Final Report

Improved store management of diseases affecting seed tubers and its effects on the subsequent crop

Ref: R457

Reporting Period: 2011-2012

Report Authors: Glyn Harper[1], David Firman[2], Jeff Peters[3]
[1]Sutton Bridge Crop Storage Research, [2]Cambridge University Farm (CUF), [3]The Food and Environment Research Agency (Fera)

Project No. 2013/06

The Potato Council is a division of the Agriculture and Horticulture Development Board.

Additional copies of this report and a list of other publications can be obtained from:

Publications

Potato Council
Agriculture & Horticulture Development Board
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

Tel: 02476 692051
Fax: 02476 478902
E-mail: publications@potato.org.uk

Our reports, and lists of publications, are also available at www.potato.org.uk

CONTENTS

1. SUMMARY

This one year study aimed to holistically investigate potato production by examining the effects of different storage regimes on seed-borne diseases and seed tuber quality attributes and how these regimes impact on the subsequent agronomic performance of the crop. The contribution of seed storage conditions to disease risk and the threshold inoculum loading on seed tubers required to cause disease in the field is understood for some pathogens but requires determination for other important pathogens.

Two varieties, Estima and Maris Piper, were sourced from different geographical areas of GB. Norfolk-grown sourced crop was stored under varying experimental conditions at SBCSR and in commercial stores, with field trials carried out at both Cambridge University Farm (CUF) and within commercial fields.

Three pathogens *Fusarium coeruleum* (dry rot), *Helminthosporium solani* (silver scurf) and *Phoma exigua* var. *foveata* (gangrene) were the major disease targets of the study. By visual inspection *H. solani* was found to be present in all stocks at sufficient inoculum levels to cause disease given appropriate conditions. To ensure sufficient fungal rot potential in the samples for the trial, Estima tubers were artificially inoculated with *P. exigua* var. *foveata* and Maris Piper with *F. coeruleum* to provide approximately 5% stock infection level. These variety/pathogen combinations were chosen because of known susceptibility of variety to each disease.

Storage treatments included two pull-down regimes, good (1°C/day) and poor (0.25°C/day), two storage temperatures, low (3°) and (5°C), each with and without fungicide treatment. Storage treatments affected disease development. Silver scurf was abundant post-storage in all stocks and all storage conditions. Generally there was a clear difference between the different pull-down regimes with a lower incidence of this disease found in good compared to poor pull down regimes. Application of fungicide reduced the incidence of silver scurf in most storage treatments. Unexpectedly the incidence and severity of silver scurf on one fungicide treated sample was greater than in the equivalent untreated sample. Storage treatments also affected sprouting, it being expectedly more pronounced at the warmer storage temperature than in the cooler storage temperature for both Estima and Maris Piper. Fungicide treatment affected sprouting of both varieties.

Overall, despite widely contrasting seed storage regimes having an effect on both disease development and sprouting, they generally had limited or no effect on final yield in either variety. Extensive sprout development following storage at 5°C advanced emergence but effects on stem and tuber populations were limited and were not consistent across experiments. Fungicide treatment consistently delayed emergence although virtually complete emergence was eventually achieved. Fungicide treatment generally reduced stem populations and consistent with this tuber populations were also generally reduced in the CUF experiments. However, although a similar effect on stem numbers was found for Estima grown in the commercial field trial, no associated effect on tuber numbers was observed. In Maris Piper grown at CUF, fungicide treatment reduced yield, an effect not seen with Estima in the CUF trial or either variety in the commercial field trial. Although differences were observed in both stem number and tuber count between seed stocks stored under commercial and experimental conditions, there was no effect on final yield.

The overall effects of storage treatments on growth were small and, with the exception of fungicide treatment, final yields were unaffected by any storage treatments. These results may be associated with the initial high health status of the seed stocks used.

This study was unable to establish the impact of seed disease thresholds on field disease, in part because the relationship between pathogen DNA on the tuber and disease was not direct.

It was also not possible, due to the early termination of the trial, to look at wider impacts of seed multiplication under controlled condition on other important storage factors such as dormancy break which, potentially, could have a major impact on quality attributes within subsequent generations.

2. INTRODUCTION

Manipulation of storage conditions provides an opportunity to prevent multiplication or reduce inoculum loading of both fungal and bacterial pathogens. The contribution of seed storage conditions to disease risk in the subsequent crop and the threshold inoculum loading on seed tubers required to cause disease in the field is understood for some pathogens but requires determination for other important pathogens.

This study aimed to quantify the effects of different storage regimes on seed-borne diseases and the agronomic performance of the subsequent crop; and to determine whether the experimental approach could be used to generate disease risk potentials for seed at-planting and for both seed and ware at-harvest. The four specific objectives of the study were:

(a) To quantify the effect of varied storage management of seed potatoes on pathogen populations
(b) To quantify the effects of varied storage management on crop establishment and the development of disease in the growing crop
(c) To compare varied storage management and subsequent crop performance with commercial practice
(d) To establish a storage-field cycle baseline against which other or new threats, or changes to practice, can be compared experimentally through the use of seed of known, controlled history and provenance

3. MATERIALS AND METHODS

3.1. Seed tuber selection and supply

Norfolk grown Estima (SE2 40-50 mm) and Maris Piper (SE2 40-50 mm) were delivered to SBCSR on the 30th August and 9th September 2012 respectively. Perthshire grown Estima (EC2 35-55 mm) and Maris Piper (SE2 35-55 mm) were delivered to SBCSR on 1st November 2012. All treatments were applied within four days of receipt of tubers.

3.2. Quality and disease assessments of stocks, artificial inoculation of pathogens

Three pathogens *Fusarium coeruleum* (dry rot), *Helminthosporium solani* (silver scurf) and *Phoma exigua* var. *foveata* (gangrene) were the major disease targets of the study.

All stocks were assessed for quality characteristics including disease, greening, defects, bruising, sprouting at store loading and unloading and weight loss at intake and following the storage period. By visual inspection *H. solani* was found to be present in all stocks at sufficient inoculum levels to cause disease given appropriate conditions. Other significant potato pathogens found as natural infections on each stock of potato at intake were visually assessed for disease development following storage. No soft rot infection was observed in assessed samples.

To ensure sufficient fungal rot potential in the samples for the trial, Estima tubers were artificially inoculated with *P. exigua* var. *foveata* and Maris Piper with *F. coeruleum* to provide approximately 5% stock infection level. These variety/pathogen combinations were chosen because of known susceptibility of variety to each disease. Pathogens for inoculation were each grown on PDA agar plates at 20°C. A pathogen suspension was produced by scraping all of an actively growing, confluent culture from the surface of the Petri dish into 2 ml of sterile water. This mass was briefly blended using a Qiagen TissueRuptor for 30 seconds to provide a pipettable suspension. Tubers were wounded with a sterile 3” nail to give a 7mm deep hole into which 10µl of the pathogen suspension was immediately pipetted using a cut-off pipette tip.

Quantitative PCR (qPCR), carried out by Fera, was used to provide a quantitative assessment of pathogen loading for the target diseases at intake and following storage.

3.3. Store treatments

Fungicide was applied to provide a common commercial standard against which the effects of store treatment could be evaluated. Storite Super (250 g/litre thiabendazole and 125 g/litre imazalil), generously provided by David Turner (Turner Agriculture Ltd.), was applied by conventional spray mist roller table treatments using Mint Green

nozzles, by personnel trained to NPTC[1] PA11, at 120 ml/t on a roller table separately to pathogen inoculated and not inoculated stock sub-samples. Untreated tubers were passed across the table, with equivalent volumes of water instead of fungicide to control for the effects of application.

For each treatment ~120 tubers, sufficient for assessment following storage or for planting at CUF or the commercial field site (Norfolk), were loaded into nets and buried within bulk seed tubers, of the same stock and chemical treatment (fungicide or untreated), in sectioned one tonne boxes (shown in Appendix 1). Inoculated treatment tubers were held in separate sections from not inoculated tuber samples. Each of the four replicate nets of any treatment was assigned a random position within a section and all replicates were stored in different sections. The position of the boxes within a store was randomised.

Two different controlled and reproducible pull-down regimes were applied. During "poor" pull-down the temperature was reduced at 0.25°C/day at a ventilation rate of *c.* 0.02 m^3/s/t while "good" pull-down temperature was reduced at 1.0°C/day and a ventilation rate of *c.* 0.05 m^3/s/t. Following pull-down, samples were stored at 3°C or 5°C, both at a ventilation rate of *c.* 0.04 m^3/s/t and at 95% relative humidity. All boxes were at the final storage conditions in 16 tonne capacity experimental stores by 20th December 2011.

Store unloading began on the 10th April 2012. Once unloaded from one tonne boxes, the nets were returned to the same store to maintain the appropriate temperature pending assessment or delivery to planting site. Delivery of the samples for CUF trials were made on the 11th April 2012 and for commercial site trials on 16th May 2012. Samples of the Estima and Maris Piper (Norfolk) stocks used in this trial but which had been stored under commercial conditions in Norfolk were collected on the 12th April 2012 and held at SBCSR at 3°C prior to a comparative assessment of the effects of experimental and commercial treatments on tuber quality.

Storage treatment summary: 4 replicates of each of four stocks, pathogen inoculated or not inoculated, fungicide treated or untreated, poor or good pull-down, stored at 3°C or 5°C.

[1] National Proficiency Test Council www.nptc.org.uk

3.4. Field Trials

Cambridge University Farm trials

Two separate experiments with the same design and treatment combinations were planted at Cambridge University Farm, one with Estima and one with Maris Piper Norfolk stock samples stored under different treatment conditions at SBCSR. Treatments consisted of all combinations of two seed storage pull-down regimes (good, bad); two seed storage temperatures: low (3 °C), high (5 °C); two fungicide regimes: none, treated with Fungicide; two inoculation treatments: none or inoculated and an additional control of the same seed stocks which had been stored under commercial conditions.

Experiments were planted by hand on 12 April 2012. The row width was 76 cm and each plot consisted of four rows of 25 plants at a within-row spacing of 30 cm. A pre-emergence herbicide application of flufenacet / metribuzin and glufosinate ammonium was applied on 11th May 2012. Nitrogen fertilizer was applied on 15 May 2012 by hand to the soil surface as ammonium nitrate granules at 200 kg N/ha.

Emergence counts were made every 3-4 days from the beginning of emergence until complete and ground cover was recorded weekly throughout growth. An assessment of stem disease was made on 27 June 2012.

A harvest of guarded plants was dug from a 2.4 m length each of the two central rows and the number of main and secondary stems counted. Tubers were graded in 10 mm size fractions and the fresh weight and number in each size grade recorded prior to dispatching samples to Fera for disease testing. The Estima and Maris Piper experiments were harvested on 4 and 20 Sept 2012, respectively.

Trials in commercial fields

Two separate experiments with the same design and treatment combinations were planted within commercial seed crops of Estima and Maris Piper in Norfolk. The treatments consisted of all combinations of two seed storage pull-down regimes (good, bad); two seed storage temperatures (low 3 °C, high, 5 °C); two fungicide regimes (none, fungicide). An additional control of the same seed stocks stored under commercial conditions was also planted.

Experiments were planted by hand on 24 May 2012. Each plot consisted of two 183 cm wide beds and each bed was planted with two rows of 25 plants at a within-row spacing of 20 cm. Herbicide and fertilizer applications were as for the surrounding

commercial crop. Emergence counts were made on 13, 20 and 28 June 2012 and an assessment of stem disease was made on 28 June 2012. A harvest of guarded plants was dug from a 1.6 m length of each of the two central rows and the number of main and secondary stems counted. Tubers were graded in 10 mm size fractions and the fresh weight and number in each size grade recorded prior to dispatching samples to Fera for disease testing. Both the Estima and Maris Piper experiments were harvested on 9 August 2012.

3.5. Pathogen testing by Quantitative PCR

Prior to Storage (2011)

Seven samples, each containing approximately 100 tubers, were received from SBCSR. Four samples, originating from Norfolk, were received on 6 September 2011 (two samples of Estima, and two samples of Maris Piper). A further three samples, originating from Perthshire, were received on 24 November 2011 (a sample of Estima and two samples of Maris Piper). For Estima, one sample had been inoculated with *P. exigua* and the other not inoculated and for each sample of Maris Piper, one sample had been inoculated with *F. coeruleum* and the other not inoculated.

Samples were processed for total DNA extractions using a modified method previously described in a Potato Council report (R413 Final Report). In summary, strips of peel were removed from each tuber. The combined peel strips for each subsample (approximately 10 to 12 g) were placed into a sample grinding bag (Bioreba Ltd) containing 7.5 mL PB7 buffer (2ml Tetrasodium pyrophosphate in 100mL Phosphate Buffer pH7). Ten subsamples were processed for each tuber sample.

The contents of each sample bag was ground and homogenised using a large sample grinder (Homex Ltd). The supernatant from each bag was transferred to a labelled 5 mL sample tube, centrifuged at 1000 rpm for 10 minutes and supernatant transferred to a clean, labelled 5mL tube. A final 6200 rpm for 15 minutes centrifugation step was included to pellet any sediment. DNA was extracted from each pellet using the Wizard® Magnetic DNA Purification System for Food (Promega, FF3750) in conjunction with a Kingfisher ML magnetic particle processor (Thermo Electron Corporation). Samples were eluted into 200 uL TE buffer and stored at –30°C until required.

All DNA extractions were carried out within a week of sample receipt at Fera, except samples received in November 2011 in which repeat extracts were performed on 9 February 2012. Extracts were tested by QPCR analyses for *F. coeruleum, P. exigua,* and *H. solani*. In addition, a QPCR assay to detect plant DNA (cytochrome oxidase gene) was carried out on all subsamples as a positive internal control. The purpose of the internal control was to test whether nucleic acid extracts had been successful.
For the purposes of the report, the results are given as number of positive subsamples (for each target) out of 10 subsamples tested.

Post harvest 2012

Store treatment samples of cv Estima and cv Maris Piper from both poor and good pull-down at each of the storage temperatures (3°C or 5°C) were planted in the CUF field trial. Both cv Estima and cv Maris Piper from a more limited set of storage treatments were planted on the Norfolk commercial field site: poor storage at 5°C; or good storage at 3°C.

Four replicate samples, each of a minimum 100 tubers, of harvested tuber samples from each of these plantings were delivered by CUF to Fera on 25/9/2012. Tubers were extracted for DNA levels within 1 week of receipt as previously described.

4. RESULTS

Stocks of Maris Piper and Estima seed were sourced from two geographically widely separated areas of GB, Norfolk and Perthshire. For various reasons, including the very diverse weather conditions at these locations, the stocks were harvested on different dates ie. late August/early September in Norfolk and some eight weeks later in Perthshire.

4.1. Intake and post-storage disease assessments

The visual assessments of disease and defects determined at intake for each stock are shown in tables 1A and 1B for Norfolk and Perthshire stocks, respectively. No sprouting was observed in any stock. Silver scurf was found in all four stocks and at a very high incidence (71.4%) in Estima from Perthshire. Black dot, caused by *Colletotrichum coccodes* and whose development can be managed to some extent by storage conditions and chemical control, was present in three stocks at experimentally useful incidence and was included in post storage assessment. No fungal rot was found at a sufficient incidence to be of practical value in this trial, artificial inoculation of dry rot and gangrene was carried out to increase the incidence of these diseases. No soft rot infection was found in any assessed tuber, although it had been observed at very low incidence during bulk handling in the Norfolk Estima stock. Other diseases and defects were found at different incidences in the different stocks (Tables 1A and 1B) but none that precluded the use of these stocks in the trial and these diseases were not assessed following storage.

Table 1A. Intake disease and defect assessment, Estima and Maris Piper, Norfolk seed

Disease or defect	**Estima** Mean % incidence	**Maris Piper** Mean % incidence
Silver scurf	42.0	18.0
Black dot	63.0	0.0
Common scab	19.0	19.5
Powdery scab	8.0	1.0
Scuffing	53.0	51.5
Lenticel discolouration (0,1)	85.5	8.5

Table 1B. Intake disease and defect assessment Estima and Maris Piper Perthshire

Disease or defect	Estima Mean % incidence	Maris Piper Mean % incidence
Silver scurf	71.4	4.4
Black dot	4.0	3.5
Black scurf	0.0	0.1
Common scab	0.4	10.4
Dry rot	0.1	0.0
Scuffing	4.6	0.6
Internal browning (0,1,2)	0.0	0.2

Tables 2A-2D inclusive show the results for the post-storage assessment of the incidence of the three target diseases and for black dot. Post-storage silver scurf was abundant in all stocks and all storage conditions. There was generally a clear difference between the different pull-down regimes with a lower incidence found with a good compared to a poor regime. The application of fungicide had an additional effect on reducing the incidence of silver scurf in most storage treatments. However, unexpectedly the incidence of silver scurf on fungicide treated Perthshire Estima (Table 2C) was consistently greater than those in nil chemical treatments, and a similar result was found for the severity of silver scurf.

Black dot was abundant in all stocks except Maris Piper from Norfolk. The application of fungicide had a slight effect on reducing the incidence under all storage treatments. There was generally a lower incidence of black dot at the lower temperature 3°C compared with 5°C but no effect of pull-down regime.

Despite inoculation both gangrene and dry rot were found at very low incidence, with no obvious pattern or effect of store treatment. Inoculated tubers separately held in very permissive conditions for disease development did develop the typical disease symptoms of each fungal rot. It is possible that inoculum levels were too low to allow infection in the store treatment conditions imposed in this trial.

Table 2A. Post-storage disease assessment, Estima, Norfolk stock

Store Temperature °C	Pathogen status	Storage regime	Seed chemical	Silver scurf % incidence		Dry rot % incidence		Gangrene % incidence		Black dot % incidence	
					sd of reps		sd of reps		sd of reps		reps sd of
3	Inoculated	Optimal	Fungicide	55	13.2	0	0	0	0	39	8.9
			Nil chemical	60	10.3	0	0	0	0	40	22.4
		Poor	Fungicide	51	8.3	0	0	0	0	42	6.9
			Nil chemical	72	5.7	0	0	0	0	45	6.0
	Not inoculated	Optimal	Fungicide	66	13.7	0	0	0	0	38	13.3
			Nil chemical	74	5.2	0	0	0	0	42	20.3
		Poor	Fungicide	52	10.3	0	0	0	0	38	19.2
			Nil chemical	67	11.5	0	0	0	0	65	16.5
5	Inoculated	Optimal	Fungicide	51	11.5	0	0	0	0	28	8.6
			Nil chemical	72	11.8	0	0	1	2	38	14.8
		Poor	Fungicide	67	8.3	0	0	0	0	34	12.4
			Nil chemical	83	11.0	0	0	1	2	38	6.9
	Not inoculated	Optimal	Fungicide	65	11.0	0	0	0	0	32	10.8
			Nil chemical	64	13.9	0	0	0	0	38	10.1
		Poor	Fungicide	61	11.0	0	0	0	0	31	14.4
			Nil chemical	77	6.0	0	0	1	2	49	6.8

Table 2B. Post-storage disease assessment, Maris Piper, Norfolk stock.

Store Temperature °C	Pathogen status	Storage regime	Seed chemical	Silver scurf % incidence		Dry rot % incidence		Gangrene % incidence		Black dot % incidence	
					sd of reps		sd of reps		sd of reps		sd of reps
3	Inoculated	Optimal	Fungicide	30.0	12.4	0.0	0.0	0.0	0.0	40.0	14.2
			Nil chemical	41.0	6.0	1.0	2.0	0.0	0.0	65.0	12.8
		Poor	Fungicide	16.0	10.3	0.0	0.0	0.0	0.0	47.0	10.0
			Nil chemical	37.0	13.2	0.0	0.0	0.0	0.0	72.0	12.7
	Not inoculated	Optimal	Fungicide	26.0	10.1	0.0	0.0	0.0	0.0	43.0	8.3
			Nil chemical	38.0	5.2	0.0	0.0	0.0	0.0	52.0	24.2
		Poor	Fungicide	32.0	12.0	0.0	0.0	0.0	0.0	37.3	2.3
			Nil chemical	39.0	7.6	0.0	0.0	0.0	0.0	61.0	15.5
5	Inoculated	Optimal	Fungicide	23.0	6.0	0.0	0.0	0.0	0.0	33.0	6.0
			Nil chemical	51.0	3.8	0.0	0.0	0.0	0.0	56.0	14.2
		Poor	Fungicide	20.0	7.3	0.0	0.0	1.0	2.0	53.0	10.5
			Nil chemical	54.0	16.8	0.0	0.0	1.0	2.0	85.0	8.9
	Not inoculated	Optimal	Fungicide	25.0	8.3	0.0	0.0	0.0	0.0	38.0	4.0
			Nil chemical	47.0	22.7	0.0	0.0	0.0	0.0	60.0	21.9
		Poor	Fungicide	32.0	3.3	0.0	0.0	0.0	0.0	45.0	8.9
			Nil chemical	64.0	29.0	0.0	0.0	0.0	0.0	71.0	20.0

Table 2C. Post-storage disease assessment, Estima, Perthshire stock.

Store Temperature °C	Pathogen status	Storage regime	Seed chemical	Silver scurf % incidence		Dry rot % incidence		Gangrene % incidence		Black dot % incidence	
					sd of reps		sd of reps		sd of reps		sd of reps
3	Inoculated	Optimal	Fungicide	84	13.5	1.0	2.0	0.0	0.0	15.0	3.8
			Nil chemical	63	3.8	1.0	2.0	1.0	2.0	27.0	11.5
		Poor	Fungicide	86	4.0	0.0	0.0	0.0	0.0	16.0	11.8
			Nil chemical	69	11.9	0.0	0.0	0.0	0.0	28.0	8.6
	Not inoculated	Optimal	Fungicide	90	7.7	2.0	2.3	0.0	0.0	22.0	12.0
			Nil chemical	67	8.3	0.0	0.0	0.0	0.0	32.0	10.8
		Poor	Fungicide	91	3.8	0.0	0.0	0.0	0.0	21.0	2.0
			Nil chemical	71	8.3	0.0	0.0	0.0	0.0	36.0	10.8
5	Inoculated	Optimal	Fungicide	92	6.5	0.0	0.0	0.0	0.0	18.0	9.5
			Nil chemical	67	12.4	1.0	2.0	0.0	0.0	30.0	6.9
		Poor	Fungicide	92	5.7	0.0	0.0	0.0	0.0	28.0	21.4
			Nil chemical	71	12.4	0.0	0.0	0.0	0.0	39.0	15.5
	Not inoculated	Optimal	Fungicide	86	4.0	0.0	0.0	1.0	2.0	26.0	11.6
			Nil chemical	74	15.1	0.0	0.0	0.0	0.0	39.0	13.2
		Poor	Fungicide	97	2.0	0.0	0.0	0.0	0.0	22.0	11.6
			Nil chemical	76	12.7	1.0	2.0	0.0	0.0	27.0	21.3

Table 2D. Post-storage disease assessment, Maris Piper, Perthshire stock

Store Temperature °C	Pathogen status	Storage regime	Seed chemical	Silver scurf % incidence		Dry rot % incidence		Gangrene % incidence		Black dot % incidence	
					sd of reps		sd of reps		sd of reps		sd of reps
3	Inoculated	Optimal	Fungicide	30.0	12.4	0.0	0.0	0.0	0.0	40.0	14.2
			Nil chemical	41.0	6.0	1.0	2.0	0.0	0.0	65.0	12.8
		Poor	Fungicide	16.0	10.3	0.0	0.0	0.0	0.0	47.0	10.0
			Nil chemical	37.0	13.2	0.0	0.0	0.0	0.0	72.0	12.7
	Not inoculated	Optimal	Fungicide	26.0	10.1	0.0	0.0	0.0	0.0	43.0	8.3
			Nil chemical	38.0	5.2	0.0	0.0	0.0	0.0	52.0	24.2
		Poor	Fungicide	32.0	12.0	0.0	0.0	0.0	0.0	37.3	2.3
			Nil chemical	39.0	7.6	0.0	0.0	0.0	0.0	61.0	15.5
5	Inoculated	Optimal	Fungicide	23.0	6.0	0.0	0.0	0.0	0.0	33.0	6.0
			Nil chemical	51.0	3.8	0.0	0.0	0.0	0.0	56.0	14.2
		Poor	Fungicide	20.0	7.3	0.0	0.0	1.0	2.0	53.0	10.5
			Nil chemical	54.0	16.8	0.0	0.0	1.0	2.0	85.0	8.9
	Not inoculated	Optimal	Fungicide	25.0	8.3	0.0	0.0	0.0	0.0	38.0	4.0
			Nil chemical	47.0	22.7	0.0	0.0	0.0	0.0	60.0	21.9
		Poor	Fungicide	32.0	3.3	0.0	0.0	0.0	0.0	45.0	8.9
			Nil chemical	64.0	29.0	0.0	0.0	0.0	0.0	71.0	20.0

4.2. QPCR testing of samples for post-storage diseases

The results of the QPCR testing are shown in Table 3. *Fusarium coeruleum* was detected in one out of 10 subsamples and 6 out of 10 subsamples in the Maris Piper samples from Norfolk and Perthshire respectively that had been inoculated with *F. coeruleum*. No *F. coeruleum* was detected in the non-inoculated control samples. *F. coeruleum* was detected in one of 10 subsamples in the Estima from Norfolk that was inoculated with *Phoma exigua* but not in any subsamples of the not inoculated Estima control crop. *P. exigua* was detected in all subsamples tested. Similarly, *Helminthsporium solani* was detected in all subsamples tested except for inoculated Maris Piper crop from Norfolk, where 8 out of 10 subsamples tested positive.

These results indicate that in all the samples stored at SBCSR, inoculum of *P. exigua* and *H. solani* was common on the periderm of tubers. *F. coeruleum* was only common at appreciable levels on tubers of Maris Piper (Perthshire) that had been artificially inoculated with F. *coeruleum*.

Table 3. Number of tuber subsamples (out of 10) testing positive by QPCR for *F. coeruleum*, *P. exigua* and *H. solani*, and potato cytochrome oxidase as a positive internal control.

			Number of positive sub-samples/10			
Cultivar	**Source**	**Treatment**	*F. coeruleum*	*P. exigua*	*H. solani*	internal positive control
Estima	Norfolk	not inoculated	0	10	10	10
		Inoculated *P. exigua*	1	10	10	10
M Piper		Inoculated *F. coeruleum*	1	10	8	10
		not inoculated	0	10	10	10
Estima	Perthshire	not inoculated	0	10	10	10
		Inoculated *P. exigua*	N/T	N/T	N/T	N/T
M Piper		not inoculated	1	10	10	10
		Inoculated *F. coeruleum*	6[a]	10	10	10

N/T Not tested, sample not available.
[a] Three of the six positive subsamples were low positives

4.3. Intake and post-storage defect assessments

Post-storage assessment of sprouting

Sprouting was assessed post-storage and the results for the length of longest sprout and the number of sprouts over 3mm for all stocks and treatments are shown in Tables 4A-D. For all the stocks there was more sprouting than would have been normally expected given the storage temperatures and quality of seed tubers.

There was a difference between varieties with sprouts longer on Maris Piper than Estima and stocks from Norfolk sprouted more than those from Perthshire.

There was a very clear effect of storage temperature with sprouting significantly greater at 5°C than at 3°C for both varieties (Norfolk stock, $P<0.001$). Perhaps surprisingly, there was an effect of store treatment with sprouting in Estima less under a “poor” regime than the “optimal” regime at both temperatures (Norfolk stock, 3°C; $P<0.001$, 5°C; $P<0.001$). This effect was also observed for Maris Piper at 3°C ($P<0.024$). The application of fungicide affected sprouting of Estima at 5°C; (Norfolk stock, $P<0.001$) and also Norfolk stock Maris Piper at both 3°C ($P<0.001$) and 5°C ($P<0.001$).

Table 4A. Post-storage sprouting assessment, Estima, Norfolk.

Store temperature °C	Pathogen level	Storage regime	Seed chemical	Length longest sprout (mm)		Number of sprouts over 3mm	
					sd		sd
3	Inoculated	Optimal	Fungicide	5.2	2.5	1.1	0.5
			Nil chemical	4.9	0.9	1.1	0.6
		Poor	Fungicide	2.8	0.3	0.4	0.1
			Nil chemical	3.5	0.6	0.5	0.1
	Not inoculated	Optimal	Fungicide	4.8	2.7	0.9	0.5
			Nil chemical	3.6	1.2	0.6	0.3
		Poor	Fungicide	2.9	0.6	0.4	0.1
			Nil chemical	3.3	0.9	0.5	0.3
5	Inoculated Inoculated	Optimal	Fungicide	23.9	4.9	2.6	0.4
			Nil chemical	34.1	3.6	3.4	1.1
	Inoculated Inoculated	Poor	Fungicide	19.4	4.0	2.8	0.6
			Nil chemical	31.4	8.5	2.8	0.3
	Not inoculated Not inoculated	Optimal	Fungicide	21.8	4.1	3.2	0.9
			Nil chemical	30.0	7.0	2.8	0.4
	Not inoculated Not inoculated	Poor	Fungicide	18.7	2.6	2.7	0.0
			Nil chemical	26.2	5.7	2.9	0.2

Table 4B. Post-storage sprouting assessment, Maris Piper, Norfolk.

Store Temperature °C	Pathogen level	Storage regime	Seed chemical	Length longest sprout (mm)		Number of sprouts over 3mm	
					sd		sd
3	Inoculated	Optimal	Fungicide	11.2	4.5	3.4	0.7
			Nil chemical	12.8	4.2	3.8	0.6
		Poor	Fungicide	5.5	2.2	1.3	0.5
			Nil chemical	4.8	2.0	1.4	0.7
	Not inoculated	Optimal	Fungicide	10.3	5.3	3.0	1.1
			Nil chemical	13.5	3.0	4.2	0.9
		Poor	Fungicide	2.8	0.9	0.6	0.5
			Nil chemical	5.8	3.3	1.6	1.1
5	Inoculated	Optimal	Fungicide	31.3	4.4	5.2	0.1
			Nil chemical	42.0	7.1	5.9	0.3
		Poor	Fungicide	24.6	5.7	4.9	0.6
			Nil chemical	35.4	6.4	5.5	0.5
	Not inoculated	Optimal	Fungicide	31.5	4.4	5.2	0.2
			Nil chemical	41.9	2.4	5.2	0.4
		Poor	Fungicide	26.1	7.6	5.2	0.4
			Nil chemical	35.3	8.0	5.4	0.1

Table 4C. Post-storage sprouting assessment, Estima, Perthshire.

Store Temperature °C	Pathogen level	Storage regime	Seed chemical	Length longest sprout (mm)		Number of sprouts over 3mm	
					sd		sd
3	Inoculated	Optimal	Fungicide	1.0	0.4	0.1	0.1
			Nil chemical	1.1	0.3	0.0	0.1
		Poor	Fungicide	1.9	0.2	0.3	0.1
			Nil chemical	2.3	0.7	0.4	0.2
	Not inoculated	Optimal	Fungicide	0.9	0.4	0.0	0.0
			Nil chemical	1.1	0.3	0.2	0.4
		Poor	Fungicide	2.7	0.2	0.4	0.2
			Nil chemical	2.7	0.9	0.7	0.5
5	Inoculated	Optimal	Fungicide	7.1	1.3	2.2	0.8
			Nil chemical	9.0	1.5	2.5	0.5
		Poor	Fungicide	7.6	2.0	1.6	0.4
			Nil chemical	9.6	2.5	2.0	0.4
	Not inoculated	Optimal	Fungicide	7.2	1.2	2.0	0.4
			Nil chemical	10.7	1.4	2.7	0.8
		Poor	Fungicide	7.1	0.8	1.6	0.4
			Nil chemical	11.1	2.0	2.3	0.5

Table 4D. Post-storage sprouting assessment, Maris Piper, Perthshire.

Store Temperature °C	Pathogen level	Storage regime	Seed chemical	Length longest sprout (mm)		Number of sprouts over 3mm	
					sd		sd
3	Inoculated	Optimal	Fungicide	4.2	1.6	1.0	0.5
			Nil chemical	3.8	0.7	1.3	0.6
		Poor	Fungicide	13.1	1.5	2.5	0.3
			Nil chemical	14.2	4.0	3.2	0.8
	Not inoculated	Optimal	Fungicide	3.2	0.9	1.0	0.5
			Nil chemical	3.7	1.1	1.2	0.4
		Poor	Fungicide	11.4	5.0	2.4	0.6
			Nil chemical	11.1	3.6	2.7	0.8
5	Inoculated	Optimal	Fungicide	28.5	7.3	4.9	0.7
			Nil chemical	32.9	8.3	4.8	0.3
		Poor	Fungicide	28.8	6.4	5.5	0.6
			Nil chemical	39.2	5.3	4.7	0.9
	Not inoculated	Optimal	Fungicide	25.1	2.1	5.3	0.7
			Nil chemical	35.1	7.1	5.0	0.7
		Poor	Fungicide	32.5	4.3	4.7	0.4
			Nil chemical	35.8	5.4	4.8	0.6

The average weight loss of Estima (Norfolk) over the storage period of 31 weeks storage was 5.25% with no significant difference at 3°C compared to 5°C. However, there was a significant difference ($P<0.016$) in the weight loss for Maris Piper (Norfolk) over the 29 week storage period, at 3°C (average loss 4.9%) and at 5 °C (average loss 5.45%).

Compression damage was evident in all stocks (Table 5). Stocks from Norfolk were more affected than those from Perthshire, Norfolk stocks were stored for 2 months longer than those from Perthshire. Store temperature was also a factor with damage more evident at 5°C than at 3°C. The incidence of compression damage was reduced in tubers held under poor compared to good storage conditions (Estima $P < 0.023$, Maris Piper $P < 0.01$).

Table 5. Incidence of compression damage during storage for Norfolk seed tuber stocks

Estima				**Compression**	
Temperature °C	Storage regime	Inoculum level	Seed chemical	% incidence	sd of reps
3	Optimal	Inoculated	Fungicide	42	25.8
			Nil chemical	42	13.3
		Not inoculated	Fungicide	40	15.7
			Nil chemical	39	26.6
	Poor	Inoculated	Fungicide	33	20.5
			Nil chemical	24	16.3
		Not inoculated	Fungicide	25	8.2
			Nil chemical	19	17.7
5	Optimal	Inoculated	Fungicide	49	13.6
			Nil chemical	58	17.7
		Not inoculated	Fungicide	40	21.4
			Nil chemical	64	8.6
	Poor	Inoculated	Fungicide	33	8.9
			Nil chemical	46	9.5
		Not inoculated	Fungicide	38	15.1
			Nil chemical	38	10.6
Maris Piper					
3	Optimal	Inoculated	Fungicide	42	9.5
			Nil chemical	27	10.5
		Not inoculated	Fungicide	45	25.6
			Nil chemical	40	21.2
	Poor	Inoculated	Fungicide	19	18.3
			Nil chemical	19	17.4
		Not inoculated	Fungicide	20	25.5
			Nil chemical	23	23.6
5	Optimal	Inoculated	Fungicide	72	11.8
			Nil chemical	63	7.6
		Not inoculated	Fungicide	64	8.6
			Nil chemical	67	11.0
	Poor	Inoculated	Fungicide	34	10.6
			Nil chemical	39	10.0
		Not inoculated	Fungicide	32	14.2
			Nil chemical	37	25.6

Defects including internal rust, scuffing, mechanical damage, internal browning, skin damage and vascular discolouration were observed at different incidences in different stocks without obvious effect of store treatment.

4.4. Field Trials

Significant sprouting occurred in all treatments of both varieties held in SBCSR stores whilst seed from the commercial store was largely unsprouted. Following low temperature treatments in experimental stores, longest sprouts on seed were *c*. 3 – 14 mm long whilst following higher temperature storage sprouts up to *c*. 40 mm were recorded.

Cambridge University Farm trials

In Estima, the date of 50 % plant emergence was earlier following storage at high temperature than low temperature, earlier where no fungicide was applied than for treated seed and slightly earlier where a good pull-down regime was used than a poor regime but differences were on average all < 2 days (Table 6). There was no effect of inoculation on rate of emergence and on average date of 50 % emergence was similar for commercially stored and experimentally stored seed. Most treatments achieved complete emergence but emergence was slightly less complete following fungicide application (99.7 %) than other combinations of pull-down and temperature (>99.9 %).

In Maris Piper, the date of 50 % plant emergence was *c*. 2 days earlier following storage at high temperature than low temperature, *c*. 2 days earlier where no fungicide was applied than for treated seed and < 1 day earlier where not inoculated than where inoculated (Table 7). There was no effect of pull-down regime on rate of emergence and on average date of 50 % emergence was similar for commercially stored and experimentally stored seed. All treatments achieved complete or near complete emergence.

Consistent with effects on emergence, in Estima early ground cover was most advanced following storage at high temperature and with no fungicide treatment and this effect remained apparent until canopy closure (Figure 1*a*). Similar effects of temperature and fungicide on early ground cover were also found in Maris Piper (Figure 1*b*).

Symptoms of blackleg were found in 0.2 % of Estima plants overall on 27 June but there was no evidence for any effect of treatments on the incidence of blackleg and

other stem diseases were not evident. No blackleg or other stem disease was evident in Maris Piper.

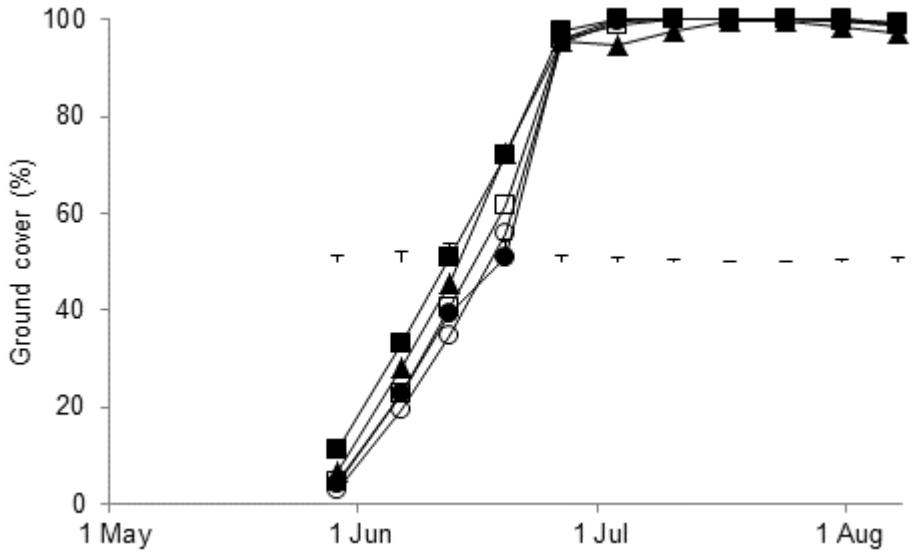
The total number of stems in Estima was on average greater from commercially stored seed than seed from the experimental stores and there were fewer stems from seed stored at low temperature than high temperature (Table 7). There were also fewer stems from fungicide treated than untreated seed but no effect of pull-down regime or inoculation on the number of stems (Table 7). Effects of treatments on the number of tubers in Estima reflected the differences in numbers of stems but there was no effect of treatments on yield (Table 7). Tubers with soft rots were present at harvest but there was no evidence that the incidence differed between treatments (overall incidence < 1 000 tubers / ha).

As for Estima, the total number of stems in Maris Piper was on average greater from commercially stored seed than seed from the experimental stores and lower from fungicide treated than untreated seed but there was no effect of pull-down regime or storage temperature on the number of stems (Table 7). There was a reduction in stem populations for inoculated compared to not inoculated seed but the effect was small and effects of treatments on the number of tubers generally reflected the differences in numbers of stems (Table 7). Yield was lower for fungicide treated Maris Piper seed than untreated seed with a particularly marked effect following the good pull-down regime whilst on average yields were also lower where seed was inoculated than with no inoculation (Table 7). There were few tubers with soft rots present at harvest in any treatment (overall incidence < 1,000 tubers / ha).

Table 6. Effect of seed storage treatments on emergence (days from planting to 50 %) in Cambridge University Farm trials.

			Estima		Maris Piper	
Pull-down	Temperature	Fungicide	Not inoculated	Inoculated	Not inoculated	Inoculated
Commercial store			40.9		41.2	
Good	Low	None	40.1	39.9	40.2	40.6
		Treated	41.3	40.8	42.2	43.0
	High	None	37.7	37.2	37.9	39.4
		Treated	39.4	40.9	40.8	41.9
Poor	Low	None	40.0	40.5	41.4	41.2
		Treated	41.2	41.7	42.6	43.4
	High	None	40.4	37.5	38.3	39.0
		Treated	40.6	40.7	40.9	41.0
S.E. (48 DF)			0.635		0.379	

(a)



(b)

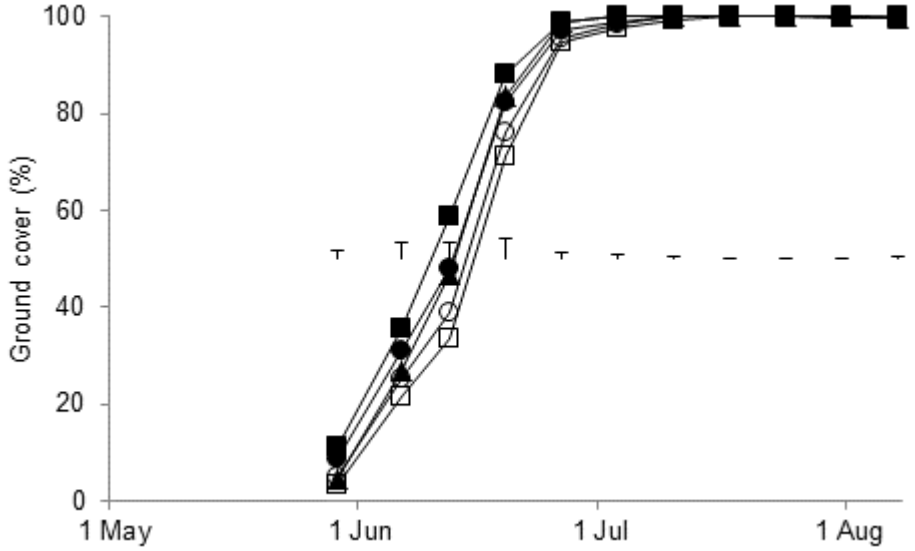


Figure 1a & b. Effect of seed storage treatments on ground cover in Cambridge University Farm trials: *(a)* Estima and *(b)* Maris Piper. Low temperature and no fungicide ●; low temperature and fungicide treated ■; high temperature and no fungicide ○; high temperature and fungicide treated □; commercially stored ▲. Good pull-down and non-inoculated treatments only shown. Bars indicate S.E. (48 DF)

Table 7. Effect of seed storage treatments on numbers of stems, tubers and yield in Cambridge University Farm trials

			Estima		Maris Piper	
Pull-down	Temperature	Fungicide	Not inoculated	Inoculated	Not inoculated	Inoculated
Stems (000/ha)						
Commercial store			150.4		212.6	
Good	Low	None	134.7	126.4	177.7	184.5
		Treated	113.5	126.4	161.3	141.5
	High	None	149.7	143.5	177.7	175.7
		Treated	121.0	122.3	155.8	151.1
Poor	Low	None	128.5	131.2	193.4	177.0
		Treated	117.6	114.1	161.3	151.1
	High	None	151.1	162.7	198.2	186.6
		Treated	134.0	133.3	164.7	155.2
S.E. (48 DF)			7.81		8.12	
Tubers (000/ha)						
Commercial store			548		710	
Good	Low	None	501	504	656	658
		Treated	455	472	633	557
	High	None	578	533	612	656
		Treated	502	492	569	598
Poor	Low	None	478	517	693	634
		Treated	501	446	630	599
	High	None	581	583	648	656
		Treated	496	494	638	603
S.E. (48 DF)			22.5		26.3	
Yield (t/ha)						
Commercial store			62.8		70.6	
Good	Low	None	64.6	67.2	81.6	74.6
		Treated	64.7	66.3	67.5	71.6
	High	None	67.4	64.0	82.7	75.3
		Treated	71.6	66.5	70.3	73.1
Poor	Low	None	62.7	67.1	75.6	70.2
		Treated	67.6	64.5	72.1	72.5
	High	None	68.4	65.5	78.3	75.8
		Treated	63.7	61.5	77.6	68.9
S.E. (48 DF)			2.60		2.78	

Commercial field trials

In Estima, emergence of plants on 13 June was on average less advanced for the commercially stored seed than seed from the experimental store (19.0 % and 51.7 % respectively) and less advanced for seed held at a lower temperature than the higher temperature (45.6 % and 57.8 % ± 1.99 respectively). Emergence was on average less advanced for fungicide treated seed than untreated seed (33.9 % and 69.5 % ± 1.99 respectively) but there was little effect of ventilation regime on emergence. By 20 June emergence was nearly complete in most treatments but remained slightly lower for fungicide treated than untreated seed (95.3 % and 99.0 % respectively) and by 28 June near complete emergence (> 99 %) was reached in all treatments.

In Maris Piper, effects of treatments on emergence were generally similar to those found in Estima. On 13 June commercially stored seed had not begun to emerge but emergence in seed from the experimental store was on average less advanced for fungicide treated seed than untreated seed (36.5 % and 60.8 % ± 1.99 respectively) and less advanced following low than higher temperature storage (28.5 % and 68.8 % ± 2.78 respectively) and with low temperature storage emergence was less advanced following the poor pull-down regime than the good regime (18.9 % and 38.1 % ± 3.94 respectively) although this effect was not apparent with higher temperature storage. Small effects of storage temperature and fungicide were still apparent on 20 June when emergence was nearly complete in most treatments and by 27 June near complete emergence (> 99 %) was reached in all treatments. No blackleg or other stem disease was evident in any treatment of either variety on 28 June.

The total number of stems in Estima was greater for commercially stored seed than seed stored in experimental stores and lower for fungicide treated seed than untreated seed but there was no effect of other treatments (Table 8). Despite no effect of storage temperature on the number of stems, the number of tubers was reduced by storage at higher temperature compared with storage at low temperature and there was no significant effect of other treatments on the number of tubers (Table 8). Yields were not affected by any storage treatments (Table 8). n Maris Piper, storage treatments had no effect on the number of stems, number of tubers or yield (Table 8).

Larger stem and tuber numbers were obtained from seed stored in the commercial store than in experimental stores. However, there was no effect on final yield.

Table 8. Effect of seed storage treatments on numbers of stems, tubers and yield in commercial field trials

Pull-down	Temperature	Fungicide	Estima	Maris Piper
Stems (000/ha)				
Commercial store			200.9	197.4
Good	Low	None	188.0	215.4
		Treated	169.2	212.8
	High	None	172.7	228.2
		Treated	171.8	230.8
Poor	Low	None	182.9	182.1
		Treated	159.0	228.2
	High	None	180.4	213.7
		Treated	160.7	224.8
S.E. (48 DF)			8.69	19.26
Tubers (000/ha)				
Commercial store			519	493
Good	Low	None	512	492
		Treated	474	490
	High	None	448	585
		Treated	462	543
Poor	Low	None	506	450
		Treated	505	577
	High	None	467	510
		Treated	465	525
S.E. (48 DF)			18.6	40.9
Yield (t/ha)				
Commercial store			34.9	27.0
Good	Low	None	35.5	26.5
		Treated	35.7	27.9
	High	None	34.6	28.6
		Treated	33.0	27.7
Poor	Low	None	34.8	27.7
		Treated	35.9	29.7
	High	None	37.3	28.7
		Treated	33.6	25.8
S.E. (48 DF)			1.31	1.16

4.5. Post-harvest pathogen testing by Quantitative PCR

The results from the pathogen levels, as tested by QPCR, on field grown tubers are presented in Tables 9 (incidence levels) and 10 (mean $\log_{10}$ pg DNA/mL peel). The DNA of *P. exigua, C. coccodes* and *H. solani* were found at very high frequency. However, there were no differences in incidence in any of the four pathogens tested between treatments (*P*=0.275). There were no differences in the amount of DNA detected in each of the four pathogens (Table 10) with one exception. The amount of DNA detected for *P. exigua* was very marginally affected by storage treatment (Figure 2, *P*=0.051). The amount of DNA detected in tubers originally stored under the poor storage treatment at 3°C was increased when stored at 5°C under the same ventilation conditions (*P*=0.022). However, the optimal storage regime (optimum ventilation and stored at 3°C) produced tubers with higher levels of *P. exigua* DNA than that of tubers stored under the poor store treatment at 3°C (*P*=0.018). It is not clear whether differences in pathogen DNA levels was a result of conditions raised after storage. The effect of these higher levels of DNA in relation to disease development is also unclear as no significant differences in gangrene were reported.

Table 9. Number of tuber subsamples (out of 40) testing positive by QPCR for *Fusarium coeruleum*, *Phoma exigua, Colletotrichum coccodes* and *Helminthosporium solani*. In addition, a QPCR assay to detect plant DNA carried out on all subsamples as a positive internal control was positive in all samples.

			Number of positive sub-samples/40			
Cultivar	**Field origin**	**Ventilation/ temperature**	*F. coeruleum*	P. exigua	*H. solani*	C. coccodes
Estima	CUF	Poor/ high	2	40	37	40
		Optimum/ low	0	40	39	40
		Poor/ low	0	40	37	40
		Optimum/ high	0	40	38	40
M Piper		Poor/ high	1	40	34	37
		Optimum/ low	0	40	33	30
		Poor/ low	1	40	36	30
		Optimum/ high	1	40	35	30
Estima	Commercial	Poor/ high	1	40	22	24
		Optimum/ low	1	40	28	27
M Piper		Poor/ high	0	40	37	13
		Optimum/ low	0	40	38	6

Table 10. Results from the real-time PCR analysis of tuber extracts (mean log_{10} pg DNA/mL peel) for *Colletotrichum coccodes*, *Fusarium coeruleum*, *Phoma exigua*, *Helminthosporium solani* and the potato gene Cytochrome oxidase as positive control.

		C. coccodes		*F. coeruleum*		*P. exigua*		*H. solani*	
Field Source	Treatment	Estima	Maris Piper	Estima	Maris Piper	Estima	Maris Piper	Estima	Maris Piper
CUF	Optimum/ high	3.28	3.70	-0.68	-0.33	2.85	2.88	0.87	1.30
	Optimum/ low	3.40	3.70	-0.68	-0.31	2.90	3.09	0.91	1.35
	Poor/ high	3.25	3.59	-0.63	-0.32	2.93	2.87	0.86	1.44
	Poor/ low	3.22	3.60	-0.68	-0.27	2.75	2.87	0.64	1.24
Norfolk	Optimum/ high	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T
	Optimum/ low	2.29	1.83	0.13	0.10	3.09	3.52	0.46	1.55
	Poor/ high	2.32	1.92	0.12	0.10	3.24	3.51	0.19	1.11
	Poor/ low	N/T	N/T	N/T	N/T	N/T	N/T	N/T	N/T

N/T. sample not tested for reasons of budget.

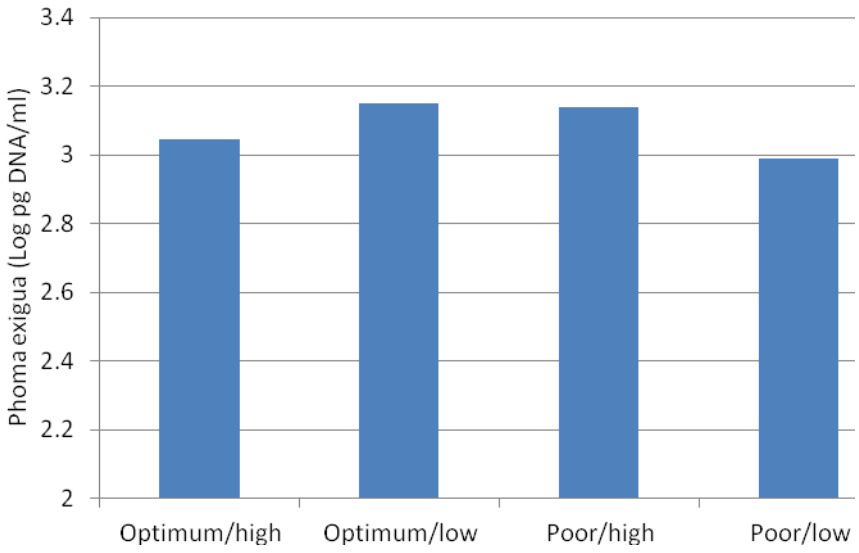


Figure 2. Effect of storage treatment on levels of *Phoma exigua* inoculum (log_{10} pg DNA/mL peel) on tubers subsequently grown at two field sites (CUF and Norfolk commercial field). Values are means of two varieties (Estima and Maris Piper). LSD=0.14 (33 df).

5. DISCUSSION

Seed tubers of both varieties from both sources were of good quality, with bacterial rots at very low incidence. The very different harvest times between Norfolk and Perthshire crops provided a geographical and temporal component to the trial. The stores at SBCSR in which the trial was carried out were new and functioned well during the first year in which they had been used.

The source and variety of the tubers and the storage treatments all had an effect on the levels of different diseases found before and after storage with a number of significant interactions. Seed from Perthshire had higher silver scurf than Norfolk seed; Estima more silver scurf than Maris Piper, and optimal storage conditions reduced silver scurf compared to poor storage conditions.

The incidence and severity of silver scurf on fungicide-treated Perthshire Estima was consistently greater than those in nil chemical treatments (Table 2C). Results for silver scurf on the three other crops are as expected with fungicide exerting control of the disease. The four replicated nets of each treatment were assessed by two different people, 2 nets each, and their results agree. The tubers assessed for silver scurf are also assessed for other diseases including black dot and Table 2C shows that fungicide treatment slightly reduces black dot incidence. In addition the slight reduction in sprout length with this chemical treatment was observed with seen in these tubers (Table 4C). This suggests that there was no confusion over the treatments for example switched labelling. In addition labelling for all inoculated and for all non-inoculated tubers was made separately which would imply labels were similarly switched on two separate occasions.

A possible explanation is related to the extremely high incidence of silver scurf on this stock at intake (71%, Table 1B), although there is no obvious mechanism as to the effect. The incidence of silver scurf in non-treated tubers has scarcely changed during storage for any treatment. There have been no reports of resistance of *H. solani* to fungicide (David Turner, pers. comm.).

Attempts to manipulate the incidence of fungal rots by pathogen inoculation appear to have been unsuccessful whereas inoculated Norfolk tubers held immediately under warm (15 °C), moist conditions succumbed to disease. Inoculated tubers destined for

storage were exposed to very dry atmospheric conditions during the inoculation and preparation for storage period and this may have been sufficient to affect disease development. Rose to stolon strips were used as samples for QPCR analysis of each fungal pathogen level. These strip samples may not have included the single wound inoculation point and hence have underestimated pathogens levels.

Varietal differences in sprouting were noted with sprouts longer on Maris Piper than Estima. In addition sprouting was more pronounced on stocks from Norfolk than those from Perthshire, a reflection of the longer post harvest period of the Norfolk stocks. As expected here was a clear effect of storage temperature with sprouting significantly greater at 5°C than at 3°C for both varieties. Fungicide treatment, in addition to reducing disease levels, significantly reduced sprouting of Estima (Norfolk) at 5°C and Maris Piper (Norfolk) at both 3°C and 5°C.

As noted previously for all stocks there was more sprouting than would have been expected given the storage temperatures and quality of seed tubers. Both Norfolk stocks had little or no sprouting when stored under commercial conditions suggesting that storage conditions or the trial procedures induced earlier sprouting or encouraged sprout development. Ventilation rate, which would affect sprouting, was measured at store setup and there was no concern with other aspects of store control during the storage period.

Handling, particularly manual handling, has an effect on sprouting and this may be one reason for the sprouting observed in the experimental stores. This was a complicated factorial trial (4 replicates each of 100 tubers, for each of four stocks, pathogen inoculated or not inoculated, fungicide treated or untreated, poor or good pull-down, stored at 3°C or 5°C). Each replicate was held in a net surrounded by bulk tubers within a section of a one tonne box. This required a much larger number of handling steps than would be required in commercial operation with each tuber destined for assessment or planting possibly handled.

Slight compression damage caused by dehydration was evident in all stocks (Table 5). Norfolk stocks were more affected than those from Perthshire, possibly due to a sandier soil type which makes the tuber skin more prone to moisture loss. Storage duration was also implicated as the Norfolk stocks were stored for 2 months longer

than those from Perthshire. Store temperature was also a factor with damage more evident at 5°C than at 3°C indicating that dehydration due to sprouting may have been contributory as opposed to loss of moisture due to extended refrigeration. Perhaps most significantly, the incidence of compression damage was less in tubers held under 'poor' compared with 'good' storage conditions indicating that the short pull-down probably slowed wound healing and curing.

Widely contrasting seed storage regimes generally had limited or no effect on emergence, disease on stems, stem and tuber populations and yield in either variety. Extensive sprout development following storage at 5 C advanced emergence but effects on stem and tuber populations were limited and were not consistent across experiments. Fungicide treatment consistently delayed emergence although virtually complete emergence was achieved. Fungicide treatment generally reduced stem populations and consistent with this tuber populations were also reduced in the Cambridge experiments and, in Estima at Cambridge, fungicide treatment also reduced yield.

The DNA of three pathogens, *P. exigua, C. coccodes* and *H. solani*, was found at high frequency post harvest. For *C. coccodes* and *H. solani* there was no clear relationship between disease found post-storage (pre-planting) compared to post harvest. Norfolk Estima had higher silver scurf and lower black dot levels than Norfolk Maris Piper post storage (Table 2a and b) but lower levels of both diseases (as measured by DNA content) post harvest. This trial did not proceed further to identify the disease potential of these pathogen loadings during storage. For *P. exigua,* which is ubiquitous in soil, infection and gangrene symptoms would only be found following tuber damage during harvest and subsequent handling.

This study was planned to investigate potato production holistically encompassing both storage and field phases for seed and progeny. Storage treatments were shown to have affected disease development (Tables 2A-D) and levels of sprouting (Tables 4A-D). However, effects of storage treatments on growth were less marked than might have been expected with final yields unaffected by any storage treatments (Table 8). This may be directly associated with the initial high health status of the seed stocks used. Some of the effects found indicate that seed store management can impact on the health and productivity of seed. This study was unable to establish

the impact of seed disease thresholds on field disease as final yields were unaffected by any storage treatments.

Further work in establishing appropriate storage regimes for seed of contrasting health status and the cumulative consequences of different seed storage practices over seed production cycles and their impact on key attributes such as dormancy would be of practical value.

6. APPENDIX 1

Sample loading at SBCSR showing sectioning of one tonne storage boxes