AHDB
POTATOES

Final Report

Storage at warmer temperatures: effect on skin finish and cost/benefit

Ref: R458

Reporting Period: September 2011 – August 2014

Report Author: G. Harper,
Sutton Bridge Crop Storage Research

Report No. 2015/3

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

The aim of the work, conducted in collaboration with the Fresh Potato Suppliers' Association (FPSA), was to understand the potential to increase the temperature at which potatoes for the fresh market are stored, whilst minimising any impact on quality and saleability. This included an evaluation of the effect of a range of storage regimes and temperature combinations on components of skin finish including skin blemish diseases, on physiology including tuber respiration rates, sprouting and weight loss, and on aspects of processing quality including fry colour, acrylamide content and taste/texture. The results informed a cost-benefit analysis for warmer potato storage.

Over the three years of the study there were no significant differences during six month storage of four potato varieties at temperatures of 2.5, 4 and 5.5 °C on the decline of skin bloom or on the development of three skin blemish diseases *Helminthosporium solani (*silver scurf), *Colletotrichum coccodes* (black dot) and *Polyscytalum pustulans* (skin spot). The effects on physiology were mixed as there was an increase in sprouting at warmer temperatures but no effect on weight loss or on respiration rate. Fry colour and acrylamide content increased at colder storage temperatures. Taste and texture of steamed tubers was little affected by storage temperature.

Calculated costs of storage showed an energy saving at the warmer temperatures of approximately 11% between the coldest and warmest temperature. This is a component of the overall cost of storage which has been estimated at approx. £6.50/tonne/month (Cunnington, A. *pers. comm*.). Although there are energy savings they may be offset by additional costs of sprout control at warmer temperatures.

Overall, this study has shown that a fine balance needs to be struck when determining storage temperature. In recent years this balance has been in favour of low temperatures for sprout and blemish disease control at the expense of electricity use. But with energy prices increasing over the long term, and with heightening need to lower risk of acrylamide formation and sugar accumulation to optimise quality for the consumer, the use of cold temperature alone is a strategy for fresh market suppliers requiring review. This work would suggest that a moderate increase in storage temperature may be worthwhile and yield benefits beyond a simple cost-saving.

2. Experimental section

2.1 Introduction

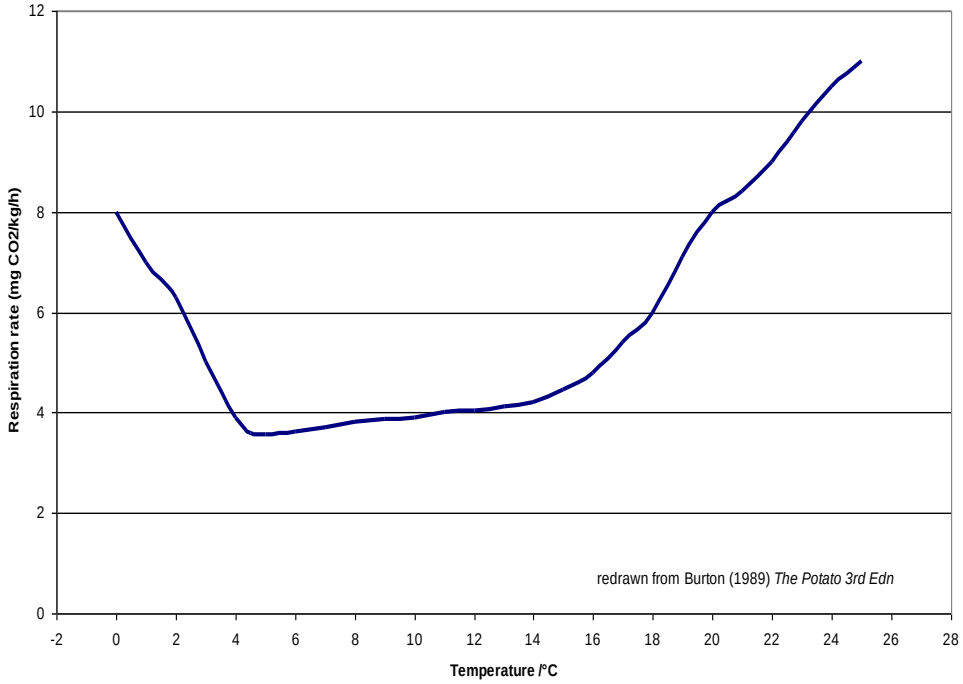
Storage of potatoes for the fresh market is carried out at low temperatures, typically in the range 2 to 3.5 °C. The exact storage regime is selected according to a range of factors aimed at maintaining the appearance of crops, by restricting the development of skin blemish diseases, preserving skin bloom and limiting sprouting and weight loss.

However, low temperature storage has two very significant drawbacks. Low temperatures add very significantly to the costs of storage as tuber respiration rates and heat production increase markedly as temperatures decrease below *c*. 5 °C, as shown in Figure 1.1. This additional energy burden is becoming increasingly incompatible with current environmental stewardship standards such as carbon footprinting. It is estimated that a saving of £1.5m per annum could be achieved by increasing potato storage temperatures by 1 °C leading to a corresponding reduction of approximately 14 M kWh of electricity per year for every 1 °C increase in storage temperature achieved (Cunnington, A. *pers. comm*.). Low storage temperatures also induce sweetening in the tubers which, as well as affecting flavour and texture, also - in combination with amino acids - results in undesirable acrylamide levels when some cooking methods are employed (Halford *et al*. 2012).

The aim of this work was to provide clearer knowledge of the cost:benefit of warmer storage temperatures for the fresh market. In addition to examining energy costs, the trial was designed to give a better understanding of the impacts on quality, and on the minimisation of dietary acrylamide.

The work included an evaluation of the effect of a range of storage regimes and temperature combinations on the components of skin finish; tuber respiration rates; sprouting; tuber weight loss; quantification of acrylamide levels in cooked tubers and provision of a cost-benefit analysis for warmer potato storage.

Figure 1.1 The relationship between tuber respiration and temperature, redrawn from Burton (1989).



2.2 Materials and methods

2011-12 season

Materials and storage treatments

Crops of the varieties, Desiree, King Edward, Maris Piper and Marfona were acquired from commercial sources. As soon as possible after intake, potatoes were graded to remove soil, rots, damaged, green and undersize tubers (<45 mm). Intake samples were taken from the graded tubers.

Tubers were loaded into nets (3kg) or trays (20kg) and loaded into stores at their intake temperature and a pull down schedule of 1 °C per day was imposed until the desired final temperature of 2.5, 4 or 5.5 °C was attained. After four months, (SO2) sub-samples were moved from 2.5 to 5.5 °C. Controlled environment rooms were set to the target temperature with a tolerance ±0.5 °C and 95 % RH with a tolerance ±5 %. Store temperature and humidity records are archived at SBCSR.

Assessments

Tubers were sampled for skin quality, respiration rate, weight loss and sprouting on four occasions; intake and at 2, 4 and 6 months of storage. On each occasion three replicates of 25 tubers were assessed. Assessments for respiration rate, weight loss and sprouting were carried out using standard procedures. Visual assessments were carried out for the skin blemish diseases *Helminthosporium solani (*silver scurf), *Colletotrichum coccodes* (black dot) and *Polyscytalum pustulans* (skin spot).

Skin bloom

The tubers were clean and dry prior to assessment. Potatoes were assessed for bloom, in replicate order, first visually and then using *Rhopoint Novogloss Lite* gloss meter. Twenty five sampled tubers were washed for 2 minutes in a flat-bed washer [Niagri Engineering, Thetford, IP26 4JQ, UK] and spread out onto seed trays, lined with tissue paper, and ventilated with a fan until dry at ambient room temperature (from 2 hours to overnight)

For visual assessment, each tuber was assessed for shine on the following subjective 1 – 5 scale in which 1 corresponds to very shiny, 2 to shiny, 3 = to neither particularly shiny or dull, 4 to dull and 5 to very dull.

Each tuber was then assessed for shine objectively with a *Rhopoint Novogloss Lite* gloss meter at each of three positions: stolon end, middle and rose end, using the flattest, most blemish-free areas available. Prior to assessment, the instrument was calibrated with a standard dull fabric and shiny glass tile of known specular reflectance measured in GU (93.3 at 60°) and provided with the instrument. The instrument was used according to the manufacturer's protocol. The machine was re-calibrated prior to assessing each sample and machine readings were record directly onto a database. The measured scale is between 1 and 100, with 100 being maximally glossy.

Potato cooking quality and acrylamide assay

Following washing and rumbling of all tubers in a sample, one chip was cut from each of 25 tubers and fried for 90 seconds in oil which was at 190 °C at the start of frying. The fry colour of individual chips was compared to a USDA standard colour chart (Munsell Color, Baltimore, Maryland, USA) under standardised lighting conditions. The USDA scale was linearised to the SBCSR scale as shown below:

USDA score	000	00	0	1	2	3	4
SBCSR score	1	2	3	4	5	6	7

Following colour assessment at SBCSR, the 25 chips from a sample were packaged in snap-lock bags, frozen overnight at -20 °C and couriered next day to the analytical laboratory in an insulated pack containing ice blocks. Acrylamide assessments were carried out by Dr Stephen Elmore, Department of Food & Nutritional Sciences, University of Reading, UK.

Statistical analysis

Microsoft Excel was used to determine descriptive statistics, Analysis of Variance (ANOVA) and other statistical analyses were calculated using SPSS version 21.0. Where a significant F-test occured in the ANOVA, a post-hoc two-tailed tests of significance using the Bonferroni correction was computed. No transformation of the data was used in the analysis.

2012-13 season

Materials and methods were as for 2011-12 except for the following:

Materials and storage treatments

Source crops were acquired through FPSA member companies. Temperature after loading was reduced at 1 °C per day to 7 °C. On reaching this temperature, CIPC was applied to half of the samples at 14g/tonne. Following application, pull-down of all samples was resumed at 1 °C per day and when holding temperature was achieved, RH control was enabled.

Storage treatments were 2.5°C, 2.5°C+CIPC, 4 °C, 4°C+CIPC, 5.5°C+CIPC. In addition a transfer treatment, where samples were transferred after 4 months from 2.5+CIPC to 5.5 °C+CIPC, was included.

Skin bloom

In 2012/13, potatoes were only visually assessed for bloom, in replicate order.

Potato cooking quality and acrylamide assay

Frying was carried out on each of the three replicate sub-samples using the method described for 2011/12 except the temperature was reduced to 150°C and the duration 3 min.

Taste and texture analysis

The different varieties and treatments were coded A-D and 1-4, respectively. Samples of each temperature treatment were presented simultaneously and the different varieties presented sequentially to the assessors. The assessor panel were seven volunteers from the FPSA meeting held at SBCSR on 31st May 2013. The test protocol is described in Annex A2. The taste and texture panel were provided with a plate of ~ $2cm^3$ cubes of steamed potato, preparation method described in Annex A2, and one or more cubes selected for the assessment of 9 quality attributes scored over 4-6 descriptors (questionnaire shown in Table 13).

2013-14 season

Materials and methods were as for 2011-12 except for the following:

Materials and storage treatments

The transfer treatment assessed in years 1 & 2 of the trial was discontinued.

Skin bloom

In 2013/14, potatoes were not assessed for skin bloom.

Potato cooking quality and acrylamide assay

Chips were fried for 180 seconds in oil which was at 150 °C at the start of frying. This cooler cooking temperature was used to try to mitigate against unacceptably dark fry colour.

Taste and texture analysis

Taste and texture analysis was conducted by Linda McWatt at the Sensory Suite, National Centre for Food Manufacturing, Holbeach Campus, University of Lincoln. The assessor panel were six volunteers from the FPSA partner companies who had some experience of taste and texture assessments. Samples of all four varieties from the

three temperature/+CIPC treatments were analysed. Samples were presented by variety, each with a randomised treatment order.

The taste and texture panel were individually presented with a plate of ~ 2cm^3 cubes of steamed potato, prepared in the Sensory Suite kitchen, for the assessment of 8 quality attributes scored over a range 1-10.

Cost/benefit analysis

A cost/benefit analysis was undertaken by Farm Energy [FEC Services, Kenilworth, CV8 2LS, UK] to assess the commercial impact of the temperature treatments used. Trial respiration data and other relevant information were used to calculate the energy and refrigeration requirements to provide the analysis, further details are described in Annex A3.

Table A. Summary of treatments and assessments over the three years of the project.

2011-12	2012-13	2013-14
Treatments (temperature °C)		
2.5	2.5	2.5
	2.5 +CIPC	2.5 +CIPC
4.0	4.0	
	4.0+CIPC	4.0+CIPC
5.5		
	5.5+CIPC	5.5+CIPC
2.5-5.5 (assessment at SO3 only)		
	2.5-5.5+CIPC (assessment at SO3 only)	
Assessments at 2, 4 and 6 month intervals (SO1, SO2, SO3)		
Skin bloom, visual and instrument	Skin bloom visual	
Black dot	Black dot	Black dot
Silver scurf	Silver scurf	Silver scurf
Skin spot	Skin spot	Skin spot
Sprouting	Sprouting	Sprouting
Respiration	Respiration	Respiration
Weight loss	Weight loss	Weight loss
Additional assessments at 6 month intervals (SO3)		
Fry colour (French fry)	Fry colour (French fry)	Fry colour (French fry)
French fry acrylamide content	French fry acrylamide content	
	Taste and texture	Taste and texture

2.3 Results

Results are presented by year or across the three years of the trial where appropriate. Tables in Annex 1 are referenced by year where a=2011/12, b=2012/13, c=2013/14 and x denotes all three years.

2.3a.1 Skin finish

Skin bloom

Both methods of determining the surface appearance of the skin provided similar results. Visual assessment data only is presented for year one in Annex Table A1.a.1 as use of the gloss meter was subsequently discontinued. In both years 1 and 2, at intake, tubers had desirable bloom levels which decreased with storage duration.

A visual bloom level of 3 or less is commercially acceptable. In year 1, both Desiree and King Edward were within that specification for the duration of storage period. However, the bloom values for Marfona, for all storage periods, and Maris Piper, at the final storage occasion, were poorer than this specification. The differences between bloom mean values across all the temperatures for sampling occasions were highly significant ($P<0.001$) for all varieties, with the exception of red-skinned Desiree ($P=0.553$) suggesting that storage duration was a significant factor.

There was no consistent or large effect of either temperature or CIPC on levels of bloom in year 2 (Annex Table A1.b.1). There were no significant differences between the mean bloom values and storage temperatures, for Desiree, Maris Piper and Marfona ($P>0.05$). In the absence of CIPC, King Edward bloom values were slightly better at cooler rather warmer temperatures.

Overall, duration was the most significant determinant of skin bloom duration during storage. There was no consistent or large effects of storage temperature on levels of bloom and no significant differences ($P>0.05$) between mean bloom values for varieties at the different temperatures.

Blemish diseases

There were no clear effects of storage temperatures on silver scurf incidence across the storage periods in this trial or for the transfer treatment (Annex Tables A1.*x*.2). There was a general increase in black dot incidence with increasing storage duration; however, there was no apparent effect of storage temperature on incidence nor was there a clear effect observed for the transfer treatment (2.5 to 5.5 °C) (Annex Tables

A1.*x*.3). No significant differences were obtained by ANOVA for silver scurf or black dot incidence with storage temperatures.

Levels of skin spot were very low and no pattern of either store temperature or store duration could be determined (data not shown).

2.3a.2 Physiological effects of warmer storage

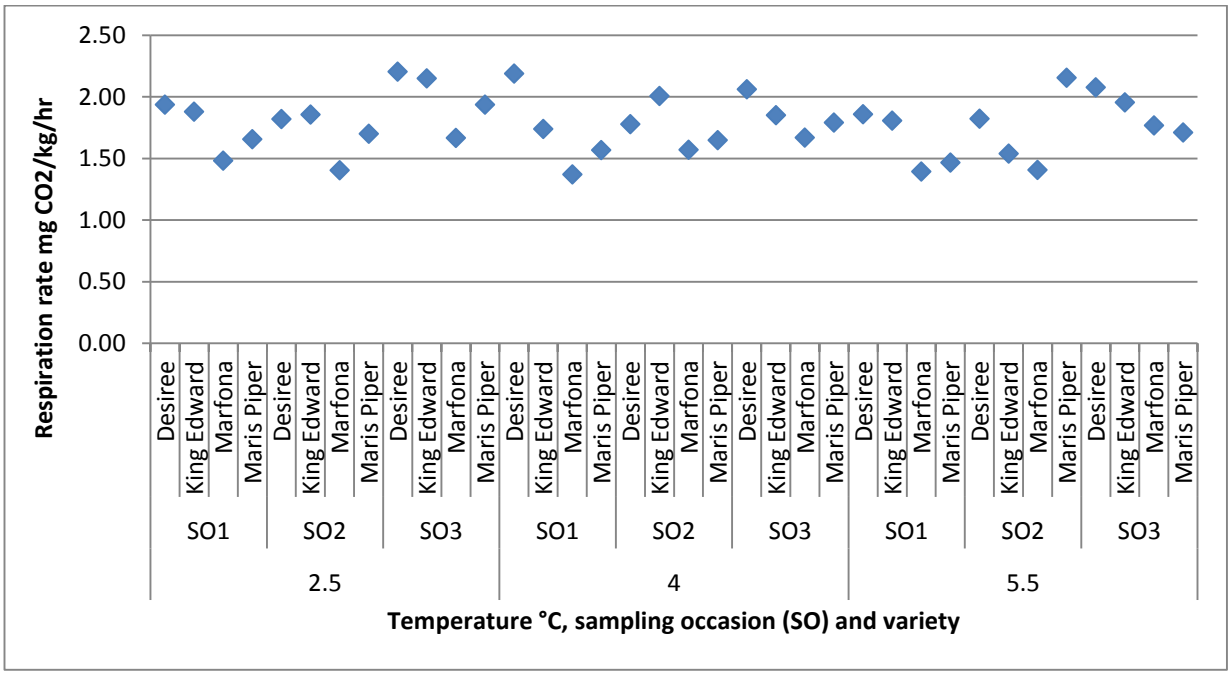
Rate of respiration

Respiration was high at intake and decreased markedly in all varieties by SO1. Generally respiration rate increased with storage duration although there was little difference between the storage regimes at 2 and 4 months (Annex Tables A1.*x*.4). Sampling occasions were always highly significantly different ($P<0.001$) for all varieties, apart from Maris Piper, suggesting changes in respiration over storage duration. Over the three years of trials the lowest respiration rates were generally found in tubers at 4 and 5.5 °C. Marfona generally had the lowest respiration rate.

There were some statistically significant differences in the respiration rates, at each sampling occasion, between storage temperatures for the varieties in the trials. However, there was no pattern to the differences and they usually involved one high or low respiration value between the temperatures at a sampling occasion. For example in year 1 at SO3 a single significant ($P=0.011$) pairwise comparison was obtained with Desiree between 2.5C and 5.5C but not between other temperatures. In year 2, differences were found for King Edward during SO2 with respiration higher at 4 °C + CIPC than other treatments, and at SO3 where respiration was higher at both 2.5 °C + CIPC and 5 °C + CIPC than with other store treatments. In Desiree at SO1 respiration was higher at 2.5 °C than other treatments and at SO3 higher at both 2.5 °C + CIPC and 5 °C + CIPC than other treatments.

The reasons for the differences are not understood, particularly as they were not consistent in other years. Figure 2 shows the mean respiration rates per variety at different storage temperatures and sampling occasions, over three years of study and highlights the overall similarity of respiration rate over the different storage regimes and durations.

Figure 2. Average variety respiration rates at different storage temperatures and sampling occasions over three years of study.



Sprouting

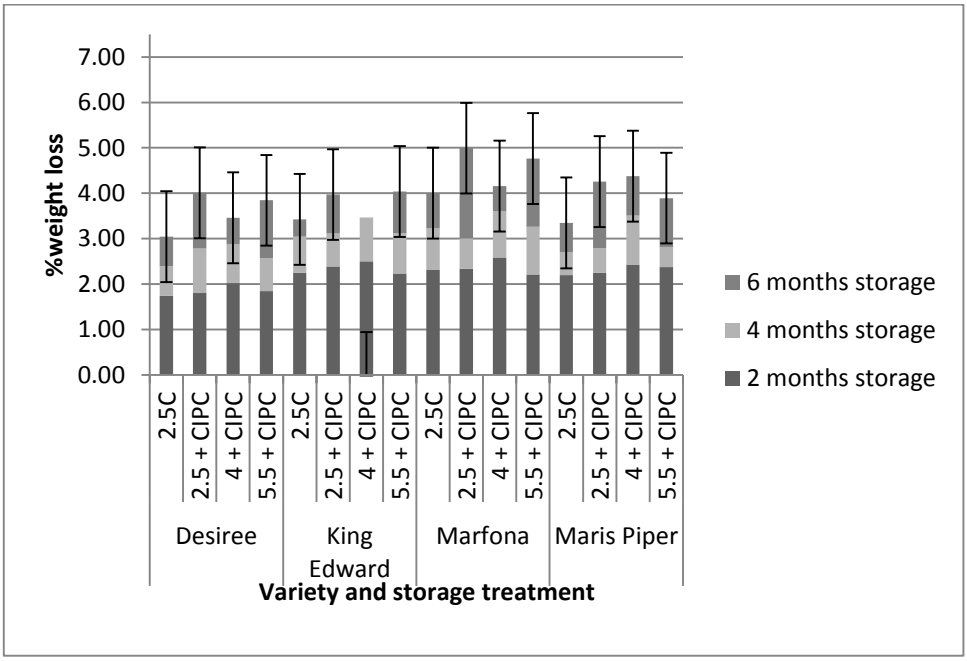
As expected, there was a difference in the rates of sprouting between varieties, as measured by the length of the longest sprout (Annex Tables A1.*x*.5). King Edward sprouted earlier than the other varieties. For all varieties, temperature had an effect with sprouting least at 2.5 °C, particularly when compared with that at 5.5 °C. With the exception of King Edward, sprouting was only slightly greater at 4 °C than at 2.5 °C. In year one, sprouting would have required additional (chemical) control for all four varieties stored for longer than two months at 5.5 °C. In subsequent years an additional CIPC treatment was included to control sprouting and its potential effects on both respiration and weight loss. In year two, sprouting was more vigorous than in year one and not well controlled by CIPC. In year three, sprouting was well controlled by CIPC. Sprouting in the transfer treatment was intermediate between the initial and final store temperatures.

Weight loss

There was a small difference between varieties in the weight loss experienced during the storage period, weight loss increasing with storage temperature with the minimum at 2.5 °C (Annex Tables a1.x6). There were significant (P≤0.05) to highly significant (P≤0.001) differences in pairwise comparisons between 2.5 °C and the other storage

temperatures across all seasons. Weight loss increased with storage duration (Figure 3c.), increasing at approximately 0.5 % per month storage after SO1, differences between means for sampling occasions were significant for all varieties. Weight loss in the transfer treatment used in years 1 and 2 was more similar to that found at 5.5 °C than that at 2.5 °C.

Figure 3c. Cumulative weight loss of varieties during six month storage, 2013/14



Error bars = standard deviation for final assessment

2.3a.3 Processing quality and acrylamide content
Fry colour

Fry colour was measured as a standard test to provide an indication of likely risk of darkening, for example, on frying or roasting after storage.

The colour of all samples processed as French fries in the first year was very dark (Annex Table A1.*a*.7). Only colour values lower than 4 are commercially acceptable and no sample in this trial would have been acceptable for processing. Tubers stored at 5.5 °C provided a slightly less dark processed sample in three varieties.

In year two, tubers stored under warmer temperatures with CIPC sprout control, provided a less dark processed sample and, when stored at 5.5 °C, fry colours were acceptable for all varieties (Annex Table A1.*b*.7). There were significant differences ($P<0.05$) between temperature mean values for Maris Piper, but none for the 3 other varieties. Fry colour in the transfer treatment were darker than samples held at 5.5 °C

throughout storage and tended to be similar to the fry colour of samples held at the original temperature (2.5 °C) throughout storage.

In year 3, French fry colour assessment followed frying using a modified technique. Frying was carried out for 3 minutes at a lower oil temperature of 150 °C but this did not result in a markedly different fry colour scores from those attained in year 2 (Annex Table A1.*c*.7).

The chip colour score averaged for all varieties and treatments across all years of the trial at the different storage temperatures is shown in Figure 4 and with all varieties individually (Figure 5) and across the three years of the trial, there was a negative correlation between temperature with colour score (e.g. Annex Figures A1.c.2. and A1.b.3) showing a clear lightening of fry colour with increasing storage temperature. Figure 4 shows the average reduction in fry colour score to be 0.36 SBCSR units/ °C.

Figure 4. Chip colour score average of all varieties and treatments at different storage temperatures across all years of the trial.

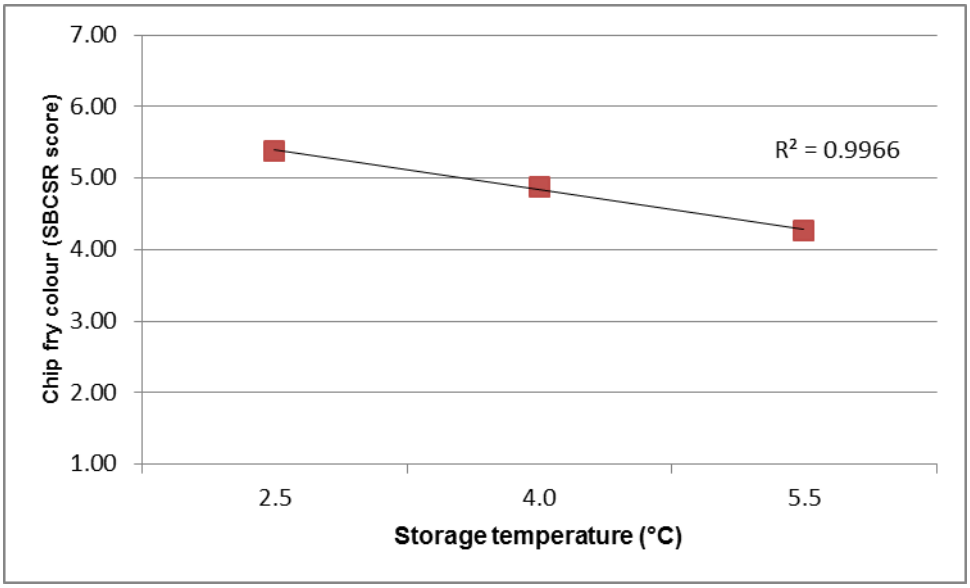
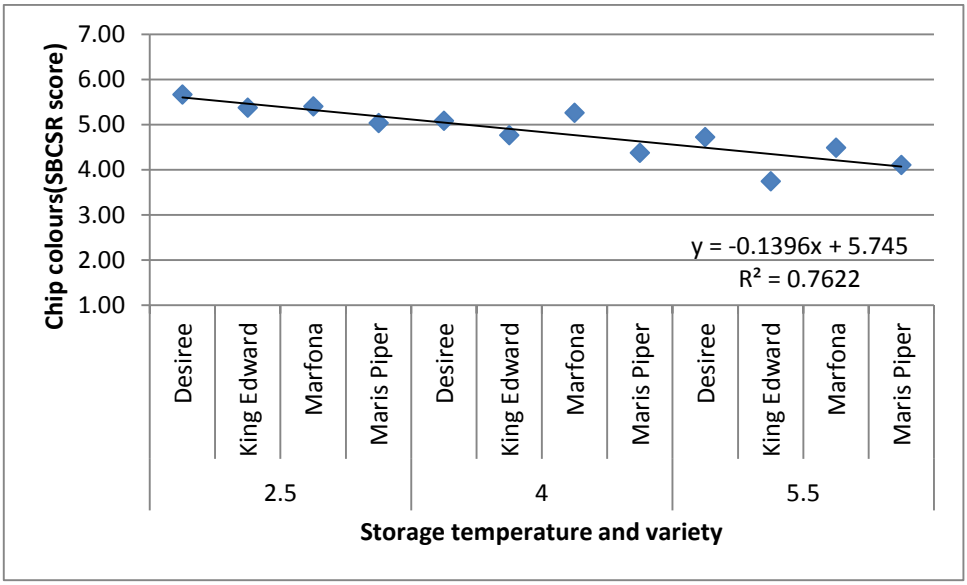


Figure 5. Chip colour score average of all varieties and treatments at different storage temperatures across all years of the trial.



Acrylamide

Very high acrylamide values (Annex Table A1.a.8) were obtained from the dark French fry samples in year 1. There were very significant differences ($P<0.01$) between the storage temperature mean values for King Edward, Marfona and Maris Piper but not for Desiree ($P=0.074$). Annex Table A1.a.8b shows the post-hoc Bonferroni test of significance of pairwise comparisons between the 4 temperatures. Acrylamide levels of French fries prepared from tubers stored at 5.5 °C were significantly less than those stored at 2.5 °C across all varieties with the exception of Desiree. Varietal differences were also observed with Desiree samples containing approximately twice the acrylamide levels found in other varieties, even though the fry colours were similar to Marfona (Annex Table A1.a.8).

There was a negative correlation between storage temperature and acrylamide content for each variety for the second year of the trial (Figure 6) and for temperature and acrylamide content averaged for all varieties and treatments (Figure 7). In year 2, the average decrease of acrylamide was 41µg/kg per degree increase in store temperature. This relationship reflects the relationship of storage temperature and fry colour and a correlation of increasing acrylamide content on increased fry colour was observed in years one and two (Annex Figures A1.a.1 and A1.b.4.). Year one data was less amenable to analysis due to the very high fry colours obtained (Annex Table A1.a.8).

Figure 6. Relationship between acrylamide content for all varieties and treatments, 2012/13.

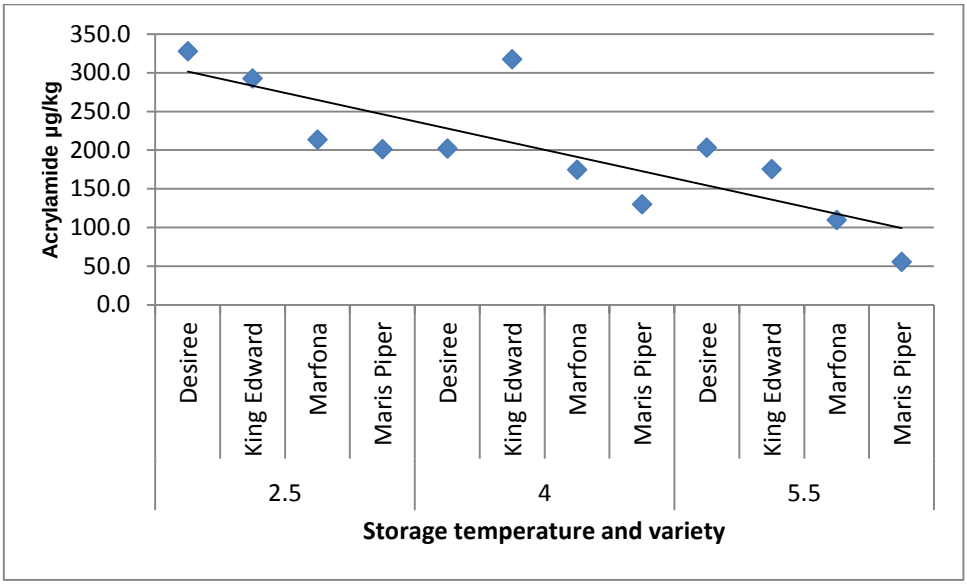
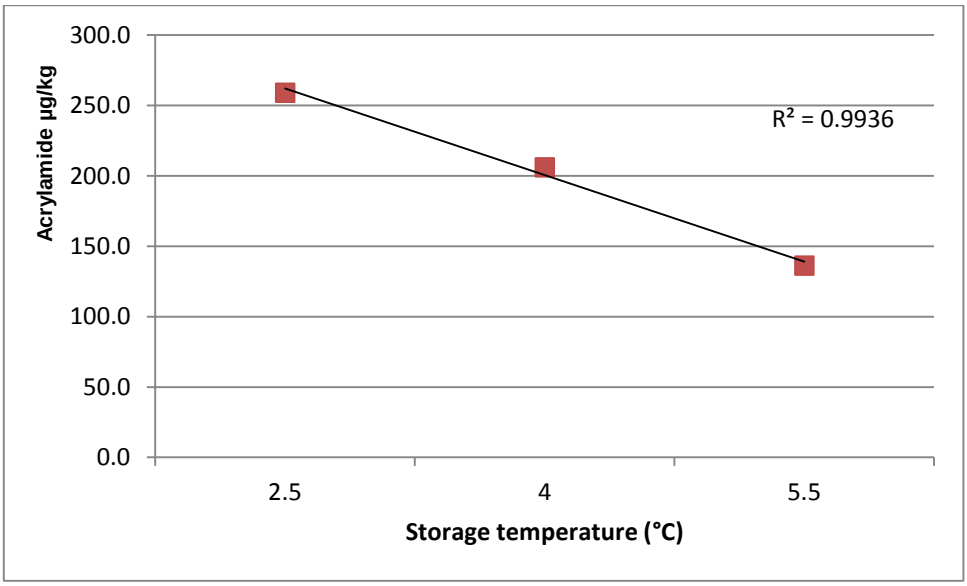


Figure 7. Relationship between acrylamide content for all varieties and treatments, 2012/13



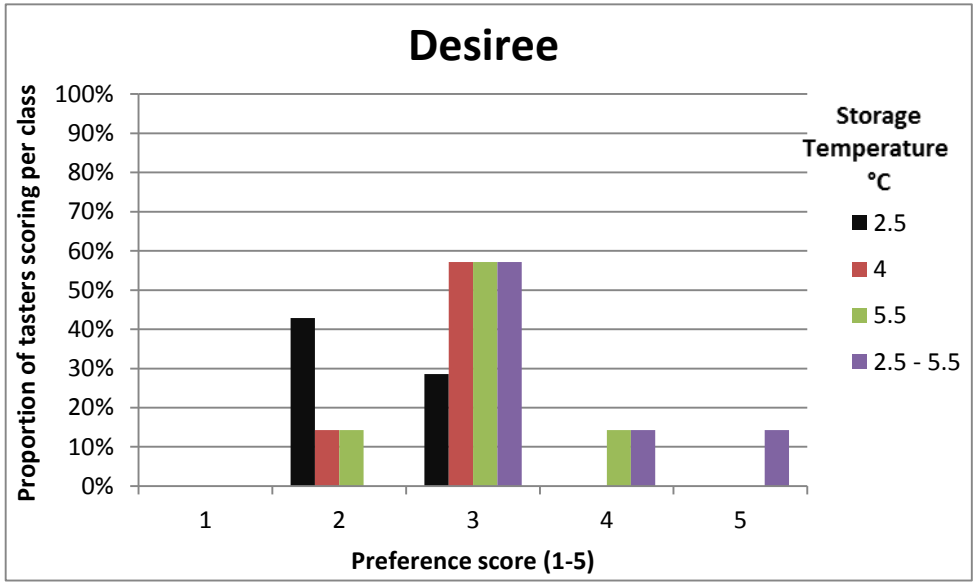
Taste and texture

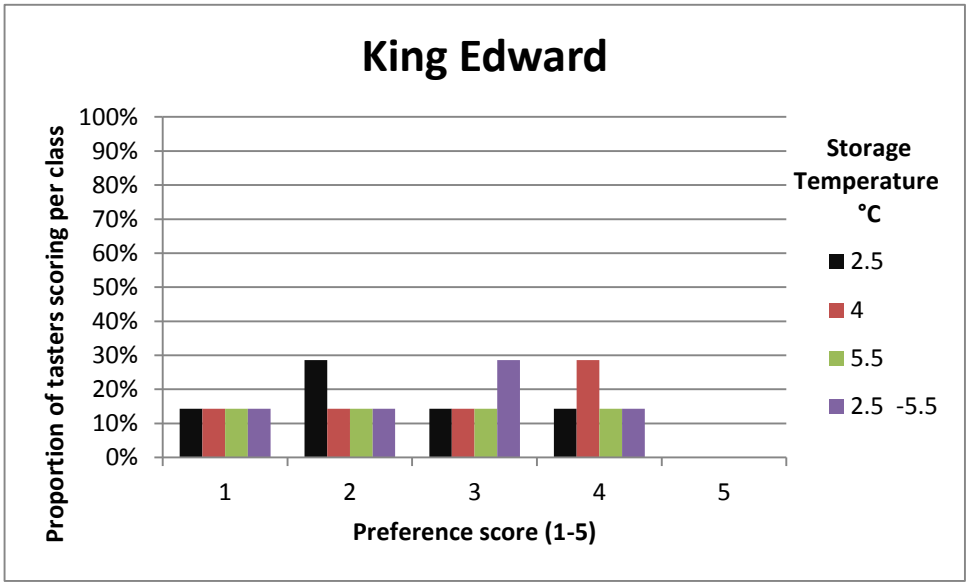
In year 2, a taste and texture exercise was completed by seven assessors for the four varieties for each of the four CIPC storage treatments (2.5, 4 and 5.5 °C, and transfer treatment). Further details of the study are described in Annex A2.b. 2 & 3. The overall taste and texture score for the variety/treatment combinations is shown in Figure 8. This shows that Desiree was preferred following storage at the warmer temperatures and in

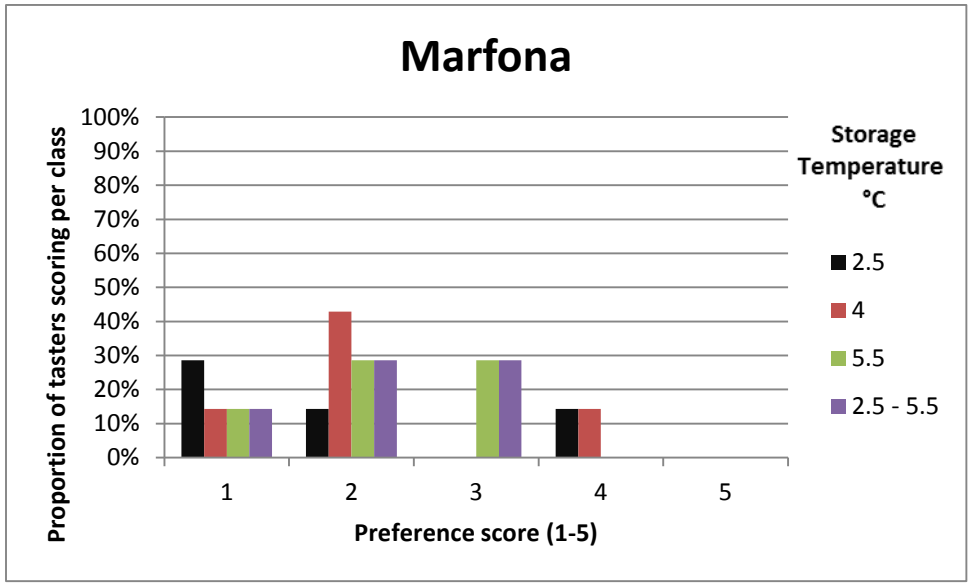
the transfer treatment. However, there was no clear trend of preference for the other varieties.

The data set of taste and textures attribute scores for each variety is shown graphically in Annex A2.b.1. Despite the panel being variably experienced and trained, the limited direction of the panel and no prior agreement over descriptors, there was some consensus over trends for some quality attributes as shown in Table 1.

Figure 8. Overall subjective taste and texture score for all varieties after 6 months storage, 2012/13.
For each variety and storage temperature, each taster provided a score from 1-5, with 5 the highest, for the overall taste and texture.
The proportion of tasters for each score is given as a percentage (y axis).







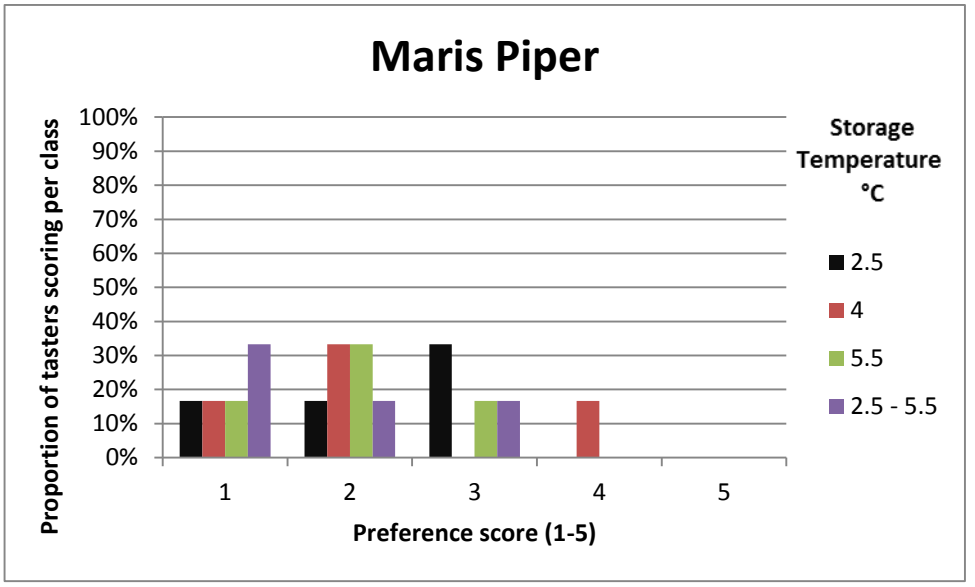


Table 1. Trends of change in taste and texture attributes at different storage temperatures, after 6 months storage, 2012/13.

	Variety			
Attribute	Desiree	K. Edward	Marfona	M. Piper
Colour	whiter at lower temperature	whiter at lower temperature	whiter at lower temperature	variation in transfer treatment & 5.5, perhaps whiter at lower temperature
Dis-colouration	variation in transfer treatment	greater at lower temperature	least at lower temperature and transfer treatment	
Dis-integration	less variation at warmest temperature	greater at warmer temperatures and transfer treatment	greater at warmer temperature	lower in transfer treatment
Aroma	slightly more starchy at lower temperatures	slightly more starchy at lower temperature	slightly more starchy at lower temperature	slightly more starchy at lower temperature, earthier at warmer temperatures.
Flavour		less potato flavour at lower temperature?		more bitter/unpleasant at lower temperature
Sweetness	sweeter at lower temperatures	sweeter at lower temperatures	sweeter at lower temperatures	slightly sweeter at lower temperature
Hardness (initial bite)	wider variation at lower temperatures	wider variation at low temperatures	softer texture at lower temperatures	
Texture	waxier at warmer temperatures, more floury at lower temperatures	wetter and waxier at lower temperatures	wetter at lower temperatures	wetter and waxier at lower temperatures
Texture Uniformity	perhaps smoother at lower temperatures & transfer treatment	more variation at 2.5, perhaps smoother at lower temperatures	perhaps smoother at lower temperatures	perhaps smoother at lower temperatures
Overall Score	warmest temperatures /transfer treatment best score, low temperatures worst			low temperatures scores slightly better
	= consensus in attribute trend across the varieties			

In year 3, tubers of each of variety held for six months at 2.5 °C + CIPC, 4 °C + CIPC and 5.5 °C + CIPC were professionally cooked and presented to a six person taste panel under highly controlled conditions. Tasters were tasked to assess eight characters colour, smoothness, floury texture, wetness, earthy flavour, bitterness, sweetness and shape retention on a ten point scale. Results are shown in Figure 9a-d. The assessors found no significant differences between the temperature treatments for each variety for the majority of attributes. Sweetness increased as the storage temperature decreased although these results were not statistically significant.

There were some apparent significant differences related to storage temperature, in King Edward (shape retention, sweetness and smoothness) and Maris Piper (shape retention). However, this analysis was compromised by statistically significant variation in scoring by tasters Annex A2.c 1&2). Both shape retention and smoothness may have been affected by the cooking method and time.

Figure 9 a-d. Mean analysis of variance, taste and texture assessment of varieties stored at 2.5, 4 and 5.5 °C during 2013/14. Attributes were scored on a scale 0-10, the higher the score the more prominent the attribute e.g. shape is better at 10 than at 0. Attribute labels in red or blue text indicate whether the assessment did or did not have statistical significance respectively.

Figure 9a. King Edward

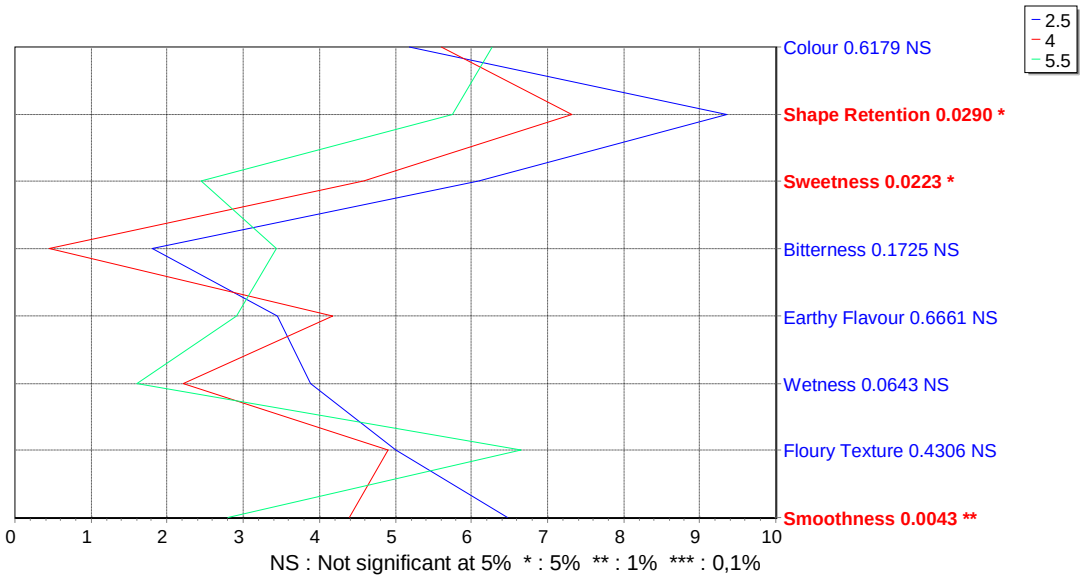


Figure 9b. Desiree

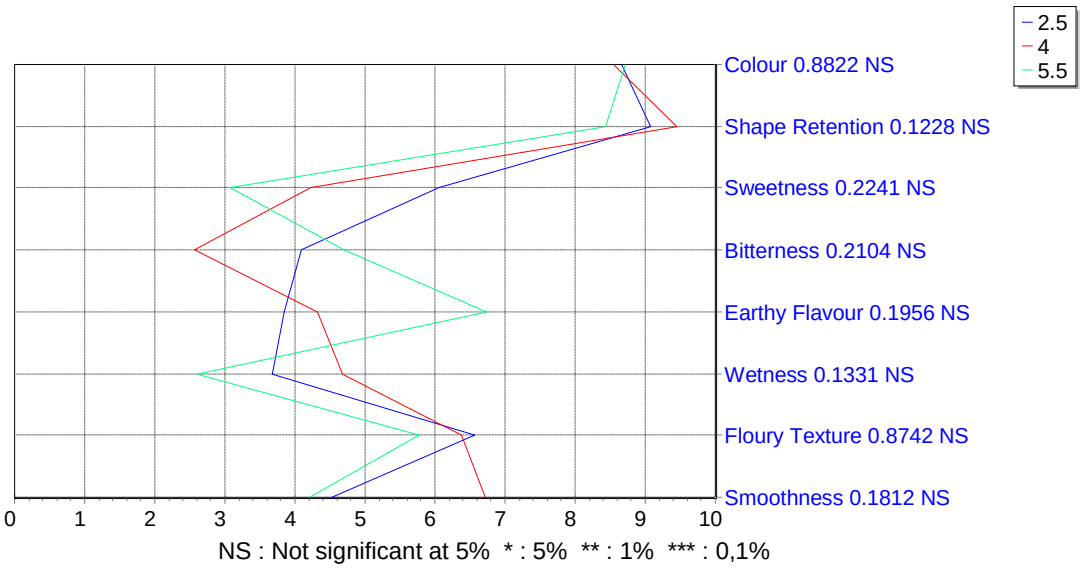


Figure 9c. Maris Piper

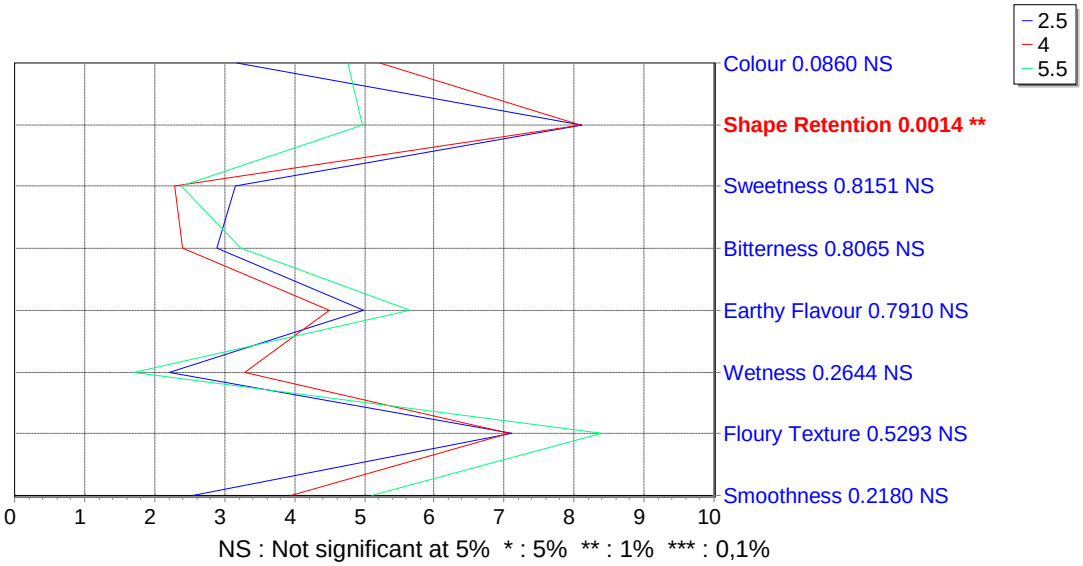
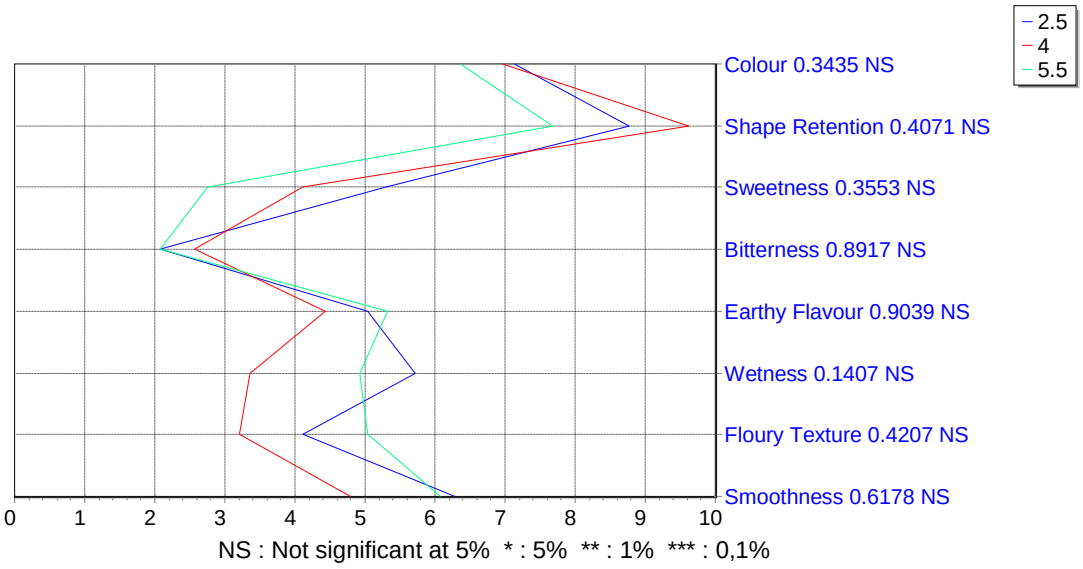


Figure 9d. Marfona.



2.3.4 Costs of storage

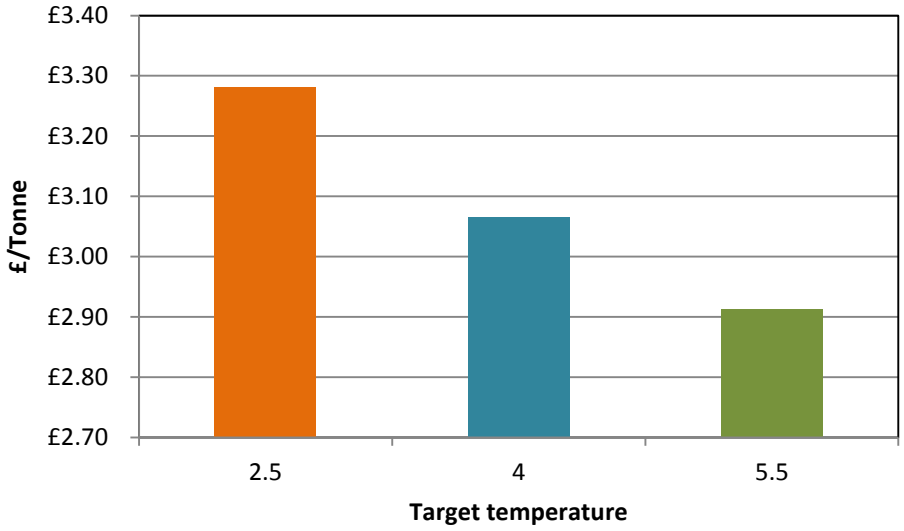
The energy and costs required to maintain a 1000 tonne potato store over the temperature range used in this study were modelled by Farm Energy Centre (FEC, Figure 10). An increase in target temperature from 2.5°C to 4°C exhibits an energy saving of 7% on average, and increasing to 5.5°C gives an 11% saving in energy consumption. Both measured and estimated data from typical stores from different parts of the UK (Annex A3), including the respiration rates determined during this study, were used in the calculations.

There were small differences in energy requirement depending on geographic store location, principally because of small different ambient temperature profiles over the modelled storage duration. There was a larger difference for the predicted costs, between 4 and 2.5 °C than between 4 and 5.5 °C reflecting the different and larger differences between the crop and ambient temperatures.

Reduction in energy consumption also has an effect on the carbon footprint; the carbon emissions associated with the energy consumed will be reduced by 0.96KgCO2e/tonne (Carbon Trust 2013) and 1.67KgCO2e/tonne for each of the warmer target temperatures respectively compared with 2.5°C.

Modelling, in which respiration values widely used in the industry (e.g. Farm Electric Handbook, Golob *et al.,* 2002) and higher than those found in this study, was also performed. This modelling further assumed a relationship between tuber respiration and temperature during storage for 2.5 °C and 5.5 °C of 2.4 and 3.0 mg CO_2/kg.hr, respectively. This modelling predicted an energy usage some £0.25/Tonne/month and £0.15/Tonne/month more expensive for storage at 2.5 °C and 5.5 °C, respectively (Annex A3) compared to the model using observed respiration values.

Figure 10. Estimated average cost per tonne required to maintain target temperatures (°C) over 10 months storage.



2.4 Discussion

2.4.1 Changes in skin finish and skin blemish diseases during storage

A number of aspects of skin finish deteriorate during storage including skin bloom, lenticel appearance, and blemish diseases.

Skin bloom

Numerous factors are known or thought to determine skin bloom (sometimes also called shine or lustre) by the time of harvest including crop duration, variety, nutrition, soil texture, and other factors associated with the growing season. Within the packing industry it is generally recognised that skin finish is best on tubers grown in silt or clay soils compared with more abrasive, sandy soils. Crop duration influenced skin bloom with longer duration crops tending to have duller skins following prolonged storage (Wiltshire *et al*., 2005). Skin finish varies between varieties but skin finish characteristics of varieties are not well documented. Skin bloom is not correlated with tuber size.

The surfaces of tubers lose bloom over time in storage. Poor skin bloom was shown to result from a loss of integrity of the periderm caused by cell collapse in the phellum layer, probably caused by water loss for example during the curing period (Napier & Andrews, 2005). An immediate temperature pull-down following harvest

minimised the rate of skin bloom deterioration (Wiltshire *et al*., 2005). However, these same authors found that storage treatments generally had minimal impact on the skin bloom other than the rate of decline with the final bloom values relatively unaffected by various treatments.

Bloom declined significantly from intake to the first assessment period after two months storage after which time there was a general very small further decline with increased storage duration. No significant or consistent effect of temperature or CIPC treatment was observed. Desiree, Marfona and Maris Piper, were commercially acceptable throughout the trial.

Blemish diseases

Despite a general very slight increase in black dot incidence with increasing storage duration, the blemish diseases were well controlled in all years. There was no statistically significant effect of storage temperature for any blemish disease in any year of the trial. This level of disease control is probably because a rapid pull-down (1°C per day) and good control in store of ventilation and humidity, all known to be best practice for the control of silver scurf and black dot and used for fresh pack storage.

2.4.2 Physiological effects of warmer storage

Rate of respiration

Respiration was affected by storage duration in all varieties in all years of the trial being high at intake and decreasing markedly during the first two months of storage and usually reducing further on longer storage. Burton (1989) presented a graph of the respiration rate of three mixed varieties, Arran Consul, King Edward and Majestic, at various temperatures after one month of storage and the graph is redrawn and shown in (Figure 1.1). This graph shows three phases, a sharp increase in respiration at temperatures from 4 to 0 °C, a minimum respiration at around 4°C and slow increase up to 15 °C followed by a sharp increase at temperatures greater than 15°C. The results of this trial do not support these findings over the range 2.5 – 5.5°C over the longer storage periods used in this trial. Additional research is being carried out on this subject (AHDB Potatoes project R484).

There were no statistically significant differences in the respiration rates between storage temperatures at each storage duration for any variety during 2013-14, nor for Marfona and Maris Piper during 2012-13 and nor for King Edward, Marfona and Maris Piper in 2011-12. For varieties for which there were statistically significant differences, respiration was lowest at 4°C but this was not consistent through the storage period.

Respiration will be affected by sprouting and the interpretation of this respiration data in year 1 was confounded by the increasing level of sprouting at the warmer temperatures and at longer storage durations. The use of CIPC in the second two years of the trial reduced this.

Rates of sprouting

Where sprouting was not controlled i.e. at higher temperatures without CIPC treatment the expected difference in sprouting between varieties was observed. Sprouting therefore required additional control for all varieties stored for longer than two months at 5.5 °C.

Weight loss in stored tubers occurs because of respiration, the process of carbohydrate conversion to carbon dioxide and water, and water loss from tubers because of vapour pressure differences between tuber and store air. Sprouts lose moisture at a much greater rate than occurs through intact potato tuber skin. Low respiration rates and high relative humidity (RH) will minimise weight loss. In the trials described here, RH was maintained at 95% ± 5%. Butchbaker *et al* (1973) found that after 60 days storage at 40°F (4.4°C) and 93%RH the contributions of respiration and vapour pressure to weight loss of tubers were 38 and 62%, respectively.

Weight loss increased with storage duration with the largest loss, approximately half the total, occurring during the first 2 months of the 6 month storage duration. Loss was only slightly affected by storage temperature with inconsistent results between years. In 2011-2012, the minimum loss was generally at 2.5°C whereas during 2012-13 the minimum losses were found at 5.5°C. During 2013-14 the smallest losses were at 2.5°C but for the three +CIPC treatments smallest losses were at 4°C.

As described by Butchbaker *et al* (1973), differences between varieties in weight loss were also observed in all three years of this trial although there were inconsistencies between years for weight losses by the varieties. Any specific

differences between varieties are more likely to have been overridden by factors such as different agronomic conditions and different levels of maturity at harvest.

Respiration rate, sprouting (sprouts longer than approximately 10 mm) and weight loss are interrelated (Schippers, 1977). Sprouting in this trial during 2012-13 and 2013-14 was controlled and is not considered a factor affecting respiration or weight loss. Extensive sprouting was observed in all varieties during 2011-2012, particularly at 5.5 °C at SO3, and may consequently have impacted weight loss.

2.4.3 Processing quality (fry colour), acrylamide content and taste & texture

Fry colour

During 2011-12 a variety of cooking methods had been attempted to produce a "home-cooked" effect, to mimic the potential use of these potatoes in the home. It was hoped that taste and texture of samples prepared by other cooking methods could also provide useful information in relation to the benefits and disadvantages of the trial storage treatments. These methods were unsatisfactory largely because of the inconsistency of final processed colour/appearance within a sample. Also, very distinct differences in sweetness, as judged by taste, could be detected between samples stored at different temperatures but these did not manifest as differences in processed colour because of the relatively low storage temperatures used. The fry colour of samples processed by a standard method, were very dark. During 2012-13 and 2013-14 frying was at lower temperatures for a longer time to provide greater colour discrimination and to match the range that might be expected within the home setting.

No variety stored in this trial at 2.5 °C would have been acceptable for commercial processing. As expected, tubers stored under warmer temperatures provided less dark processed sample and, when stored at 5.5 °C, fry colours were acceptable for all varieties albeit using reduced frying temperature. For home cooking fry darkening may be a less significant factor but tubers stored at the warmer temperatures would be more forgiving of cooking temperatures and times than those stored at the coldest temperature. Fry colour in the transfer treatment was darker than samples held at 5.5 °C throughout storage and were similar to the fry colour of samples held at the original temperature (2.5 °C) throughout storage. This suggests that the two months in the warmer temperature was insufficient to re-condition sugar metabolism from the previous lower temperature.

During both 2012-13 and 2013-14, a negative correlation between storage temperature and fry colour score was found (Figures 3b.3 and 3c.2). This supports prior knowledge of cold temperature sweetening and shows a potential benefit of warmer storage in reducing the risk of sugar accumulation and its impact on taste, texture and acrylamide.

Sprouting and respiration can both impact on fry colour but in these trials there was very little difference in the measured rates of these parameters between the treatments.

Acrylamide

Acrylamide content varies widely within the same food product with, in general, darker colour processed food products containing higher acrylamide contents. In this study acrylamide content increased with increasing fry colour and tubers stored at the lowest temperature had both darkest fry colours and highest acrylamide content. There are differences between varieties in acrylamide formation capacity because of other factors including asparagine content (Halford *et al.,* 2012). In these trials, and despite similar fry colours, Maris Piper and Marfona produced less acrylamide than King Edward and Desiree. In 2011-12, Desiree chips had approximately twice the acrylamide levels found in other varieties, even though the fry colours were similar to Marfona (Table A1.a.8).

During 2011-2012, the very dark fry colours at all storage temperatures were associated with very high acrylamide levels 500-2000 µg/kg, within the maximum range reported by European Food Safety Authority (EFSA, 2011). During 2012-13, using a modified frying procedure, lower overall fry colours and lower acrylamide levels of between 50 and 400 µg/kg were measured in French fries, around the European mean over 2007-2009 of 350 µg/kg (EFSA, 2011). This study has shown for year 2 that as storage temperature increased by 1°C, acrylamide decreased by 41 µg/kg (2012-13, Figure 6).

The Food Standards Agency recommends that, when making chips at home, they are cooked to a light golden colour, a recommendation that is also included in cooking advice in some potato packaging. However, if the potatoes have been stored at very cold temperature it may not be possible to cook the potato adequately before a dark colour has occured. A move to warmer storage temperatures would reduce this risk.

Taste and texture

The taste and texture of fresh market potato is a very strong determinant of appeal and this study investigated the assessment of consumer appeal in respect to taste and texture.

During 2012-13, some attributes were identified as having changed in a similar fashion across all varieties. Colour appeared whiter at lower temperature, aroma was slightly more starchy at lower temperatures, taste was sweeter at lower temperatures and texture was somewhat smoother at lower temperatures and in the transfer treatment. Overall these changes appeared to have had little consequence as, except for Desiree being preferred following storage at the warmer temperatures, there was no clear preference for any particular storage treatment for the varieties. A texture assessment run under professional guidance during 2013-14 could not substantiate the findings, there being little discernible difference between the attributes of potatoes stored at different temperature that was detected by the panel of assessors. Overall there appear to be few differences in attributes between the different temperatures.

2.4.4 Energy costs of storage

The costs of maintaining a 1000 tonne potato store at warmer temperatures were shown to provide an energy saving of 7% and 11% saving in energy consumption for 4 °C and 5.5 °C respectively compared with 2.5 °C.

Overall the calculations show a small energy and cost saving of warmer temperature storage compared with the cost of storage although it should be noted that additional sprout control may be required at the two warmer temperatures.

2.5 Conclusions

Consumer preference, through supermarket feedback and response, is a strong driver for variety selection and treatment and handling post-harvest. This study has shown that storage at warmer temperatures does not significantly affect tuber quality important in consumer preference or, other than in sprouting, for management during storage.

Over the range of storage temperatures 2.5 to 5.5 °C, skin bloom and blemish diseases were essentially unaffected by storage temperatures. Similarly, neither weight loss or respiration rate were significantly affected by temperature of storage. Very little

sprouting was observed in the trial, either because of low temperature storage or CIPC control. All these measured properties increased with storage duration.

After six months, fry colour was darker and acrylamide content of French fries highest at the coldest storage temperatures. The different storage temperatures had little or no measurable effect on taste and texture attributes assessed during the study. During 2012-13, Desiree was preferred after six months storage at the warmer temperatures but there was no clear preference for the other varieties.

Overall the disadvantages of cooler storage are most evident in increased processing colour and consequent acrylamide levels and energy use. The primary disadvantage of using warmer storage, particularly at 5.5 °C, is the requirement to provide additional sprout control.

Energy cost of storage at 5.5 °C was the least expensive but there would be additional costs of sprout control. Calculated costs of storage showed an energy saving at the warmer temperatures of approximately 11% between the coldest and warmest temperature.

Based on this study, advice to store managers and the industry is that there are likely to be small advantages in tuber quality and market acceptance and acrylamide levels in storing at intermediate temperatures (for example 3.5-4°C) in preference to 2.5°C, providing adequate sprout control measures are available.

2.6 Recommendations for future work

Tuber respiration rate has been shown not to conform to accepted wisdom, in particular there is no evidence of significant differences in rate between tubers stored 2.5°C and slightly warmer temperatures. Further work is being carried out to investigate this finding.

2.6 References

Burton W. G. (1989). The Potato 3rd Edn. Longman Scientific and Technical, London, UK.

Butchbaker A.F., Promersburger W. J., and Nelson D. C. (1973). Respiration and weight losses of potatoes during storage. Farm Research Jan-Feb 33-40.

Carbon Trust (2013)
http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf.

EFSA Journal (2011). Scientific report of EFSA results on acrylamide levels in food from monitoring years 2007-2009 and exposure assessment. 9 (4): 2133.

Farm Electric Handbook, Potato Storage (1984) Electricity Council Stoneleigh, UK.

Golob P. Farrell G. and Orchard J. E. (2002). eds. Crop Post-harvest:Scence and Technology, Volume 1 Principles and Practice.

Halford N.G., Curtis T.Y., Multucumaru N., Postles J., Elmore J.S. and. Mottram D.S. (2012). The acrylamide problem: a plant and agronomic science issue. Joumal of Experimental Botany. Vol 63. Pp. 2841-2851.

Potato Storage (1983), Farm Electric Handbook, The Electricity Council - EC 4457/10.85.

Institute of Food Science & Technology (2012). Information statement: acrylamide in foods. October 2012. *www.ifst.org/document.aspx?id=2142.*

Napier R, Andrews J, (2005). The physiology and biochemistry of skin set and skin netting in potatoes. Research report to Defra (Project code HP0140).

Sanny M., Jinap S., Bakker E.J., van Boekel, M.A.J.S. and Luning P.A (2012). Possible causes of variation in acrylamide concentration in French fries prepared in food service establishments: An observational study. Food Chemistry, 132, Pages 134–143.

Schippers, P.A. (1977). The rate of respiration of potato tubers in storage 1, review of literature. Pot Res 20, 173-188.

Wiltshire J., Peters J., Milne F. (2005). Improving the understanding and management of skin set and bloom in potatoes. British Potato Council Final Report Ref: 807/222.

3. Annexes

Due to the size of the document- the annexes are provided as a separate pdf: R458 Annexes.pdf