (95% RH) in controlled environment stores. Assessments of the stored crops were carried out in February, April (cv. Marfona only) and July. Unfortunately, planned assessments of Maris Piper in April and both cultivars in May/June had to be suspended due to equipment failure.

At each sampling occasion, samples were assessed for respiration rate and 100 tubers were cut longitudinally in half and assessed for blackheart symptoms.

Additionally, all stocks of cv. Maris Piper were packaged (2.5 kg capacity, punched polythene) on one occasion (31st July, 2012). and assessed after a period of shelf-life (2 weeks at 20°C).

3.3. Year 2: 2012-13 season

Selection of stocks

In year 2, FPSA member companies supplied three stocks of cv Marfona, ten stocks of cv Maris Piper and one stock of cv Blue Belle between 1 October and 30 November 2012 for storage.

At store loading, all stocks were assessed for respiration rate and subjected to the blackheart induction method. This method was also used for selection of stocks for detailed analysis at Cranfield University, as in year 1. Two stocks were again chosen that were showing susceptibility to blackheart and one stock was selected for not showing any susceptibility.

Storage trial

At store loading, crops were decanted into SBCSR half-tonne boxes and sub-samples of each stock held in controlled environment stores at 3.5°C and 1.5°C (95% RH).

Stocks held at 3.5°C and 1.5°C were assessed during storage for respiration rate and for blackheart symptoms following packing (2 weeks at 20°C in 2.5kg capacity, punched polythene bags). Assessments were carried out on four occasions in January, March, May and July.

In addition, the three stocks selected for Cranfield University were also subjected to the blackheart induction procedure at each occasion during storage.

3.4. Year 3: 2013-14 season

Selection of stocks

For the final year of this study, the FPSA member companies supplied ten stocks of cv Maris Piper potatoes for the trial. It was decided to concentrate analysis on this variety in the last season's work. At store loading stocks were assessed for blackheart susceptibility using the induction method, respiration rate and blackheart following packing (2 weeks at 20°C in 2.5kg capacity punched polythene). Crops were not despatched to Cranfield University for storage in the final year, but 10-tuber sub-samples of all stocks were delivered on three occasions (representing store loading, mid-term and long term storage) for immediate sample preparation (freeze drying) with material to be retained for potential subsequent targeted analysis.

Storage trial

In the final season, stocks were held in store at 3.5°C and 95% RH only. Samples from these stocks in store were assessed on four occasions, with assessments taking place in January, March, May and June/July. At each occasion, respiration rate and blackheart incidence after packaging (2 weeks at 20°C in 2.5kg capacity punched-polythene packs) were measured. Selected stocks were also assessed for blackheart symptroms, following induction, at each sampling occasion.

3.5. Risk assessments

Some additional detailed assessments were carried out in years 2 and 3 to further assess blackheart risk in relation to both packaging and warming. Both of these phases within the supply chain have the potential to increase stress on the crop and therefore impact on respiration and gaseous exchange.

Packaging

Two packaging trials were carried out, both using cv Maris Piper. In the first, all stocks from both storage temperature treatments were packed into 2.5 kg capacity punched polythene packs on 31 July 2012. Packs were held at 20°C for a period of 13 days. Incidence of blackheart was compared to sub-samples held unpackaged in 'open' 20kg capacity trays under similar temperature conditions.

In the second packaging trial, selected Maris Piper stocks (12, 20 and 23) were packed into 2.5kg capacity punched polythene bags and laser perforated film packs on 13 August 2012 and held at 20°C for 8 days. Sub-samples from both storage temperature treatments were used.

In both trials, crops were washed at SBCSR and then re-wetted immediately prior to packing by the FPSA collaborators.

Warming

The warming of potatoes from cold stores, for bruise avoidance, was identified as a risk for blackheart because of the potential for condensation to form on tubers as temperature is increased, and thereby influence gaseous exchange across the periderm.

Two methods of warming were assessed in year 3 (2013-14 season):

Passive
Boxes were simply placed at a warm ambient temperature (14°C).

Positive
This used a system based on positive delivery of air to pallet slots using a plenum ‘drying wall’ (Fig 3).

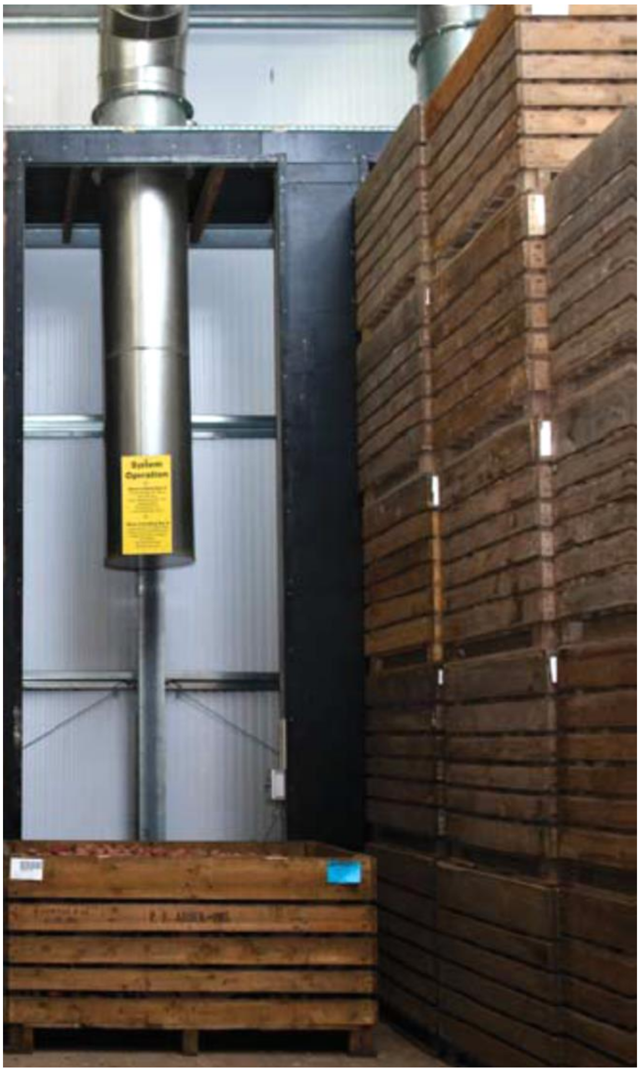


Fig. 3. Open letterbox system used for warming potatoes for the reduction of bruising during washing and grading operations.

Three stocks (numbers 4, 8 and 10) were selected and netted sub-samples were located within boxes undergoing the treatments, using commercial warming facilities at FPSA collaborators.

Stocks were selected on the basis of induced and actual incidences of blackheart in-pack. Stock 4 was deemed ‘not susceptible’. Stocks 8 and 10 were identified as ‘susceptible’, after showing blackheart symptoms both in-pack and following induction. After completion of the warming cycle (3 days), crops were returned to SBCSR and packaged (into 2.5kg capacity punched polythene bags) and assessed for blackheart development after a two week shelf-life period during which they were held at 20°C.

3.6. FPSA survey of blackheart incidence

To supplement the information gathered from this study and to ensure the findings can be put into a commercial context, an online survey of FPSA member companies was designed to collect data on the occurrence of blackheart in these commercial businesses. The survey (appended at Annex 1) was designed to capture historical information where blackheart was reported across the period 2009-2012 with emphasis on the following factors:

- timing/frequency of consumer complaints
- cultivar and tuber characteristics of affected stocks
- agronomy
- storage
- processing
- packaging

4. RESULTS

4.1. Method development and selection of stocks

A method was successfully developed for inducing blackheart symptoms (Appendix 1). Potato samples were held in sealed 30 litre chambers and incubated for 60 hours at 30°C. This method was used in all three seasons of work and was used for selection of stocks for the detailed analyses at Cranfield University.

4.2. Year 1 results: 2011-12 season

Selection of stocks

Results of susceptibility testing, carried out at store loading, using the blackheart induction method are shown in Table 1. Just one stock (12) showed no blackheart symptoms after the induction process and two stocks (20 and 23) showed a very high incidence (>70%). These stocks were selected for storage and analysis at Cranfield University.

Table 1. Frequency of blackheart symptoms in cv Maris Piper (% tubers >60mm) following use of SBCSR induction method

stock	incidence (%)	blackheart nomination*
11	56	
12	0	not susceptible
13	5	
14	32	
15	3	
16	36	
17	55	
18	36	
19	32	
20	74	susceptible
21	41	
22	52	
23	80	susceptible
24	32	
93% of stocks with blackheart overall		

**Highlighted stocks (12 - not susceptible and 20 & 23 - susceptible) selected for Cranfield University trials.*

Storage trial

Blackheart symptoms were not found in tubers assessed directly from store in year 1. The respiration rate of samples (Annex 2) of stocks of both cultivars was similar from storage at 1.5°C, compared with 3.5°C, except at store unloading (July) when the lower storage temperature resulted in a significantly higher respiration rate (both cultivars p=<<0.05).

The incidence of blackheart in-pack (2.5kg polythene, 20°C, 13 days) is shown in Table 2, for samples after storage. The incidence of blackheart in-pack was generally lower than that from the induction process carried out at store loading. In general, the mean incidence of blackheart was greater from storage at 1.5°C, and the proportion of stocks affected by the defect was greater from storage at 1.5°C, but with one stock (19) a higher incidence was detected from storage at 3.5°C.

Table 2. Blackheart incidence (% tubers>60mm) cv Maris Piper in-pack 2011-12.

stock	1.5°C	3.5°C
11	4	0
12	0	0
13	8	12
14	1	0
15	8	0
16	0	0
17	9	1
18	0	0
19	3	11
20	0	0
21	1	1
22	0	0
23	7	7
24	28	4
mean	**4.9**	**2.6**
stocks with blackheart	9.0	6.0

When packaged, Stock 12 which had been identified as ‘not susceptible’ at store loading, did not develop symptoms of blackheart.

Nine of the thirteen stocks showing symptoms following the induction process did subsequently develop blackheart after packaging. However, four stocks which had showed symptoms following the induction process, failed to develop any symptoms in-pack.

4.3. Year 2 results: 2012-13 season

Selection of stocks

Results of the blackheart induction process are shown in Tables 3 and 4. Of the ten Maris Piper stocks supplied, three stocks did not show symptoms following the induction process, five showed moderate incidences (2.6%-8.1%) and two showed high or very high incidences (18.8% and 74.5%).

Table 3. Frequency of blackheart symptoms (% tubers>60mm) in stocks of cv Maris Piper following SBCSR induction method at store loading 2012-13.

stock	% blackheart	blackheart nomination*
1	0.0	
3	0.0	not susceptible
4	2.6	
6	7.5	
7	18.8	susceptible
8	4.3	
9	8.1	
10	0.0	
12	74.5	susceptible
13	4.4	
70% of stocks with blackheart overall		

**Highlighted stocks (3 - not susceptible and 7 & 12 - susceptible) selected for Cranfield University.*

The induction process produced moderate blackheart symptoms (4.9-8.6%) in two stocks of cv Marfona but the defect was not detected in the third stock. Blackheart symptoms were not detected in cv Blue Belle at store loading.

Table 4. Frequency of blackheart symptoms in stocks of cvs Marfona (% tubers >60mm) and Blue Belle (% all tubers) after use of SBCSR induction method at store loading, 2012-13.

stock	cultivar	% blackheart
2	Marfona	8.6
11	Marfona	4.9
14	Marfona	0.0
5	Blue Belle	0.0

Storage trial

<u>Blackheart in packaging</u>

The results of blackheart assessments after packaging, during the 2012-13 storage season, are shown in Table 5.

Blackheart was not detected on any occasion in-pack in two stocks (stocks 8 & 9). However, with the remaining stocks, prior storage temperature had an important effect on blackheart incidence during shelf-life. From a storage temperature of 3.5°C, seven of the 10 Maris Piper stocks remained defect-free while, from a storage temperature of 1.5°C, only two stocks remained free from blackheart symptoms on all sampling occasions.

In stocks stored at 1.5°C, where the defect developed, there was a tendency for symptoms to occur only at the latest sampling occasion, although stock number 12, identified as susceptible during the induction process, was an exception.

Table 5. Blackheart incidence (% tubers>60mm) cv Maris Piper in-pack 2012-13.

Stock	Jan		Mar		Apr		Jun		**mean**	
	1.5° C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C	**1.5° C**	**3.5° C**
1	0	0	0	0	0	50**	8	0	**2.1**	**0.0**
3	0	0	0	0	0	0	5	0	**1.4**	**0.0**
4	0	0	0	0	2	0	3	0	**1.2**	**0.0**
6	2	0	0	0	0	3	6	0	**2.0**	**0.7**
7	0	0	0	0	0	0	2	6	**0.4**	**1.6**
8	0	0	0	0	0	0	0	0	**0.0**	**0.0**
9	0	0	0	0	0	0	0	0	**0.0**	**0.0**
10	0	0	0	0	0	0	4	0	**1.0**	**0.0**
12	0	0	9	0	8	0	0	0	**4.2**	**0.0**
13	0	0	0	0	0	0	7	3	**1.7**	**0.7**
mean	**0.2**	**0.0**	**1.0**	**0.0**	**0.9**	**0.3**	**3.3**	**0.8**	**1.4**	**0.3**
stocks with blackheart	1	0	1	0	2	2	7	2	7	3

*** This value excluded from calculation of means due to very low tuber numbers.*

<u>Blackheart induction as a predictor of blackheart in-pack</u>

Induction of blackheart at store loading suggested seven stocks were potentially at risk of developing blackheart in-pack. Of these, during storage at 3.5°C, only three stocks actually developed blackheart symptoms in-pack but, at 1.5°C, symptoms occurred in five of the seven stocks. There were three stocks with no blackheart symptoms during induction testing at store loading (stocks 1, 3 and 10). However, all three developed symptoms in-pack following storage at 1.5°C. Only one stock developed symptoms after storage at 3.5°C.

<u>Respiration rate</u>

The respiration rate of samples (Table 6) was generally greatest in material held at a storage temperature of 1.5°C. Mean respiration rate of all stocks held at 3.5°C varied little in storage and was in the range 1.7 – 2.7 mg kg^{-1} hr^{-1}.

During storage at 1.5°C, relatively low respiration rates (mean 2.1 mg kg^{-1} hr^{-1}) were recorded at assessment in March, whereas mean values were in the range 3.3-3.5 mg kg^{-1} hr^{-1} at other sampling occasions.

Table 6. Respiration rate (mg CO_2 kg^{-1} hr^{-1}) of cv. Maris Piper stocks (2012-13)

Stock	January		March		April		June		**mean**	
	1.5 °C	3.5 °C	1.5 °C	3.5 °C	1.5 °C	3.5 °C	1.5 °C	3.5 °C	**1.5 °C**	**3.5 °C**
1	3.8	1.9	2.9	3.2	4.2	2.6	4.0	3.0	**3.7**	**2.7**
3	3.7	1.8	2.5	2.3	3.4	1.9	3.7	2.5	**3.3**	**2.1**
4	3.7	1.7	2.4	2.3	3.5	2.4	3.2	2.4	**3.2**	**2.2**
6	3.3	1.6	1.6	2.0	3.5	2.2	3.0	2.1	**2.8**	**2.0**
7	3.0	1.4	2.0	2.0	2.5	2.3	2.6	2.1	**2.5**	**1.9**
8	3.3	1.7	2.5	1.6	2.2	1.9	3.4	2.3	**2.8**	**1.8**
9	3.2	1.8	1.8	1.6	3.8	2.0	3.8	2.1	**3.2**	**1.9**
10	3.3	1.6	1.1	1.4	4.4	2.5	3.6	1.8	**3.1**	**1.8**
12	2.5	1.7	2.1	1.5	3.9	2.2	2.5	1.7	**2.8**	**1.8**
13	3.3	1.6	2.2	0.9	4.1	2.4	4.4	2.1	**3.5**	**1.7**
mean	**3.3**	**1.7**	**2.1**	**1.9**	**3.5**	**2.2**	**3.4**	**2.2**	**3.1**	**2.0**
min	2.5	1.4	1.1	0.9	2.2	1.9	2.5	1.7	2.5	1.7
max	3.8	1.9	2.9	3.2	4.4	2.6	4.4	3.0	3.7	2.7

Respiration rate as a predictor of blackheart in-pack

The respiration rate of stocks prior to packaging was not related to incidence of blackheart symptoms in-pack. For stocks stored at 1.5°C coming out of store in June, mean respiration rate for material that developed blackheart was 3.50 mg kg^{-1} hr^{-1} (SD 0.614) while that of stocks that did not develop symptoms was only slightly lower at 3.23 mg kg^{-1} hr^{-1} (SD 0.666). For 3.5°C stored material, stocks developing blackheart had a mean respiration rate of 2.06 mg kg^{-1} hr^{-1} (SD 0.004) while samples without blackheart had a mean respiration rate of 2.24 mg kg^{-1} hr^{-1} (SD 0.407). Using randomly selected stocks with symptoms for pairing, t-tests also indicated no direct effect of sample respiration rate on subsequent blackheart incidence ($p=0.88$).

The incidence of blackheart in cv Marfona is shown in Table 7. Marfona showed similar trends, compared with cv Maris Piper but, where symptoms occurred, these were at a much higher (*c.*10x) frequency. In two crops (stocks 2 and 11) symptoms were frequent on all sampling occasions following storage at 1.5°C whereas symptoms were mitigated to a large extent, sometimes completely, by storage at 3.5°C. This effect did however reduce as the storage season progressed and symptoms became more widespread. Stock 14 showed no blackheart symptoms except from storage at 1.5°C at the final sampling occasion.

Table 7. Blackheart incidence (% tubers >60mm) cv Marfona in-pack, year 2 (2012-13*)*

stock	January		March		April		June		**mean**	
	1.5°C	3.5°C	1.5°C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C	**1.5° C**	**3.5° C**
2	12	3	6	0	29	11	44	10	**22.8**	**6.0**
11	11	0	13	0	42	7	39	7	**26.0**	**3.5**
14	0	0	0	0	0	0	36	0	**9.0**	**0.0**
mean	**7.8**	**1.1**	**6.3**	**0.0**	**23.5**	**5.9**	**39.6**	**5.7**	**19.3**	**3.2**
min	0.0	0.0	0.0	0.0	0.0	0.0	36.1	0.0	9.0	0.0
max	12.4	3.2	12.7	0.0	41.9	10.7	44.1	10.1	26.0	6.0

As in cv Maris Piper, storage temperature had an important effect on the rate of respiration of cv Marfona (Table 8), with the lower storage temperature resulting in a significantly higher (*p*=0.001, student t-test) respiration rate.

Although there was a tendency for the respiration rate of stock 14, which had only occasional blackheart symptoms, to be greater than the other cv Marfona stocks, differences were not significant (*p*>0.69, student t-test).

Table 8. Respiration rate (mg CO_2 kg-1 hr-1) of cv Marfona stocks (2012-13*)*.

stock	January		March		April		June		**mean**	
	1.5° C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C	1.5° C	3.5° C
2	3.0	1.4	2.2	2.3	3.4	1.6	3.0	2.5	**2.9**	**1.9**
11	3.2	1.5	1.9	1.3	3.5	1.9	3.9	2.2	**3.1**	**1.7**
14	3.4	1.4	2.1	1.4	3.9	2.0	4.1	2.4	**3.4**	**1.8**
mean	**3.2**	**1.4**	**2.0**	**1.6**	**3.6**	**1.8**	**3.7**	**2.4**	**3.1**	**1.8**
Min	3.0	1.4	1.9	1.3	3.4	1.6	3.0	2.2	2.9	1.7
Max	3.4	1.5	2.2	2.3	3.9	2.0	4.1	2.5	3.4	1.9

Blackheart symptoms in-pack are shown in Table 9 for cv Blue Belle. Results are expressed as an overall incidence, due to the relatively small tuber size of this stock. Symptoms did not develop until the third sampling occasion. At this time, incidence of the defect was low at both storage temperatures. A higher incidence (9%) of blackheart developed after long-term storage of cv Blue Belle at 1.5°C.

Table 9. Blackheart incidence (% tubers) cv Blue Belle in-pack 2012-13.

stock	January		March		April		June		**mean**	
	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C
5	0	0	0	0	<1	1	9	1	**2.4**	**0.7**

The respiration rate of cv Blue Belle (Table 10) showed similar trends to cv Marfona, with a high initial rate reducing as storage progressed. This then increased again during longer term storage. Storage at 1.5°C resulted in a significantly higher respiration rate (p=0.03) compared with storage at 3.5°C.

Table 10. Respiration rate of cv Blue Belle (2012-13).

stock	January		March		April		June		**mean**	
	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C
5	3.6	1.7	2.3	2.3	3.8	2.3	4.3	2.6	**3.5**	**2.2**

4.4. Year 3 results: 2013-14 season

Selection of stocks

Of the ten Maris Piper stocks supplied from the 2013 harvest, five showed blackheart symptoms after being subjected to the induction test (Table 11). These were at relatively low incidence in three stocks (3-4%), moderate in stock 1 (12%) and particularly high in stock 8 (74%). Packaging tests on the ten stocks at intake resulted in blackheart symptoms in just two, both of which had also shown symptoms following induction.

Table 11. Frequency of blackheart symptoms in stocks of cv Maris Piper following SBCSR induction test and frequency of blackheart symptoms 'in-pack' at store loading 2013-14.

stock	blackheart incidence (%) tubers >60mm induced	blackheart (%) 'in-pack'
1	12	0
2	4	0
3	4	0
4	0	0
5	0	0
6	0	0
7	0	0
8	74	3
9	0	0
10	3	6
50% of stocks with blackheart overall		

Storage trial

The incidence of blackheart following induction during storage in year 3 is shown in Table 12. Three stocks did not show any symptoms of blackheart following induction tests at any sampling occasion and just one (stock 10) had symptoms from induction on all occasions.

The proportion of stocks with blackheart was relatively high at intake (5 of 10 stocks) and at the final sampling occasion (6 stocks) with few (2) showing symptoms at the March sampling date.

Table 12. Blackheart incidence after induction test (% tubers >60mm), 2013-14.

Maris Piper stock	Intake	Jan.	Mar.	May	Jun.	**mean**
1	12	0	5	0	0	**3.4**
2	4	5	0	7	5	**4.2**
3	4	0	0	3	4	**2.2**
4	0	0	0	0	0	**0.0**
5	0	0	0	0	0	**0.0**
6	0	3	0	3	4	**2.0**
7	0	0	0	0	27	**5.4**
8	74	0	0	2	3	**16.0**
9	0	0	0	0	0	**0.0**
10	3	18	9	30	7	**13.0**
mean	**10**	**3**	**1**	**5**	**5**	-
stocks with blackheart	5	4	2	5	6	-

Blackheart in-pack

The occurrence of blackheart symptoms 'in-pack' (Table 13) were infrequent compared with that following induction, but followed a similar trend with more stocks affected at intake and at the final sampling occasion and no stocks with symptoms in March (SO2). Only one stock (stock 10) regularly showed symptoms of blackheart during storage (all occasions except SO2).

Table 13. Blackheart incidence (% tubers>60mm) in-pack 2013-14.

Maris Piper stock	intake	Jan.	Mar.	May	Jun.	**mean**
1	0	0	0	6	2	**2**
2	0	0	0	0	0	**0**
3	0	0	0	0	2	**0**
4	0	0	0	0	0	**0**
5	0	0	0	0	0	**0**
6	0	0	0	0	0	**0**
7	0	0	0	0	0	**0**
8	3	0	0	0	0	**1**
9	0	0	0	0	0	**0**
10	6	3	0	13	5	**5**
mean	**1**	**0**	**0**	**2**	**1**	-
stocks with blackheart	2	1	0	2	3	-

Blackheart induction as a predictor of blackheart in-pack
In year 3, induction tests at store loading suggested 5 stocks were at risk of developing blackheart in-pack. Of these, two stocks (8 and 10) developed blackheart during the simultaneous packaging trial. Stock 10 also developed blackheart symptoms in-pack during subsequent sampling occasions, but this was not the case with stock 8.

In the five stocks where the induction process did not result in symptoms at intake, blackheart was not detected after packaging throughout storage. However, induction of blackheart during storage failed to predict development of symptoms in-pack in stock 1 (in both May & June).

Respiration rate
The respiration rate of stocks measured during year 3 is shown in Table 14. Mean respiration rate increased across all stocks during the initial storage period between intake and the first sampling occasion (SO1). Respiration then remained relatively static for the remainder of storage. The highest average respiration rate, across the season, occurred in stock 8.

Table 14. Respiration rate of Maris Piper stocks (mg CO_2 kg^{-1} h^{-1}) in year 3: 2013-14.

Stock	Intake	Jan.	Mar.	May	Jun.	**mean**
1	2.24	3.97	3.72	3.86	3.87	**3.53**
2	2.56	4.38	4.12	4.24	4.05	**3.87**
3	4.02	5.07	4.48	4.43	4.22	**4.44**
4	1.93	4.57	3.16	4.46	4.19	**3.66**
5	2.36	4.45	4.14	3.95	3.24	**3.63**
6	2.76	5.23	4.20	3.95	3.24	**3.88**
7	2.18	5.22	4.26	4.50	4.31	**4.09**
8	4.19	7.04	5.13	4.43	4.15	**4.99**
9	2.07	4.59	3.49	3.37	2.90	**3.28**
10	2.30	5.43	4.18	4.01	3.79	**3.94**
mean	**2.66**	**4.99**	**4.09**	**4.12**	**3.80**	-
Min	1.93	3.97	3.16	3.37	2.90	-
Max	4.19	7.04	5.13	4.50	4.31	-

Respiration rate as a predictor of blackheart in-pack
At intake (and subsequently for much of storage), the highest respiration rate occurred in stock 8 at 4.19 mg CO_2 kg^{-1} h^{-1}. Although induction tests resulted in this stock exhibiting a very high level of blackheart at intake (74%), only a low incidence of the defect was observed in-pack. During subsequent storage of stock 8, higher respiration rates were recorded but no further blackheart was detected in-pack and blackheart symptom development after induction were infrequent.

On the other hand, Stock 10 had a respiration rate close to the mean for all stocks, but relatively consistent blackheart symptoms were seen throughout storage when packaged, or as a result of the induction procedure.

4.5. Risk assessments

Packaging

Results of the trial comparing blackheart in packaged and unpackaged stocks of Maris Piper are shown in Table 15. Packaging (2.5kg capacity punched polythene) resulted in an increase in the mean incidence of blackheart, and a large increase in the number of stocks with the defect, compared with unpackaged control samples held under similar temperature conditions. Although prior storage temperature had an effect on blackheart incidence, with 1.5°C storage resulting in greater mean incidences, this effect was not straightforward with some stocks showing greater incidences from 3.5°C storage.

Table 15. Blackheart incidence (% all tubers) in unpackaged and packaged cv. Maris Piper stocks.

Stock	packaged		unpackaged	
	1.5°C	3.5°C	1.5°C	3.5°C
11	4	1	0	0
12	0	1	6	0
13	22	21	33	17
14	1	0	0	0
15	8	0	0	0
16	0	0	0	0
17	11	3	0	0
18	0	0	0	0
19	7	13	0	6
20	1	0	0	0
21	5	2	0	0
22	0	1	0	0
23	11	16	0	0
24	30	4	0	0
mean	**7.1**	**4.4**	**2.8**	**1.6**
sd	9.06	6.93	8.84	4.70
stocks with blackheart	10	9	2	2

*

Results of packing selected Maris Piper stocks in punched polythene or laser perforated packaging are shown in Table 16. The initial selection of stocks using the induction chamber method did not correlate well with results, with stocks 12 and 20, nominated as ‘not susceptible’ and ‘susceptible’ respectively, both exhibiting low levels of blackheart. High levels of the defect were recorded in stock 23, selected as ‘susceptible’. Previous storage temperature did not have an overriding effect on blackheart incidence. A similar pattern was found in both packaging trials with low incidences of blackheart in stocks 12 and 20 and a high incidence in stock 23.

Table 16. Blackheart incidence (% all tubers) in selected Maris Piper stocks in punched polythene (PP) and laser perforated (LP) packaging.

stock and blackheart nomination*	PP 1.5	PP 3.5	LP 1.5	LP 3.5	**mean**	sd
12 ns	4	2	0	6	**3.0**	2.58
20 s	0	0	2	2	**1.0**	1.15
23 s	20	11	17	27	**18.8**	6.65
mean	**8.0**	**4.3**	**6.3**	**11.7**		
sd	10.58	5.86	9.29	13.43		

**Stock 12 deemed not susceptible (ns) and stocks 20 and 23 susceptible (s).*

Warming

The two methods of warming potatoes, passive and positive ventilation, did not result in frequent development of blackheart symptoms in packs after shelf-life testing. Blackheart was only detected in one lot (stock 10) and one treatment (positive ventilation). Incidence was low at just 3% with the affected tubers all coming from one pack. The temperature and humidity profiles of the two warming methods that were used are shown at Annex 3.

4.6. FPSA survey of blackheart incidences

The survey was completed by 6 companies. Results are summarised below:

- Blackheart symptoms were not observed in the field or in storage. Crops only became symptomatic in-pack, at retail or with the consumer.
- Symptoms were most frequent in the months of April, May and June.
- The pattern of customer complaints showed no clear trends, but the company reporting the most indicated blackheart was responsible for 48% of all complaints in quarter 1 (April-June).
- Blackheart was most reported in cvs Maris Piper, Marfona and King Edward.
- Blackheart was not reported in cvs Rooster, Osprey or Charlotte and was only reported at low incidences in cvs Estima, Maris Peer and Harmony.
- Symptoms were most frequent in tubers of size 61-70mm, from a store temperature of less than 4°C after between 6 and 11 months of storage.
- Blackheart symptoms were reported following use of CIPC, ethylene and where no sprout suppressants were used.
- Blackheart occurred in stores with and without carbon dioxide ‘flushing’.

- Blackheart occurred in crops that were warmed whether this was done passively or by using positive ventilation.
- Four of the six companies used some form of blackheart induction method for screening stocks, but only three of these thought this was successful.
- Field conditions including waterlogging, flooding, drought, compaction and soil temperatures over 10˚C were all suggested as being conducive to blackheart development.
- When asked about the three most important factors in determining blackheart development, respondents to the survey included:
    - variety
    - tuber size
    - storage temperature
    - length of storage
    - rapid warming
    - temperature control in the supply chain
    - packaging type

5. DISCUSSION

Blackheart was not generally observed in samples assessed directly from store. Symptoms typically only occurred in washed and packaged samples after a period of shelf-life at elevated temperature (20°C).

Based on this work's shelf-life test results (generally following two weeks storage at 20°C in punched polythene packs), data from both 2012-13 and 2013-14 suggested an increasing risk of blackheart symptom development as the storage season progressed.

During early season storage at 3.5°C (January 2013 and January 2014 assessments), the number of cv Maris Piper stocks developing blackheart was very low (none in 2013 and 1/10 stocks in 2014) and the incidence of blackheart in the affected stock was low (3% >60mm tubers). As storage progressed, the number of stocks with symptoms (in-pack) increased to 2/10 and 3/10 stocks respectively by June. The incidence of blackheart remained at or below 6% (>60mm).

These packaging trial results appear to contrast with those of the trial carried out in 2011-12 (shelf-life test: 13 days at 20°C in punched polythene) when 6/14 stocks (43%) exhibited symptoms. However, this packaging trial was carried out relatively late in the season (31 July) which may have contributed to the relatively high incidence of affected stocks.

The storage trend was also evident in cvs Blue Belle and Marfona in 2012-13. For the single stock of Blue Belle, stored at 3.5°C, blackheart symptoms initially remained absent in-pack, only becoming evident at samplings in April and June. For Marfona, the number of stocks with blackheart increased from 1 of 3 stocks in January to 2 of 3 stocks at samplings in June. Data indicated Marfona tubers to be more susceptible to blackheart than Maris Piper, with relatively high incidences of the defect.

Blackheart symptoms in Maris Piper were exacerbated by storage at 1.5°C. Although there were exceptions (Maris Piper stock 19, 2011-12, Table 2 and Maris Piper stock 6, April 2012-13, Table 5), storage at 1.5°C generally resulted in earlier symptoms of blackheart, a greater proportion of stocks with the defect and more frequent symptoms in affected stocks. This was the case especially after long periods of storage. In Marfona, a greater proportion of stocks were affected and in both Marfona and Blue Belle a higher incidence of blackheart occurred, in affected stocks, at the lower storage temperature.

Data for blackheart development in-pack for Maris Piper in years 2 and 3, using stocks stored at 3.5°C, did not suggest a strong seasonal difference in blackheart susceptibility.

The use of industry-developed blackheart induction methods in 2011-12 did not result in the accentuation of blackheart symptoms during store loading/early storage. A more challenging method was therefore developed as the design of experiments required early selection of high and low risk stocks for storage at Cranfield University. The blackheart induction method devised for this study involved incubation of tubers in sealed chambers and resulted in the successful development of a broad range of symptoms at store loading (0%-80% blackheart incidence in year 1; 0%-75% in year 2 and 0%-74% in year 3).

The number of stocks with symptoms of blackheart and often the incidences of blackheart in 'susceptible' stocks was generally greater using the induction method than for blackheart development in-pack. The adoption of the induction test as a QC procedure could therefore discourage packing of some stocks that would not go on to develop blackheart under normal circumstances. However, it would ensure that the lowest risk crops are always used first and allow other mitigation strategies to be employed in the storage and packing of any higher risk stocks.

In year 2, packaging of Maris Piper stocks identified as 'not susceptible' (ie resulting in 0% blackheart incidence from the induction procedure) would have prevented blackheart in-pack (at the sampling rates used), when material was packaged in January and March. However, these stocks nominated as 'not susceptible' at store loading did still develop symptoms in-pack in April and June.

For Maris Piper, in year 3, adoption of the induction test at store loading would have prevented packaging of the two stocks that developed blackheart during simultaneous shelf-life testing. All five stocks nominated as 'not susceptible', following the induction test, remained free from blackheart during subsequent storage in-pack and, of the five stocks nominated as 'susceptible', four stocks developed blackheart.

Although relatively successful at identifying blackheart risk, results from repeated induction testing in year 3 did not identify all the stocks that eventually developed blackheart in-pack (Stock 1, May & June, Table 13). Results of the repeated induction tests carried out in 2013-14 also suggest susceptibility of stocks to blackheart changed during storage, with just one stock consistently showing blackheart symptoms on all assessment occasions using the induction test. This lot (stock 10) also exhibited symptoms most frequently in-pack, with the defect detected on four out of the five sampling occasions.

For Marfona in 2012-13, the induction test undertaken at store loading predicted that two stocks were ‘susceptible’, and a third was ‘not susceptible’ to blackheart. Both stocks identified as ‘susceptible’ from induction tests developed blackheart in-pack during storage at 3.5°C, while the stock identified as ‘not susceptible’ did not. However, all three stocks developed symptoms in-pack during storage at 1.5°C.

Although high respiration rate may be a significant risk factor for the development blackheart, there is no evidence from this study that shows respiration rate was linked *directly* to blackheart susceptibility. For Maris Piper in year 3, the respiration rate of stock 10 (showing consistent symptoms in-pack) was not significantly different to that of 4 of the 5 stocks that did not develop blackheart (p=0.18-0.71). In year 2, although storage at 1.5°C resulted in significantly higher respiration rates, compared with 3.5°C, respiration was similar in stocks that developed blackheart and those that did not. For Marfona, there was no significant difference in respiration rate between stocks with and without blackheart.

A case study on blackheart in a crop of Melody has been appended at Annex 4.

6. CONCLUSIONS

- Blackheart is a physiological disorder of potatoes
- Blackheart is not usually found within crops when they are in storage; it more typically occurs during shelf-life, following washing and packing. This was the case in this study.
- Commercial demand and consumer preference for Maris Piper meant that control of blackheart in this cultivar was considered most important by FPSA and experimental work focused on it most in this trial.
- Blackheart symptoms were most prevalent in larger tubers. Although occasionally detected in the 50-60mm interval, the majority of tubers with symptoms were >60mm.
- Proprietary methods of blackheart susceptibility testing were assessed but these did not produce any symptoms of blackheart early in storage.
- A method of induction was developed within this study that gave good differentiation of stocks at store loading. The method involved sealing samples of tubers in chambers and incubating these for 60 hours at 30°C.
- Using the induction test, more stocks showed symptoms of blackheart and the incidence of blackheart in affected stocks was greater than for blackheart that subsequently occurred in-pack (ie some false positives were generated) However, the test would have been successful as a blackheart risk assessment method. There were few cases of false negatives although, unsurprisingly, data indicated that repeated assessment may be advantageous to achieve more accurate results.

- The susceptibility of cvs Marfona and Maris Piper to blackheart in-pack were not correlated with average respiration rate of those stocks, or the respiration rate of the potatoes immediately prior to packaging.
- Although fewer stocks of cv Marfona were evaluated, the limited data suggest that this cultivar is more susceptible to blackheart than cv Maris Piper.
- Throughout the study, susceptibility to blackheart after packaging increased with time, with the highest incidences always occurring at the end of the storage season.
- Despite the effect of time, there was still an important effect of storage temperature, with the highest incidences occurring at the lowest temperature. Storage at 3.5°C generally maintained a low incidence of blackheart with relatively few stocks affected.
- A comparison of washed stocks of Maris Piper indicated risk of blackheart was highest when the crop was packed after storage at 1.5°C.
- Two methods for warming potatoes prior to packing, for bruise prevention, were evaluated but did not result in blackheart at a sufficient frequency to allow any meaningful comparison to be made.

The data from this study will, it is anticipated, enable further work to be undertaken to better understand the factors influencing blackheart development. However, on the strength of the work carried out to date within this trial, the following factors can be identified as contributing to the risk of blackheart:

- Storage of susceptible varieties (further data are needed for commonly grown varieties within the fresh market sector)
- Long-term storage, especially at very low temperature (<3.5°C)
- Tuber size, with an increased prevalence for blackheart in tubers >60mm

The adoption within industry of a more aggressive risk assessment methodology, such as the test used in this study, is recommended to enable high risk stocks to be more readily identified and blackheart risk to be managed more actively.

Annex 1. Blackheart survey

You are invited to participate in our survey on Blackheart as part of a Potato Council funded research project. Please answer the following questions as thoroughly as possible, given your day-to-day observations, customer feedback and other records. The questions are based on reported or observed blackheart incidence over the last 4 years (2009-2012 inclusive), in GB produced potatoes. Any information that you provide will be used in confidence by Potato Council/SBCSR to inform its research only. All results will be presented in aggregate and anonymously. The survey should take approximately 45 minutes to complete. If you cannot complete this in one sitting, you are able to save your responses and return to the survey later. Thank you very much for your time and support.

Occurrence of symptoms

Q1. During which months of the past 4 years do you think blackheart symptoms were most prevalent? Please select all the months that apply for each year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Don't know / N/A
(i) 2009	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐	☐							☐

Q2. At which stage in the production/ supply chain were blackheart symptoms most prevalent?

	Growing crop	Burn-off to harvest	Storage	In pack	Retail	Home	Don't know/ N/A
(i) 2009	☐	☐	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐	☐	☐

Customer complaints

Q3a. Please provide the approximate number of customer complaints received each quarter for each year. Where Q1 = Jan-Mar, Q2 = Apr-Jun, Q3 = Jul-Sep, Q4 = Oct-Dec.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Don't know/ N/A
(i) 2009					☐
(ii) 2010					☐
(iii) 2011					☐
(iv) 2012					☐

Q3b. Please provide the approximate number of blackheart complaints received each quarter for each year. Where Q1 = Jan-Mar, Q2 = Apr-Jun, Q3 = Jul-Sep, Q4 = Oct-Dec. Please enter DK (dont know) or NA (not applicable) if this applies.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
(i) 2009				
(ii) 2010				
(iii) 2011				
(iv) 2012				

Tuber characteristics

Q4ai How frequently have blackheart symptoms been observed in MARIS PIPER?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bi Approximately what percentage of stocks of MARIS PIPER were affected on each occasion? Please provide your best estimate for each year.

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4aii. How frequently have blackheart symptoms been observed in ESTIMA?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bii. Approximately what percentage of ESTIMA stocks were affected on each occasion? Please provide your best estimate.

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4aiii. How frequently have blackheart symptoms been observed in MARIS PEER?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4biii. Approximately what percentage of MARIS PEER stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4iv. How frequently have blackheart symptoms been observed in MARFONA?

Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4biv. Approximately what percentage of MARFONA stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4av. How frequently have blackheart symptoms been observed in HARMONY?

Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bv. Approximately what percentage of HARMONY stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4avi. How frequently have blackheart symptoms been observed in MELODY?

Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bvi. Approximately what percentage of MELODY stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4avii. How frequently have blackheart symptoms been observed in SAXON?

Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bvii. Approximately what percentage of SAXON stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4aviii. How frequently have blackheart symptoms been observed in DESIREE?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bviii. Approximately what percentage of DESIREE stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4aix. How frequently have blackheart symptoms been observed in KING EDWARD?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bix. Approximately what percentage of KING EDWARD stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4ax. How frequently have blackheart symptoms been observed in ROOSTER?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bx. Approximately what percentage of ROOSTER stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4axi. How frequently have blackheart symptoms been observed in CHARLOTTE?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bxi. Approximately what percentage of CHARLOTTE stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q4axii. How frequently have blackheart symptoms been observed in OSPREY?
Regularly ☐ Occasionally ☐ Never ☐ Not applicable ☐

Q4bxii. Approximately what percentage of OSPREY stocks were affected on each occasion?

	<1%	1-5%	6-20%	>20%	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q5. What was the typical tuber size when blackheart was most prevalent? Please provide the approximate diameter.

	<40mm	40-50mm	51-60mm	61-70mm	>70mm	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐	☐

Storage conditions

Q6. What was the typical storage temperature of stocks that developed blackheart? Please select all those that apply.

	< 3.0°C	3.0 - 4.0°C	> 4.0°C	Don't know
(i) 2009	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐

Q7a. Please provide the typical length of storage?

Q7b. What were the storage characteristics when blackheart was most prevalent? Please select all those that apply.

	Ventilation +ve (e.g. letterbox)	Ventilation non +ve (e.g. overhead throw)	No sprout suppre-ssant	CIPC sprout suppre-ssant	Ethylene sprout suppre-ssant	Store flushing regime in place	CO2 control in place	Other	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐	☐	☐	☐	☐

Q7c. And what were the typical CO_2 levels when blackheart is most prevalent?

1. Less than 3000ppm ☐
2. 3000-5000ppm ☐
3. > 5000ppm ☐
4. Don't know ☐

Q7d. And at these times, at what concentration is flushing typically enabled?

1. 3000ppm ☐
2. 5000ppm ☐
3. Timed flush only ☐
4. Not flushed ☐
5. Other ☐

Q7e. Please provide any relevant details of the store not covered above?

Q8a. Still thinking about the times of blackheart prevalence, how were the crops that were previously in storage typically warmed prior to washing and/or packing?

	Passively (placed in a warm store)	Actively (positively ventilated)	Humidification	Other	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐

Q8b. Were any temperature controls usually in place when potatoes were warmed from storage?

1. Yes ☐
2. No ☐
3. Don't know / not applicable ☐

Q8c. What is the maximum air temperature that could be used when the potatoes were warmed from storage?

1. Up to 8°C ☐
2. 8-12°C ☐
3. 12-20°C ☐
4. >20°C ☐
5. Don't know ☐

Q9a. what is the typical duration between unloading and washing?

Q9b. What is the typical duration between washing and packing?

Packaging

Q10a. What type(s) of packaging were used when the incidence of blackheart was most prevalent? Please select all that apply?

	No packaging	Paper	Plastic - punched	Plastic micro-perforated (MAP)	Other	Dont know/ N/A
(i) 2009	☐	☐	☐	☐	☐	☐
(ii) 2010	☐	☐	☐	☐	☐	☐
(iii) 2011	☐	☐	☐	☐	☐	☐
(iv) 2012	☐	☐	☐	☐	☐	☐

Q10b. What was the typical target pack atmosphere?

O_2 (ppm)	CO_2 (ppm)	Don't know/ N/A
		☐

Q11. Is transport from the packer to the distribution centre temperature controlled?

	Yes	No	Don't' know/ N/A
(i) 2009	☐	☐	☐
(ii) 2010	☐	☐	☐
(iii) 2011	☐	☐	☐
(iv) 2012	☐	☐	☐

Induction of blackheart

Q12a. Over the past 4 years have you run any QC procedures to induce blackheart symptoms?

1. Yes ☐
2. No ☐
3. Don't know ☐

Q12b. To what extent has the induction been successful in producing the symptoms?

1. Successful ☐
2. Quite successful ☐
3. Unsuccessful ☐
4. Don't know ☐

Q12c. In your opinion, does induction of blackheart successfully allow susceptible stocks to be identified?

1. Yes ☐
2. No ☐

Biochemical and physiological tests

Q13. Were any biochemical or physiological tests conducted in the last 4 years?

1. Yes ☐
2. No ☐
3. Don't know/ not applicable ☐

Q14. Please provide details of the most recent biochemical and physiological tests? Please provide details of up to 5 of the most recent, starting with the most recent test first.

	(i) Variety	(ii) Type of test e.g. respiration
Test no. 1		
Test no. 2		
Test no. 3		
Test no. 4		
Test no. 5		

Growing conditions

Q15. What are the field conditions that you have identified as being most conducive to blackheart development over the last 4 years? Please select all those that apply?

1. Waterlogging ☐
2. Flooding ☐
3. Drought ☐
4. Soil temperatures <10°C ☐
5. Soil temperatures 10-20°C ☐
6. Soil temperatures >20°C ☐
7. Compaction ☐
8. Ridging ☐
9. None of these ☐
10. Don't know ☐
11. Other ______

Q16. Which soil textures have you identified as being most conducive to blackheart development? Please select all that apply.

1. Sand ☐
2. Loamy sand ☐
3. Sandy loam ☐
4. Sandy silt loam ☐
5. Silt loam ☐
6. Clay loam ☐
7. Silty loam ☐
8. Sandy clay loam ☐
9. Silty clay loam ☐
10. Clay ☐
11. Sandy clay ☐
12. Silty clay ☐
13. Don't know ☐

Overview

Q17. What factors do you believe are the most important in determining blackheart? Please rank the top 3 factors, where 1= most important.

- Cultivar ______
- Field conditions ______
- Crop nutrition ______
- Irrigation ______
- Tuber size ______
- Storage temperature ______
- Storage length ______
- Sprout suppressant ______
- Packaging type ______
- Rapid warming ______
- Temperature control in supply chain ______
- Other ______

Q18. If there are any other factor(s) that you consider to be important in the incidence of blackheart, please state below?

Follow up

F1. We may wish to follow up on some of the surveys that have been submitted. Are you willing to be contacted again in the future?

1. Yes ☐
2. No ☐

First Name

Surname

Company

Email Address

Telephone number

Annex 2. Respiration rate of cvs Marfona and Maris Piper 2011-12

Respiration rate of cv Marfona 2011-12.

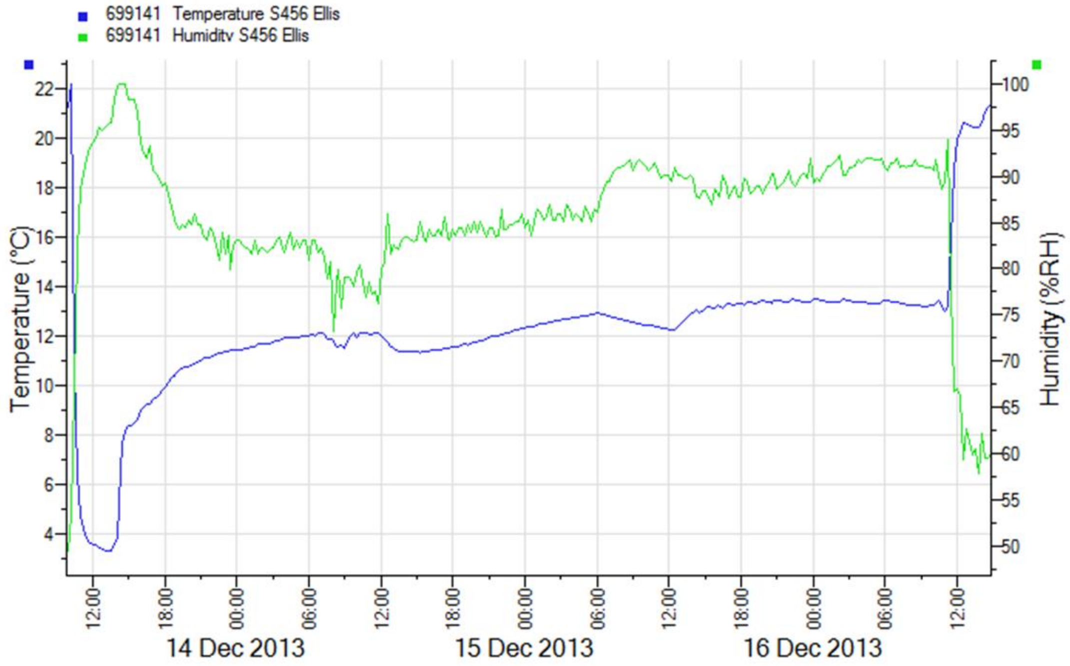
stock	February		April		July	
	1.5°C	3.5°C	1.5°C	3.5°C	1.5°C	3.5°C
1	1.29	1.65	1.41	1.60	3.43	2.32
2	1.39	1.46	1.64	1.71	3.22	1.98
3	1.40	1.48	1.51	1.59	2.66	2.39
4	1.65	1.59	1.53	1.67	3.20	2.63
5	1.97	1.46	1.75	1.83	3.66	2.65
6	1.66	1.39	1.80	1.67	2.65	2.22
7	1.52	1.28	1.39	1.58	3.60	1.85
8	1.65	1.69	1.67	1.69	3.64	2.32
9	1.55	1.45	1.83	1.75	3.96	2.29
10	1.50	1.61	1.51	1.54	3.63	2.25
Mean	**1.56**	**1.51**	**1.60**	**1.66**	**3.36**	**2.29**
Min	1.29	1.28	1.39	1.54	2.65	1.85
Max	1.97	1.69	1.83	1.83	3.96	2.65
p	0.533		0.103		0.0001	

Respiration rate of cv Maris Piper 2011-12.

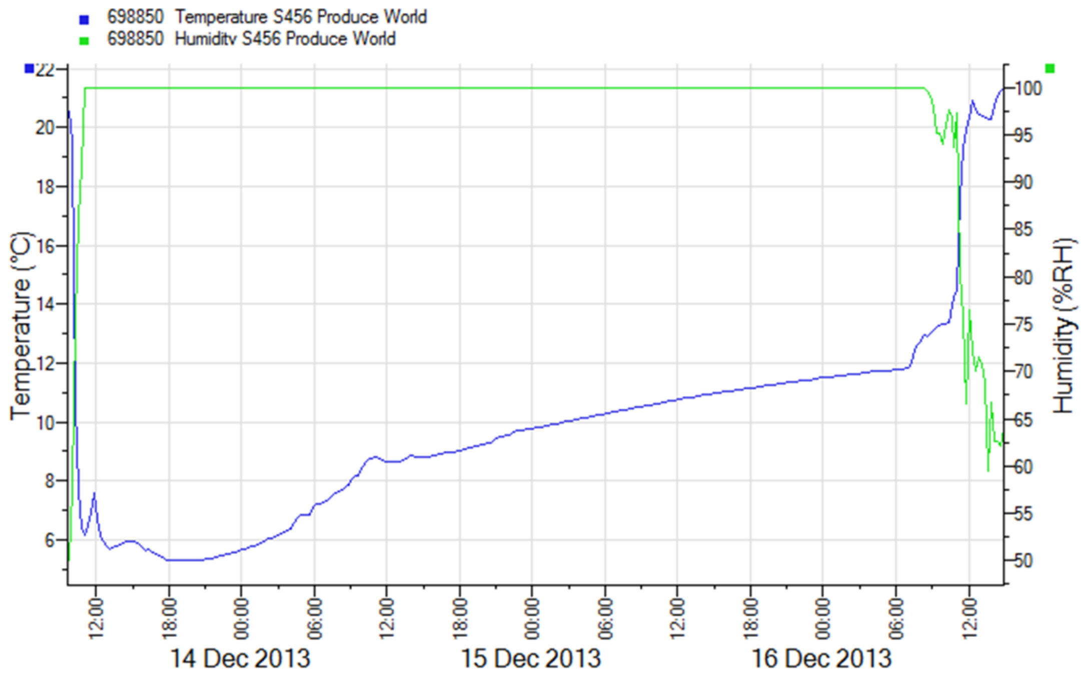
stock	February		July	
	1.5°C	3.5°C	1.5°C	3.5°C
11	1.28	1.53	2.09	1.97
12	1.68	1.54	2.19	2.08
13	1.41	1.40	1.90	1.93
14	1.72	1.53	2.29	1.84
15	1.64	1.43	2.17	1.88
16	1.60	1.57	2.19	1.70
17	1.54	1.27	2.12	1.71
18	1.60	1.45	2.45	1.89
19	1.46	1.54	2.43	2.01
20	1.53	1.57	1.94	2.01
21	1.45	1.25	2.33	1.80
22	1.80	1.62	2.51	2.26
23	1.35	1.53	2.10	2.10
24	1.43	1.28	1.77	1.59
Mean	**1.54**	**1.46**	**2.18**	**1.91**
Min	1.28	1.25	1.77	1.59
Max	1.80	1.62	2.51	2.26
p	0.116		0.0006	

Annex 3. Temperature and humidity profiles for 'warming' trial

Passive



Positive ventilation



Annex 4. Case study of blackheart in cv Melody in a commercial store

The SBCSR Storage Advice Line (0800 02 82 111) was contacted (27 January 2012) by a store manager who suspected blackheart in a stored crop. The store and crop was inspected on 31 January 2012.

The store contained c. 550 tonnes in boxes with a roof mounted refrigeration system at one gable end, centrally positioned, with the main (sliding) doors at the opposite end (Fig.2). The store was asbestos clad, with EEP type insulation blocks fixed to the inside and spray foamed over. The store was not 'state of the art', but fit for purpose.

Fig. 4. Blackheart symptoms in cv Melody in a commercial store.

The problem crop was cv. Melody, grown on a silt soil. Common seed was also supplied and grown by others locally without issue, although most of these crops were marketed before Christmas.

The crop was grown in one unirrigated field and harvested between 20th and 22nd October 2011.

A range of box types were used, giving uneven stack heights and some were over-filled. Stacking pattern was ‘tight’ with no clear path for air distribution. Temperature control was achieved via a single return air probe on the evaporator.

The right hand side of the store was loaded with cv Estima in mid-September and pulled down to *c.* 4°C, before the cv Melody was harvested. There was uncertainty over the temperature of the Melody at harvest but conditions were described as “warm”. Historical weather data indicate ambient temperature in the area was approximately 14 -15°C at the time of harvesting.

After loading, crop was pulled down to c. 2°C. No sprout suppressant was used. At the time of the store visit, core tuber temperature was 2.1 – 2.2°C across most of the store, with the exception of the back corners, adjacent to the refrigeration unit, where the temperature was 2.7 – 2.8° C. The refrigeration was off at the time of the visit.

Extensive blackheart was found in cv Melody (30 – 50% of tubers affected). Blackheart was not found in the earlier harvested cv Estima. Symptoms were not found in cv Melody in the back corners of the store, where the temperature was warmest.

Samples were returned to SBCSR. The defect was confirmed as blackheart, with the following incidences.

Top box in front of the refrigeration unit – 39.5%
Top box furthest from refrigeration unit – 13.5%
Bottom box, front of store – 3%
Top box in back corner, adjacent to refrigeration unit – 0%

Appendix 1 SBCSR BLACKHEART INDUCTION ASSESSMENT

1. Use c.30 litre chambers for this test.

2. Inspect chambers before use – they need to be undamaged.

3. Fill the chamber with tubers (as many as will comfortably fit). Label the chamber (not the lid) with sample/stock number and date.

4. The lid must be able to close fully. Put on the lid and seal the chamber with duct tape, to ensure it is airtight, and transfer to a controlled environment incubation store at 30°C for 60 hours.

5. At the end of the incubation period, unseal the chamber and remove the lid. After washing, hand-grade each sample and then cut each tuber in half (length ways - rose to heel). Put the halves in single layers in trays dependent on grading size per stock. Label the trays with stock/sample number and size.

6. Stack the trays and leave them at room temperature for 24 hours to allow any blackheart symptoms to develop.

7. After 24 hours complete a visual assessment.

8. Record tubers displaying no symptoms and symptoms of blackheart and their size on an assessment form.