Project Report

Managing maturity to improve crop processing quality and storage

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Preface

This project builds on work carried out in the BPC-funded Agronomy and Storage for Processing project. This showed that tuber maturity was the predominant factor influencing processing quality, both at harvest and throughout storage. The aim of the current project was to test the relative importance of agronomic factors that may have an effect on the physiological age of the ware crop and therefore tuber maturity at harvest on processing quality.

Two years of field and storage trials were carried out at ADAS and Sutton Bridge Experimental Unit. Both chipping and crisping varieties were included, and fry colour and fry defects were used to gauge processing quality. The field experiments included different seed crop husbandry, chitting and planting date treatments whilst the storage trials evaluated the influence of storage temperatures on processing quality.

The work has shown that although the planting date and chitting treatments resulted in significant effects on fry colour during storage, these effects were small relative to the seasonal differences in fry colour that were observed during the study. It was not possible to use simple in-field measurements such as rate of canopy senescence, level of senescence at defoliation or tuber sugar concentrations to predict storage potential. In store, raised temperature generally maintained fry colour better.

British Potato Council

1. Summary for growers

1.1 Project aims

The main aim of this project was to understand how crop management decisions influence the processing quality of four potato cultivars (Maris Piper, Russet Burbank, Lady Rosetta and Saturna) during long term storage. This knowledge would enable growers to better manage crops to achieve the necessary standards for the chip and crisp industries. Additionally the project seeks to establish whether physiological characteristics of the crop in the field, which are thought to be linked to crop 'maturity', may be used as predictive indicators of processing quality during storage.

The objectives were:

- To investigate the potential for using field measurements of 'maturity' as indicators of storage potential.
- To improve the understanding of the influence of seed crop husbandry, seed chitting and planting date on the processing quality of potatoes during long-term storage.
- To evaluate the use of different storage temperatures as a means of maintaining processing quality during storage.

1.2 Work undertaken, key findings and conclusions

1.2.1 Experiments

This project consisted of four separate experiments with the same treatment design, each using one of the cultivars Maris Piper, Russet Burbank, Saturna and Lady Rosetta conducted over two growing seasons. The field phase of the experiments were conducted on medium sandy loam soil over a sand sub-soil at ADAS Gleadthorpe, Nottinghamshire, during the growing seasons of 2002 and 2003. The subsequent storage phase was conducted at Sutton Bridge Experimental Unit between September and June subsequent to each harvest. The field treatments were designed to produce potatoes with a range of processing quality characteristics. The responses to these treatments were assessed under contrasting storage temperature regimes. The field treatments are presented in Table 1.

TABLE 1. FIELD TREATMENTS.

Factor 1 Seed production	**S1** 'Immature' seed (ie growing season of seed crop constrained by late planting and/or early defoliation)	**S2** 'Mature' seed (ie growing season of seed crop not limited by late planting and/or early defoliation)
Factor 2 Chitting treatment	**C1** Seed unchitted at planting	**C2** Seed chitted at planting
Factor 3 Planting date	**P1** Planted early	**P2** Planted late

The experiments were of a factorial design with all combinations of the 3 factors. After harvest, the produce from each plot was split into 2 lots and stored at 2 temperatures (8.5 and 11^{o}C, except R. Burbank, which was stored at 7 and 11^{o}C).

The treatments were designed to investigate management practices that are available to growers, and that have potential to affect tuber 'maturity' at harvest. 'Maturity' has been linked to good processing quality in store and there is, therefore, the potential to improve the storage quality of the tubers by managing their 'maturity'.

A comprehensive set of field and storage assessments was undertaken.

1.2.2 Effect of field treatments on crop maturity

The seed production treatment had only a limited and inconsistent effect on green canopy cover at the time of defoliation, which is an indicator of crop maturity in the field.

The chitting and planting date treatments affected the date of tuber initiation and the area of green canopy cover at the time of defoliation. The effects of chitting and planting date on canopy cover at defoliation were substantial (Figure 1), with planting date providing the largest treatment differences in most varieties. These treatments, therefore, produced ware tubers at different stages of 'maturity' prior to storage, so that the influence of management practices, which affect maturity, could be investigated in relation to storage quality.

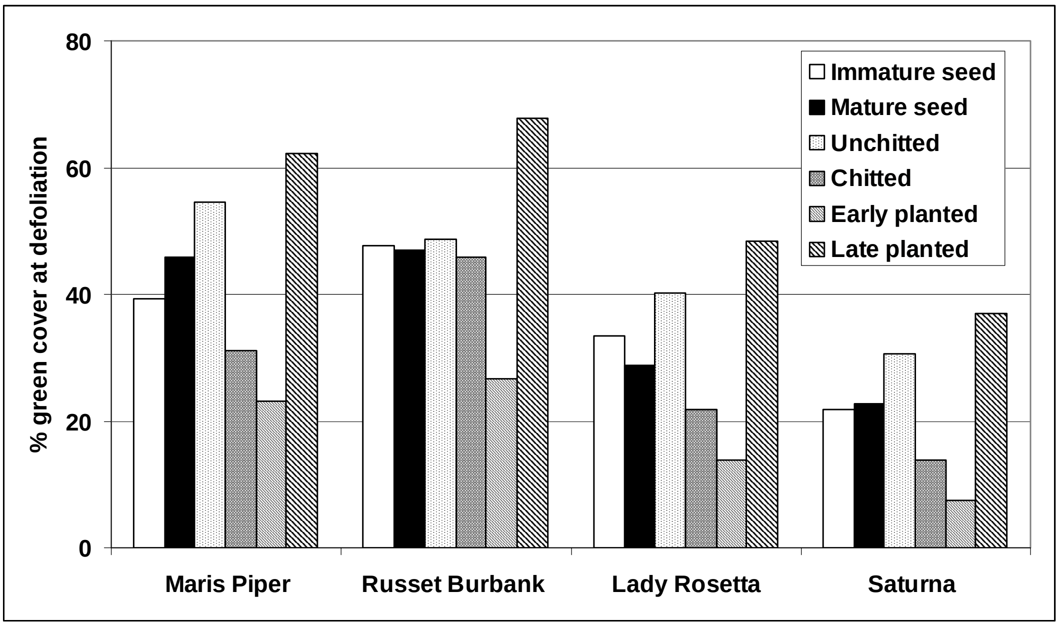

FIGURE 1. THE EFFECT OF FIELD TREATMENTS ON CANOPY SENESCENCE AT DEFOLIATION (MEAN OF BOTH YEARS).

1.2.3 Yield

All treatments significantly affected ware yield at harvest in at least one variety in one season. The most consistent and largest effects were associated with planting date with early planting increasing yields. The mature seed and seed chitting treatments increased yields in one variety only, and in one year only, respectively.

All treatments, including the seed production treatment, affected ware tuber sugar concentrations at defoliation and at intake into store. In general treatments which would be expected to encourage a 'mature' state at harvest (seed chitting and early planting) were associated with lower tuber sucrose concentrations at defoliation and harvest. However, the effect of the seed production treatment was less consistent.

1.2.4 Effect of seed maturity on storage quality

Despite the fact that seed maturity significantly affected canopy cover at defoliation, tuber sugar concentrations and ware yield in at least one variety in one year, there was no effect of this treatment on any of the storage parameters measured.

1.2.5 Effect of seed chitting on storage quality

Chitting had little effect on the storage quality of Maris Piper or Russet Burbank. However, chitting affected the fry colour and the weight of fry defects for both crisping varieties. In both years of the study and for both crisping varieties, seed chitting gave a small but significant reduction in the weight of fry defects during storage up to March. In some cases this effect was reversed during late storage with chitting significantly increasing fry defect. Figure 2 shows data for Saturna in Year 2.

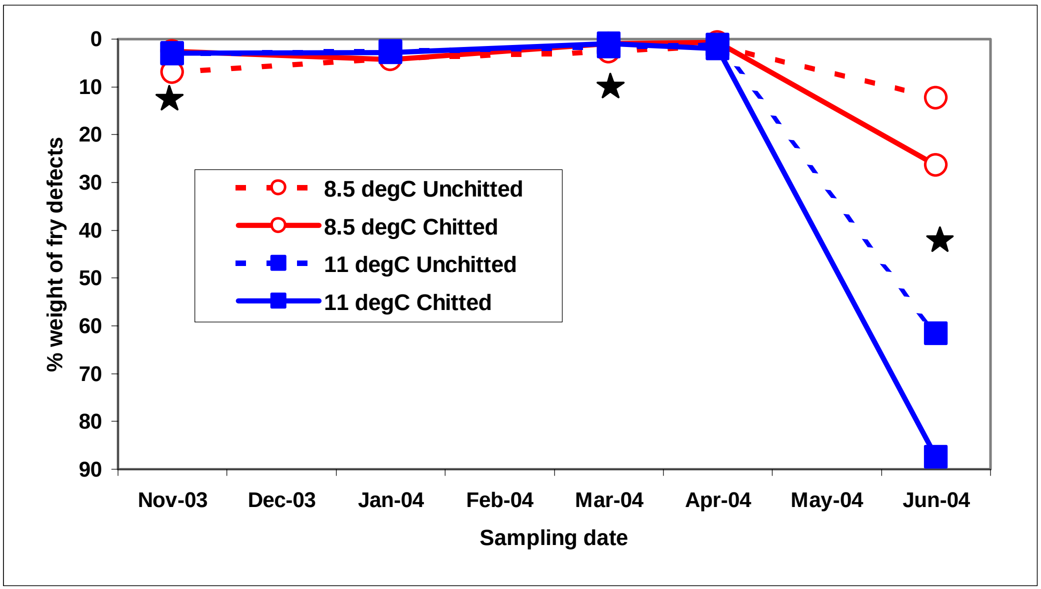

FIGURE 2. THE EFFECT OF CHITTING TREATMENT ON THE % WEIGHT OF FRY DEFECTS (YEAR 2) DURING STORAGE AT 2 DIFFERENT TEMPERATURES (SATURNA). ★ INDICATES SIGNIFICANT FIELD TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P<0.05).

Seed chitting was associated with darker fry colours in both crisping varieties for both seasons, on at least one occasion during long term storage.

1.2.6 Effect of planting date on storage quality

The planting date field treatment provided the most consistent and marked effects on long term storage quality across all varieties and both seasons. For the chipping variety Maris Piper, the early planting date was associated with darker fry colours (Figure 3).

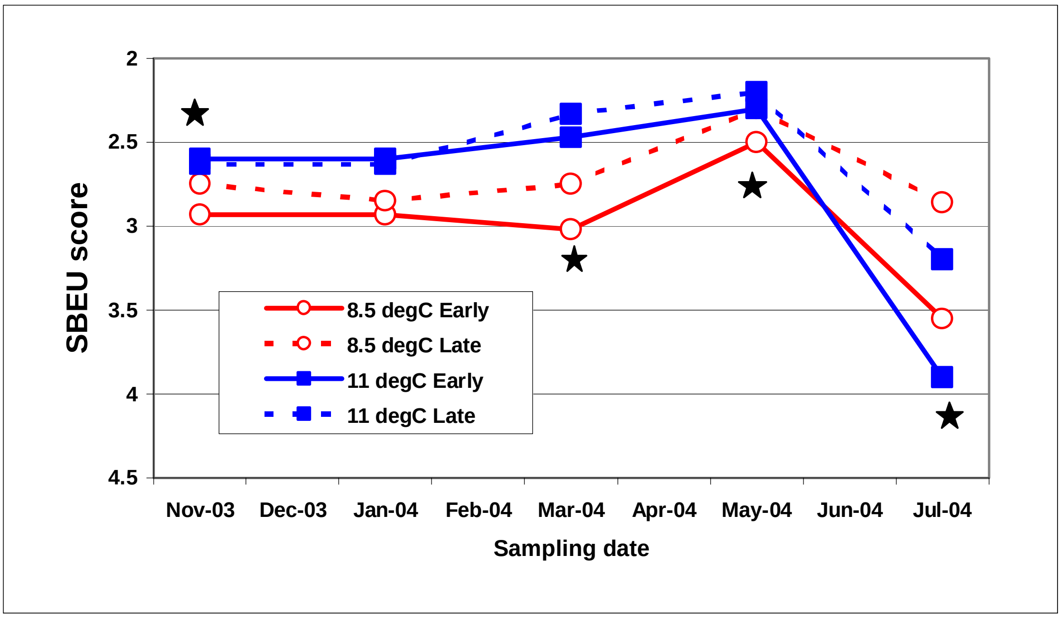

FIGURE 3. THE EFFECT OF PLANTING DATE TREATMENT ON FRY COLOUR (SBEU SCORE) DURING STORAGE AT 2 DIFFERENT TEMPERATURES (YEAR 2, MARIS PIPER). ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (*P*=<0.05).

Conversion of USDA class to SBEU score:

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

The effects of planting date on fry colour for the variety Russet Burbank, although occasionally significant, were too small to be of commercial relevance.

Planting date had little affect on fry colour in the crisping variety Lady Rosetta, but did produce effects in Saturna at the last 2 sampling dates in both years. In both years the darker fry colours were associated with the earlier planting date, suggesting a senescent sweetening effect.

Planting date treatment affected the % weight of fry defects during storage in both crisping varieties in both years. In Lady Rosetta early planting was associated with a higher incidence of fry defects in both years of the study. This effect was particularly apparent towards the end of the storage period (Figure 4). For Saturna in Year 1, early planting gave rise to fewer fry defects during storage up to March, but this situation had reversed by the end of storage in June.

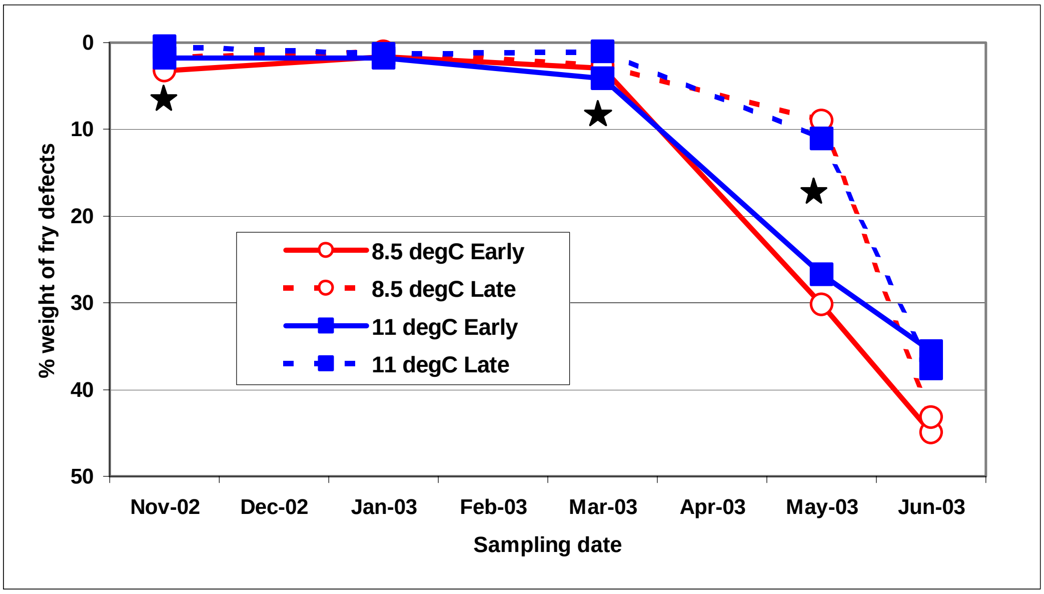

FIGURE 4. THE EFFECT OF PLANTING DATE TREATMENT ON THE % WEIGHT OF FRY DEFECTS DURING STORAGE AT 2 DIFFERENT TEMPERATURES (YEAR 1, LADY ROSETTA). ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05)

1.2.7 Effect of storage temperature on processing quality

Fry colour during storage up to March was consistently superior where tubers were stored at the higher temperature of 11°C. Storage at this temperature after this date gave rise to darker fry colours and an increased proportion of fry defect in the crisping varieties.

In addition to the measurements of treatment effects on processing quality, the data were extensively analysed to study the relationships between the physiological characteristics of the crop in the field and their subsequent storage quality. The purpose of this exercise was to establish whether simple, in-field assessments, such as rate of canopy senescence, level of senescence at defoliation, or tuber sugar concentrations, might predict storage quality. This analysis was a key part of the study because, if such relationships could be reliably established, the information would help growers decide priorities for crop storage. However, in this project, no reliable relationships were identified.

1.2.8 Conclusions

- Of the field treatments investigated planting date and seed chitting had the greatest effects on crop development in the field.
- Treatments, which encouraged a ‘mature’ state at harvest, resulted in generally poorer processing quality in store. However, treatment differences, although significant, were often small in commercial terms.
- Processing quality until March was generally superior where tubers were stored at the higher temperature.
- No reliable relationships between measurements taken prior to storage and quality during storage could be established
- Although the results of this study suggested that increased maturity at harvest compromised fry colours during storage, previous work has shown the opposite effect. It is suggested that the reason for these contrasting results relate to seasonal differences.
- Processing quality in the two seasons was very different, despite similar planting dates and length of growing season. These differences in fry colour between seasons exceeded those between field treatments. It was recognised at the start of this work that there would be interacting seasonal factors that affect processing quality. These factors also directly affect crop development and the aim of this work was to identify crop parameters that reflect these interacting seasonal factors and relate to processing quality. However, such predictive crop parameters were not found.
- A lack of understanding of tuber ‘maturity’ remains a significant obstacle to further progress.

1.3 Practical recommendations

- Field/storage trials were carried out evaluating effects of seed age, seed chitting and planting date on quality of processing crops during storage at two temperatures.
- In detailed field trials, crop canopy and changes in canopy close to harvest were unrelated to fry colour of progeny crops during storage.
- Sugar content of tubers (glucose, fructose or sucrose) at defoliation and/or harvest, were also unrelated to the fry colour of crops out of storage.
- Planting date and chitting treatments resulted in significant effects on fry colour during storage, but effects were smaller than seasonal differences in fry colour. Although the experimental design does not allow the evaluation of interactions with storage temperature, the data suggest that knowledge of the physiological age of crops may be useful for decision making in the identification of crops for long-term storage. In seasons where senescent sweetening occurs, processing quality from long-term storage may be improved in crops where agronomic treatments have tended to conserve physiological age.

2 Experimental section

2.1 Introduction

Fry colour is a major criterion for assessing the quality of potato crops for processing. Early work showed that, during frying, reducing sugars combine with amino-N compounds in the Maillard reaction to produce a brown colouring of processed products (see a review by Gray and Hughes, 1978). As a consequence, considerable efforts have been made to relate processing quality to the substrates for the Maillard reaction with variable success (see Hogge, Stalham and Allen, 1993 for a résumé of these). These relationships have been inconsistent and are of limited commercial value. For example, Mazza (1983) reported relationships between fry colour, tuber dry matter, sucrose and reducing sugars, but concluded that the quantitative relationship between these factors was not sufficiently stable to be used predictively.

Sowokinos (1998) proposed that the level of sucrose at harvest was a good indicator of subsequent processing quality and suggested ratings for a number of varieties between 0.17 and 0.28% sucrose on a fresh weight basis. Some UK processors are using this method as part of their assessment of chemical maturity.

Reports of the effects of agronomic factors on fry colour are notable by their inconsistency of response. Length of growing season appears to be important (Hogge *et al.,* 1993; Hermann *et al.,* 1995), but if a long season coincides with late harvesting and low soil temperatures at harvest, processing quality is poor (Twiss, 1963). It is also reported to be poor if the tubers are immature but this is not invariably so (Hogge *et al.,* 1993).

Hope, MacKay and Townsend (1960) reported that more mature tubers had better fry colour, whereas Kissmeyer-Neilsen and Weckel (1967) showed that late harvesting results in higher levels of reducing sugars because of low soil temperatures. This latter paper shows the danger of confusing effects of maturity with effects of low-temperature sweetening.

There are many reports of the effects of nitrogen fertilisation on processing quality in the scientific literature. This is of relevance to this study, as nitrogen nutrition is known to influence crop maturity at harvest. The reports show some inconsistency in the response of processing quality to nitrogen. For example, Roe, Faulks and Belsten (1990) showed that as nitrogen application increased, fry colour improved. High nitrogen resulted in low concentrations of sugars, but increased free amino acid content, and these could be expected to have opposite effects on fry colour. Hughes and Fuller (1984) also found that high nitrogen fertilisation resulted in low levels of total reducing sugars, but found no effect on fry colour. In contrast, Hope, MacKay and Townsend (1960) found that more nitrogen resulted in darker chips, and this is supported by Dahlenburg, Maier and Williams (1990), who concluded that excess nitrogen and nitrogen deficiency both resulted in darker fry colour.

Santerre, Cash and Chase (1986) found that increased nitrogen resulted in higher tuber dry matter at harvest, but that this affect decreased as harvest was delayed. This illustrates that consideration of agronomic or environmental factors in isolation may lead to inconsistent results because of interactions.

The experimental section below describe experiments designed to study the influence of field agronomy treatments on processing quality and seeks to establish relationships between crop characteristics which can be measured in the field and long term storage potential. The study covers 4 separate experiments of the same treatment design, each using one of the cultivars **Maris Piper, Russet Burbank, Lady Rosetta** or **Saturna**. The experiments consisted of a field and a storage phases. The field phase of each experiment was conducted at ADAS Gleadthorpe during the 2002 and 2003 growing seasons, and the subsequent storage phase were carried out at Sutton Bridge Experimental Unit between September and June after each harvest.

2.2 Material and Methods

2.2.1 Field phase

Four experiments (one for each cultivar) were conducted in 2002 and 2003 at ADAS Gleadthorpe, Meden Vale, Nottinghamshire, on a loamy sand soil with a low available water capacity (100 mm of water in the top metre of soil @ 15 bars tension). Field plots of cultivars Maris Piper, Russet Burbank, Saturna and Lady Rosetta were grown with the aim of producing ware tubers at a range of physiological ages and different storage potentials.

The experiments were of a factorial design, with 3 replicates of each treatment in separate blocks, with one plot of each treatment in each block. Plot size was 6 rows by 9 m (46.6 m^2), which was calculated to provide a sufficient tuber yield for the storage phase of the experiments. The field treatments are given in Table 2. This design allows the influence of seed production, chitting and planting date on processing quality to be investigated separately and in combination in a full factorial design. Additionally the influence of storage temperature was investigated by splitting the produce from each plot into 2 lots and storing these at 2 different temperatures.

TABLE 2. FIELD TREATMENTS.

Factor 1 Seed production	**S1** 'Immature' seed (ie growing season of seed crop constrained by late planting and/or early defoliation)	**S2** 'Mature' seed (ie growing season of seed crop not limited by late planting and/or early defoliation)
Factor 2 Chitting treatment	**C1** Seed unchitted at planting	**C2** Seed chitted at planting
Factor 3 Planting date	**P1** Planted early	**P2** Planted late

The seed used in the study in both 2002 and 2003 were produced in the previous seasons at ADAS High Mowthorpe. For the experiments planted in 2002 the seed production treatment differences were imposed by flailing-off the foliage early (S1) or at the standard time (S2). The time difference was 2 weeks, which equated to a 200 day degree difference (tuber initiation to flailing). For the experiment planted in 2003 differences were achieved both by manipulating planting and defoliation dates. Planting dates were separated by 18 days which gave rise to differences in the date of tuber initiation of between 7 days (Maris Piper) and 14 days (Russet Burbank). The dates of defoliation were separated by 15 days. Seed tubers from the early-planted, late-defoliated crop formed the S2 treatment; those produced from the late-planted early-defoliated formed the S1 treatment. In both years the seed crops (S1 and S2) were harvested on the same date (21/9/01 and 12/9/02). After seed harvest in both seasons, all seed were stored below 4°C until the start of the chitting treatments or until 2 days before planting (to allow the seed to reach ambient temperatures) depending on treatment.

The chitting treatments were imposed at ADAS Gleadthorpe by removing seed from cold storage (<4°C) and holding at *c.*10°C under lights so that, at the time of planting, seed had *c.* 350°C days (Maris Piper & Lady Rosetta), 300°C days (Saturna) and 50°C days (Russet Burbank). The low value of day degrees in the chitted treatment for Russet Burbank was as planned and reflected commercial advice.

The seed tubers (size grade 35 to 45 mm, except Russet Burbank 40 to 50 mm) were planted by hand into previously stone separated and opened ridges, prior to re-ridging. The planting dates were 27 March (P1) and 25 April (P2) in 2002, and 27 March (P1) and 24 April (P2) in 2003. The row width was 86 cm and spacing within the row were 37 cm (Maris Piper), 34 cm (Russet Burbank), 20.5 cm (Lady Rosetta) and 29 cm (Saturna). The seed rate and spacings were advised by ADAS agronomist Denis Buckley to ensure that they were representative of best commercial practice. Fertiliser applications were based on MAFF RB209 and irrigation schedules were designed to achieve optimum yields based on previous research conducted at ADAS Gleadthorpe.

The times of 50% and full plant emergence were recorded.

Within each experiment all plots from replicate 1 were assessed for the date of tuber initiation. Two sample plants per plot were examined in discard rows. Soil was removed from one side of the potato ridge to expose the root/stolon system around the mother tuber, taking care to expose any stolons below the level of the mother tuber as tuber initiation often occurs on deeper stolons first. Stolons were traced from the mother tuber area to the tip on the exposed ridge side only. The date of initiation was taken as that on which at least two stolon tips on each of five sample plants had produced tubers. After assessment of stolon ends the soil was returned to the ridge so that minimum disturbance was caused to the plant.

Green canopy cover was assessed from emergence to defoliation in all plots at weekly intervals using a grid method. A quadrat was used which was divided into 100 equal sized squares. Three quadrat counts per plot were made at approximately equal intervals along the length of the plot. The quadrat was placed above the crop so that it spanned the row exactly, and the number of squares within the quadrat which contain more than 50% green haulm were counted. The level of green canopy cover was then estimated as the percentage of squares with more than 50% green haulm.

Plots were defoliated using a tractor-mounted mechanical flail 3 weeks before the harvest dates of 16-17/9/02 (Saturna and Lady Rosetta), 23-24/9/02 (Maris Piper and Russet Burbank), 15-16/9/03 (Saturna and Lady Rosetta), and 29-30/9/03 (Maris Piper and Russet Burbank). After this operation any remaining stems were severed close to ground level by hand. At the date of defoliation, 4 plants were hand harvested from the centre 4 rows of each plot. These were transported to Sutton Bridge Experimental Unit for analysis (see section 2.2.2).

At harvest 8 plants were hand harvested from the centre 4 rows of each plot and transported to Sutton Bridge Experimental Unit for yield analysis (see section 2.2.2). The remaining plot area was machine lifted for the storage treatments. Tubers were hand picked from the soil surface into bags which were then transported to Sutton Bridge Experimental Unit on the day of harvest.

2.2.2 Storage phase

At SBEU crops were graded 45-70 mm (cvs. Maris Piper and Russet Burbank) or 40-80 mm (cvs. Lady Rosetta and Saturna) and transferred to 10 kg capacity polypropylene storage containers. Sufficient trays were filled for the assessment of samples from all treatments at the end of curing and on 5 occasions thereafter.

Storage of crops took place in 6-tonne capacity stores, with temperature controlled by discontinuous operation of refrigeration/air recirculation. All crops were cured for a period of two weeks at 15ºC and ambient relative humidity. For each cultivar, storage occurred at two temperatures (Table 3).

Reduction in temperature from curing to holding values occurred at a rate of 0.5°C per day. Relative humidity was maintained above 95% after the stores reached their target temperature. The positions of containers in store were determined by using random numbers.

TABLE 3. STORAGE TEMPERATURES.

Cultivar	Storage temperature (°C)	
	Standard	High
Lady Rosetta	8.5	11.0
Maris Piper	8.5	11.0
Russet Burbank	7.0	11.0
Saturna	8.5	11.0

Sprout growth of samples was inhibited by the use of CIPC (MSS CIPC 50 M, Whyte Agrochemicals Ltd.) applied at 'store capacity' rate using a Motan Swingfog SN 50 (Swingtec GmbH, Isny, Germany) thermal fogging instrument. Stores were switched off prior to application. Seven to eight hours after CIPC application, stores were flushed and temperature control was re-enabled.

Stored crops were assessed for weight loss, and fry quality. In addition, at defoliation and storeloading, assessment was made of dry matter content and concentrations of glucose, fructose and sucrose.

Dry matter content

Dry matter content was assessed using a computerised system operating on the principle of specific gravity (weight in air/weight in water).

Fry quality - Chips

A random sample of 20 tubers was obtained and a single, longitudinal, 7 mm square section cut from each tuber. Pooled samples of 20 sections were fried for 1.5 minutes in oil at a temperature of 190°C at the start of frying. The fry colour of individual sections was classified, in a light cabinet, using a USDA chart. Results are presented as a mean SBEU score derived as shown in Table 4.

TABLE 4. CONVERSION OF USDA CLASS TO SBEU SCORE.

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

Fry quality - Crisps
A random sample of 30 tubers was obtained. After washing and peeling, individual tubers were cut in half longitudinally, with one half being retained and the other discarded. From the retained sample, 300 g of slices with a thickness of 1.2-1.5 mm were cut using an electric slicer, ensuring slices were obtained from all tubers of a sample.

Slices were then washed under running water for 45 seconds, before being fried for three minutes in oil with a temperature of 177°C at the start of frying. Fried samples were then weighed and inspected in a light cabinet. Crisps with fry defects were removed, and weighed. Crisps were classed as defect if they contained an area greater than 20 mm^2 subjectively judged to be darker than Hunter 'L' 49. Fry defects are expressed as a percentage of the weight of the whole fried sample.

Fry colour (L value) of samples was determined using the remaining fried sample, after removal of defects (Hunter LAB DP-9000). Results presented are the mean of three readings.

2.3 Results

The following sections present data collected for each cultivar during the field and storage phases of the study.

Where appropriate, the data collected at harvest, and subsequently during the storage study, were subjected to analysis of variance (ANOVA) using the full power of the factorial design. Data are only presented, where the analyses indicated significant treatment effects, and they are of relevance to the study objectives. Further investigation of the relationship between storage quality and measurements taken in the field are discussed.

2.3.1 Effect of field treatments on crop characteristics prior to storage

2.3.1.1 *Canopy cover*

Measurements of development and decline of crop canopy were taken as key indicators of the effect of the field treatments on the physiological characteristics of the crop. In particular the stage of senesence reached by the date of defoliation was studied as previous research has suggested a link between this measure of maturity and crop storage quality (Tables 5-8).

TABLE 5. EFFECT OF FIELD TREATMENT ON GREEN CANOPY COVER (%) AT DEFOLIATION (CV MARIS PIPER).

Field Treatment		Year 1 (2002)		Year 2 (2003)	
		% green cover at defoliation	Significance	% green cover at defoliation	Significance
Seed maturity	Immature	47.4	NS	31.4	<0.05
	Mature	51.2		40.7	
Chitting	Unchitted	62.1	<0.001	46.7	<0.001
	Chitted	36.6		25.5	
Planting date	Early	32.0	<0.001	14.3	<0.001
	Late	66.7		57.9	

TABLE 6. EFFECT OF FIELD TREATMENT ON GREEN CANOPY COVER (%) AT DEFOLIATION (CV RUSSET BURBANK).

Field Treatment		Year 1 (2002)		Year 2 (2003)	
		% green cover at defoliation	Significance	% green cover at defoliation	Significance
Seed maturity	Immature	54.2	NS	41.2	NS
	Mature	54.6		39.3	
Chitting	Unchitted	57.9	<0.05	39.6	NS
	Chitted	50.8		40.9	
Planting date	Early	33.3	<0.001	20.1	<0.001
	Late	75.4		60.4	

TABLE 7. EFFECT OF FIELD TREATMENT ON GREEN CANOPY COVER (%) AT DEFOLIATION (CV LADY ROSETTA).

Field Treatment		Year 1 (2002)		Year 2 (2003)	
		% green cover at defoliation	Significance	% green cover at defoliation	Significance
Seed maturity	Immature	31.7	NS	35.2	<0.05
	Mature	28.8		28.8	
Chitting	Unchitted	40.0	<0.001	40.4	<0.001
	Chitted	20.0		23.5	
Planting date	Early	10.8	<0.001	16.8	<0.001
	Late	49.6		47.1	

TABLE 8. EFFECT OF FIELD TREATMENT ON GREEN CONOPY COVER (%) AT DEFOLIATION (CV SATURNA).

Field Treatment		Year 1 (2002)		Year 2 (2003)	
		% green cover at defoliation	Significance	% green cover at defoliation	Significance
Seed maturity	Immature	24.4	NS	19.1	NS
	Mature	24.6		20.8	
Chitting	Unchitted	32.6	<0.001	28.8	<0.001
	Chitted	16.4		11.1	
Planting date	Early	7.3	<0.001	7.7	<0.001
	Late	41.7		32.1	

The data show that only planting date significantly affected green canopy cover at defoliation in all varieties and in both seasons. The chitting treatment produced significant effects in all varieties but the magnitude of difference was consistently less than that associated with planting date. There were no significant chitting effects with Russet Burbank in Year 2, possibly due to the limited chitting regime used (50 day degrees) used for this variety. Both the planting date and seed chitting factors that increased 'maturity' (i.e. early planting or seed chitting) decreased green canopy cover at defoliation. The seed maturity treatment only produced significant treatment effects in varieties Maris Piper and Lady Rosetta (year 2). The effects were inconsistent with mature seed delaying senscence in Maris Piper but hastening senscence with Lady Rosetta.

These data clearly indicate that all treatment factors signficantly affected crop maturity at harvest (as measured by canopy senescence). However, only chitting and planting date substantially affected this parameter with planting date associated with the largest and most consistent differences. This information is important, as it suggests the likely relative effect of the 3 field treatment factors on tuber maturity at the point of harvest and store loading. Therefore, the produce entering the storage phase of the study provided a good basis upon which to test the hypothesis that tuber maturity is linked to storage characteristics.

2.3.1.2 *Tuber sugar concentrations and dry matter*

Other measures of maturity prior to storage include tuber sucrose and reducing sugar concentrations both at defoliation and at harvest. These parameters were measured in both years of the experiment to investigate the potential relationship between measured concentrations and storage quality. The results of these analyses are discussed later (Section 2.3.4). Statistical analysis of the data confirmed that the field treatments affected sugar concentrations. However, the differences recorded were less frequent and less predictable (particularly at harvest) than differences in canopy cover, and do not add to an understanding of the issues when considered in isolation.

In year 1 dry matter content of crops was in the range 20.2-20.5%, 20.9-21.5%, 22.3-22.7% and 22.2-22.4% for Maris Piper, Russet Burbank, Lady Rosetta and Saturna respectively. In year 2 dry matter contents were a little higher, and occurred in the range 20.0-22.4%, 21.1-23.2%, 20.5-23.2% and 21.2-23.6% for Maris Piper, Russet Burbank, Lady Rosetta and Saturna respectively.

2.3.1.3 *Ware yield*

The effect of field treatments on tuber yields are summarised in figures 5 & 6. The seed maturity treatment affected yield in one variety (Saturna) in one season (2002). Chitting also affected yield in one variety (Lady Rosetta) in one season (2003). In both cases increased maturity was associated with increased ware yields. The planting date treatment provided the most consistant effect on yield with early planting increasing yields in all varieties in at least one year of the study. As with the canopy cover data, these results indicate that planting date had the greatest effect on crop development prior to harvest.

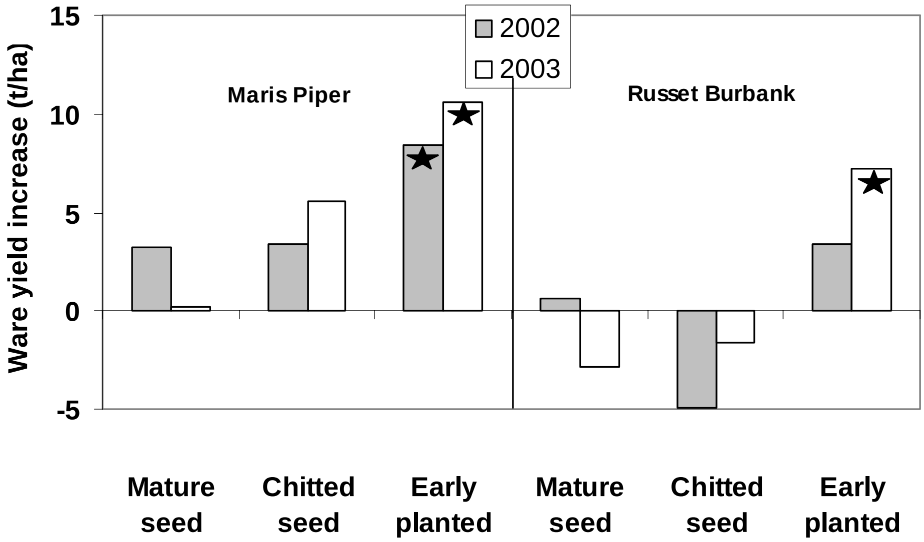

FIGURE 5. THE INCREASE IN WARE YIELD (T/HA) FOR TREATMENTS DESIGNED TO ENHANCE CROP MATURITY, COMPARED WITH TREATMENTS DESIGNED TO LIMIT MATURITY (MARIS PIPER, RUSSET BURBANK). ★ INDICATES SIGNIFICANT MAIN FIELD TREATMENT EFFECT (P<0.05).

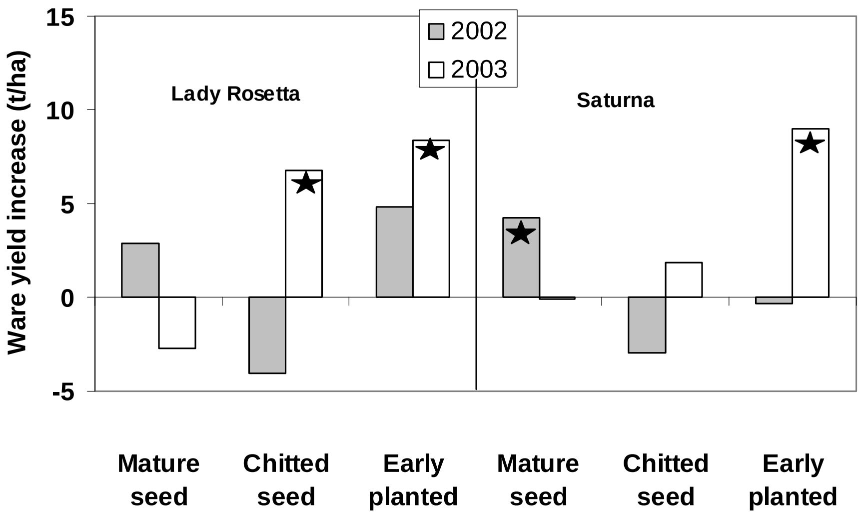

FIGURE 6. THE INCREASE IN WARE YIELD (T/HA) FOR TREATMENTS DESIGNED TO ENHANCE CROP MATURITY, COMPARED WITH TREATMENTS DESIGNED TO LIMIT MATURITY (LADY ROSETTA, SATURNA). ★ INDICATES SIGNIFICANT MAIN TREATMENT EFFECT (P<0.05).

2.3.2 The effect of field treatment on processing quality out of store

In this section we consider the effect of the seed maturity field treatment on tuber storage quality as measured by:

- fry colour (SBEU score) of the chipping varieties Maris Piper and Russet Burbank;
- fry colour (Hunter ‘L’ value) of the crisping varieties Lady Rosetta and Saturna;
- the weight of fry defects (%) of the crisping varieties Lady Rosetta and Saturna.

All data were subjected to a full factorial analysis so that the effect of each main treatment factor could be fully investigated.

2.3.2.1 *Seed maturity*

Seed maturity affected canopy cover at defoliation, tuber sugar concentrations at defoliation and harvest, plus ware yield in at least one variety in one year. However, there was no effect of this treatment on any of the storage parameters measured. It is therefore reasonable to conclude that whatever effects seed maturity may have on the ware crop, they were not of a nature or scale sufficient to affect subsequant storage quality.

2.3.2.2 *Seed chitting*

Chitting of Russet Burbank seed did not give rise to any important changes in fry colour during storage. Although a statistically significant improvement in fry colour was observed during sampling in November 2002, this was too small to be of commercial importance.

Chitting of Maris Piper seed was associated with a deterioration in fry colour late in the 2002/03 storage season (May) but the effect was slight (Fig.7). Chitting resulted in no significant changes in fry colour during early storage in 2003/04, but led to deterioration in fry quality in May and July (Fig.8).

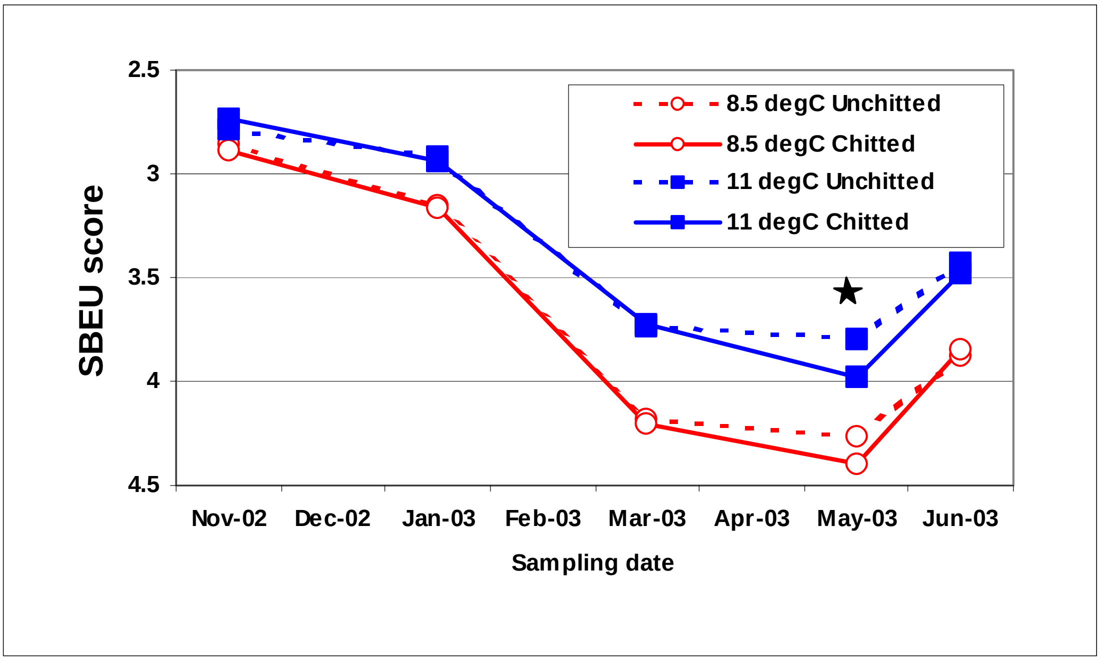

FIGURE 7. THE EFFECT OF CHITTING TREATMENT ON FRY COLOUR (SBEU SCORE) DURING STORAGE OF CV MARIS PIPER AT 8.5°C AND 11°C IN YEAR 1. ★ INDICATES SIGNIFICANT FIELD TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

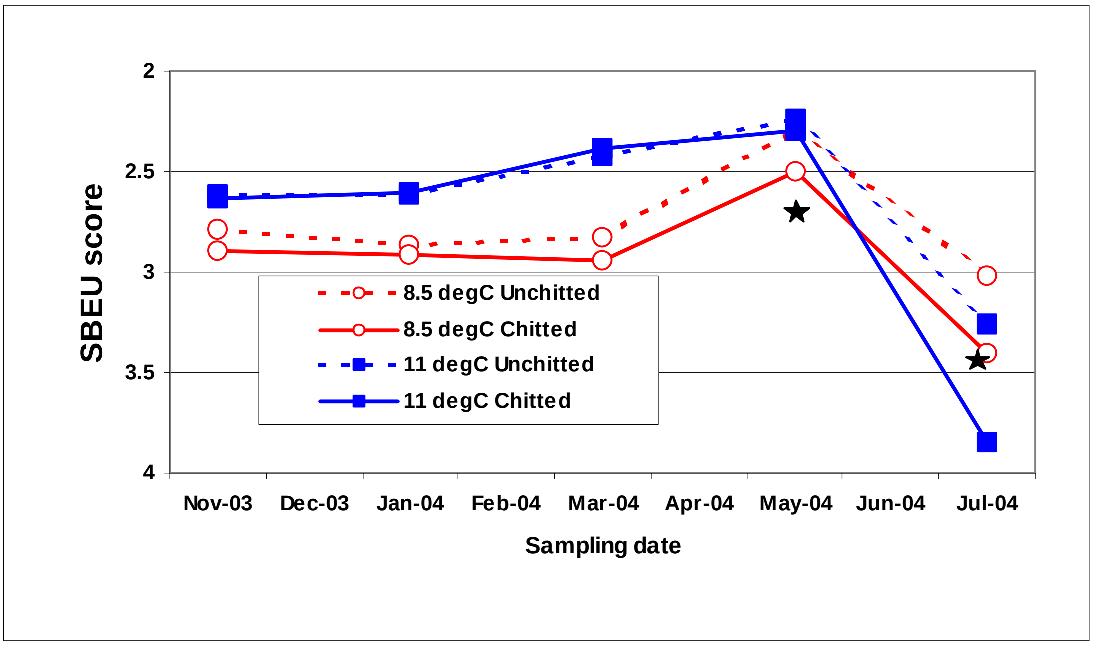

FIGURE 8. THE EFFECT OF CHITTING TREATMENT ON FRY COLOUR (SBEU SCORE) DURING STORAGE OF CV MARIS PIPER AT 8.5°C AND 11°C IN YEAR 2. ★ INDICATES SIGNIFICANT FIELD TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

Chitting of Lady Rosetta resulted in a significant, but relatively small, darkening of fry colour in Year 1 (Figure 9). Similar trends occurred in Year 2.

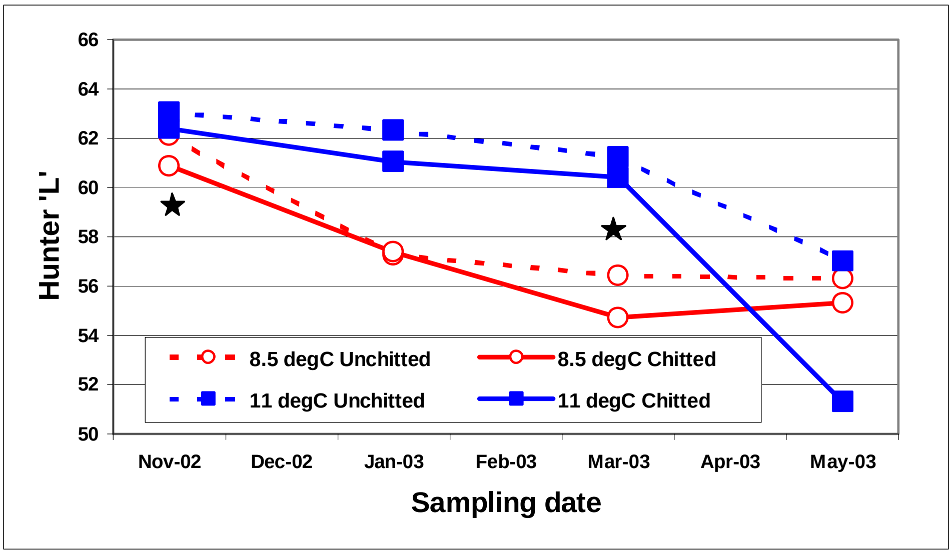

FIGURE 9. THE EFFECT OF CHITTING TREATMENT ON FRY COLOUR (HUNTER L VALUE) DURING STORAGE OF CV LADY ROSETTA AT 8.5C AND 11C IN YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

Chitting also resulted in significant changes in the level of fry defects, but differences were again very small. Where significant differences occurred in Year 1 (Figure 10), chitting was associated with an improvement in November but a deterioration in quality later on (May).

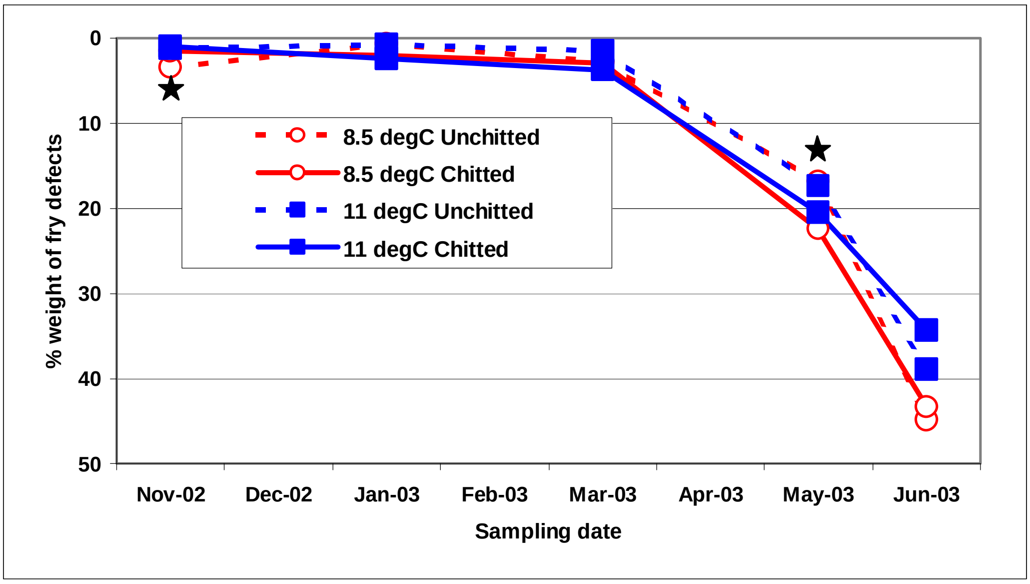

FIGURE 10. THE EFFECT OF CHITTING TREATMENT ON FRY DEFECTS (% WEIGHT) DURING STORAGE OF CV LADY ROSETTA AT 8.5°C AND 11°C IN YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

Seed chitting was associated with darker fry colour in Saturna on at least one occasion during long term storage in each season. Trends were similar to those for Lady Rosetta.

Chitting of Saturna was also associated with significantly fewer fry defects in both seasons during storage until March, but differences were small. Contrasting effects on fry defects were observed during the two storage seasons. Fry defect levels were high at the start of storage in Year 1 and reduced as storage progressed until the end of storage when levels increased again (Figure 11). In Year 2, fry defects levels remained at very low levels with the exception of the final sampling occasion when levels of fry defects were extremely high (Figure 12).

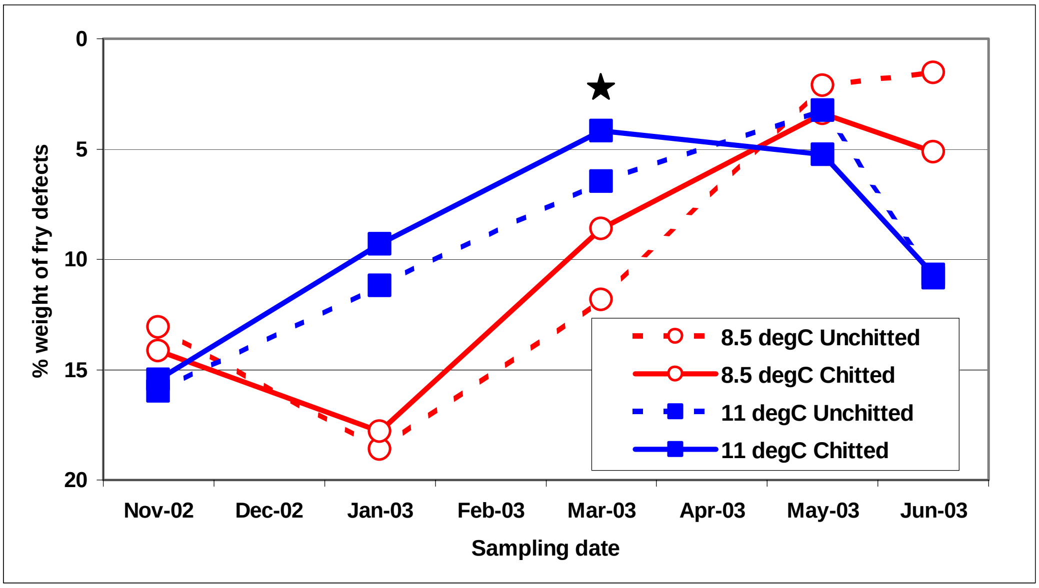

FIGURE 11. THE EFFECT OF CHITTING TREATMENT ON FRY DEFECTS (% WEIGHT) DURING STORAGE OF CV SATURNA AT 8.5°C AND 11°C IN YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (*P*=<0.05).

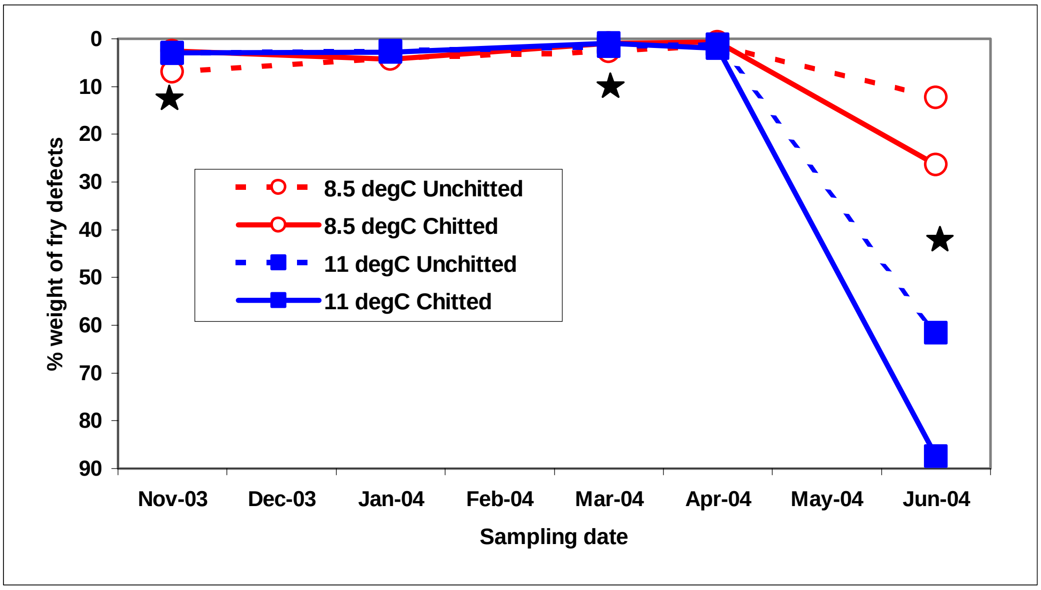

FIGURE 12. THE EFFECT OF CHITTING TREATMENT ON FRY DEFECTS (% WEIGHT) DURING STORAGE OF CV SATURNA AT 8.5°C AND 11°C IN YEAR 2. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (*P*=<0.05).

2.3.2.3 *Planting date*

The planting date field treatment provided the most marked effects on long term storage quality across all varieties and seasons. However, the exception to this was Russet Burbank where the effects of planting date on fry colour, although occasionally significant, were too small to be of commercial relevance.

In Maris Piper, early planting was associated with darker fry colours. Whilst the effect of field treatment was consistent across years, the pattern of change during storage was different. In Year 1 (Figure 13), there was a progressive decline in fry colour during storage until May, followed by an improvement in quality at the final sampling occasion in June whereas, in Year 2 (Figure 14), fry colour remained very light during storage until May, and then deteriorated rapidly.

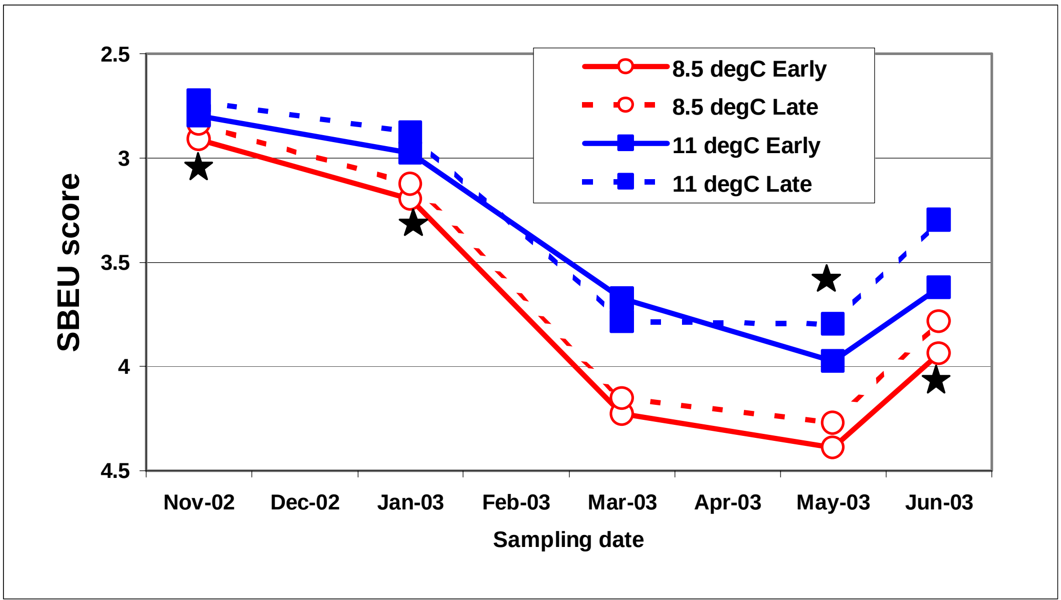

FIGURE 13. THE EFFECT OF PLANTING DATE TREATMENT ON FRY COLOUR (SBEU SCORE) DURING STORAGE OF CV MARIS PIPER AT 8.5^{o}C AND 11^{o}C IN YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (*P*=<0.05).

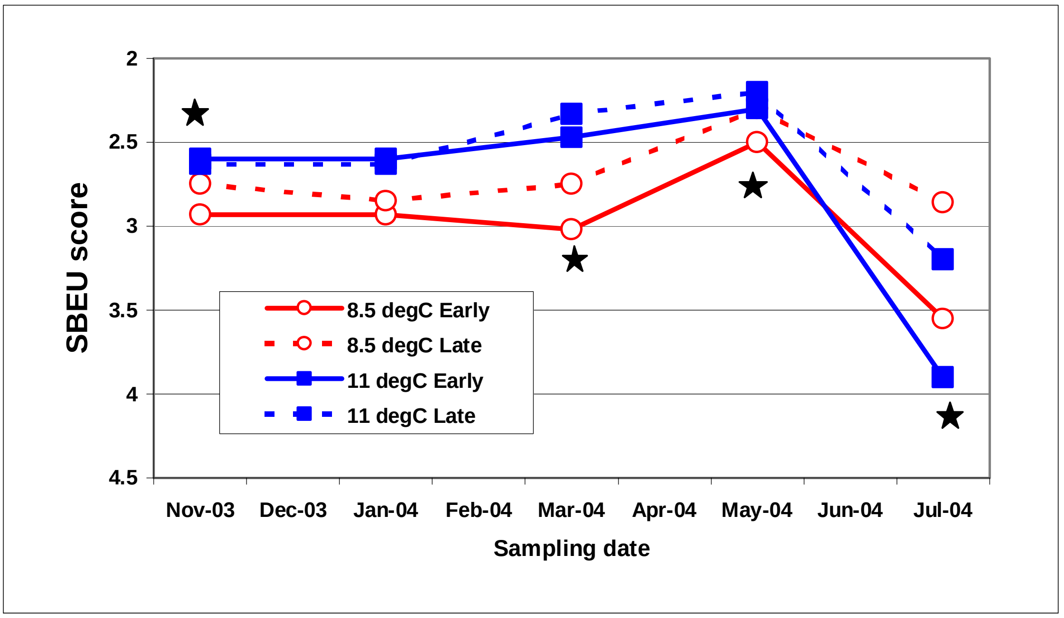

FIGURE 14. THE EFFECT OF PLANTING DATE TREATMENT ON FRY COLOUR (SBEU SCORE) DURING STORAGE OF CV MARIS PIPER AT 8.5°C AND 11°C IN YEAR 2. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

Planting date had little effect on fry colour in the crisping variety Lady Rosetta. Early planting was associated with a higher incidence of fry defects in both years of the study. This effect was particularly apparent towards the end of the storage period (Figure 15). In June, all treatments were commercially unacceptable.

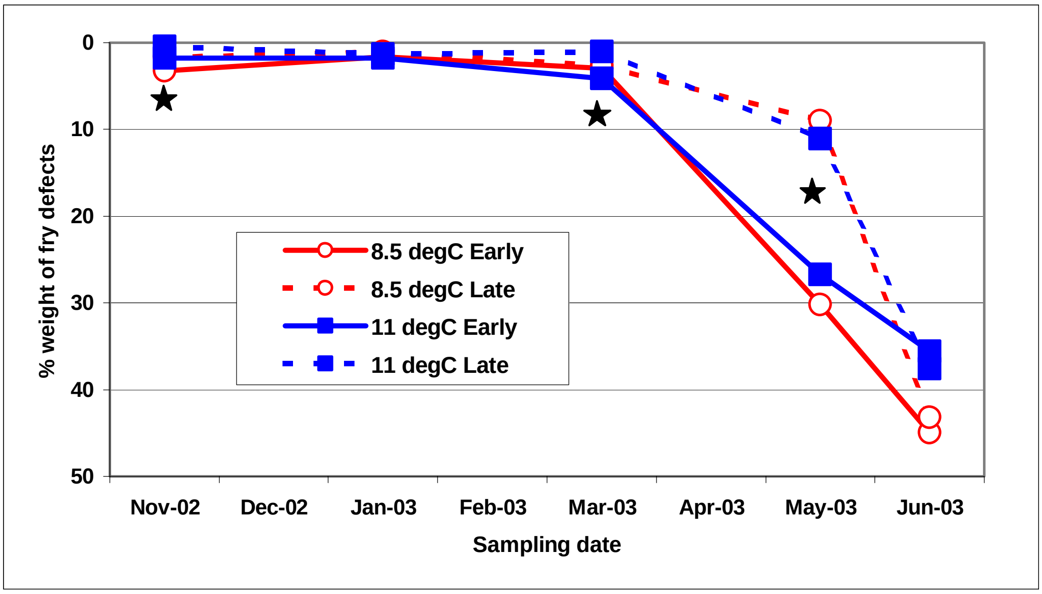

FIGURE 15. THE EFFECT OF PLANTING DATE TREATMENT ON THE % WEIGHT OF FRY DEFECTS DURING STORAGE AT 2 DIFFERENT TEMPERATURES (YEAR 1 LADY ROSETTA). ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

In both seasons, when differences were significant, fry colour was darker in Saturna grown from early-planted seed. The effect of planting date in Year 1 is shown in Figure 16. Deterioration in quality at the end of storage occurred in both seasons and tended to be most marked following early planting of seed and during storage at 11°C and is likely to be a result of senescent sweetening.

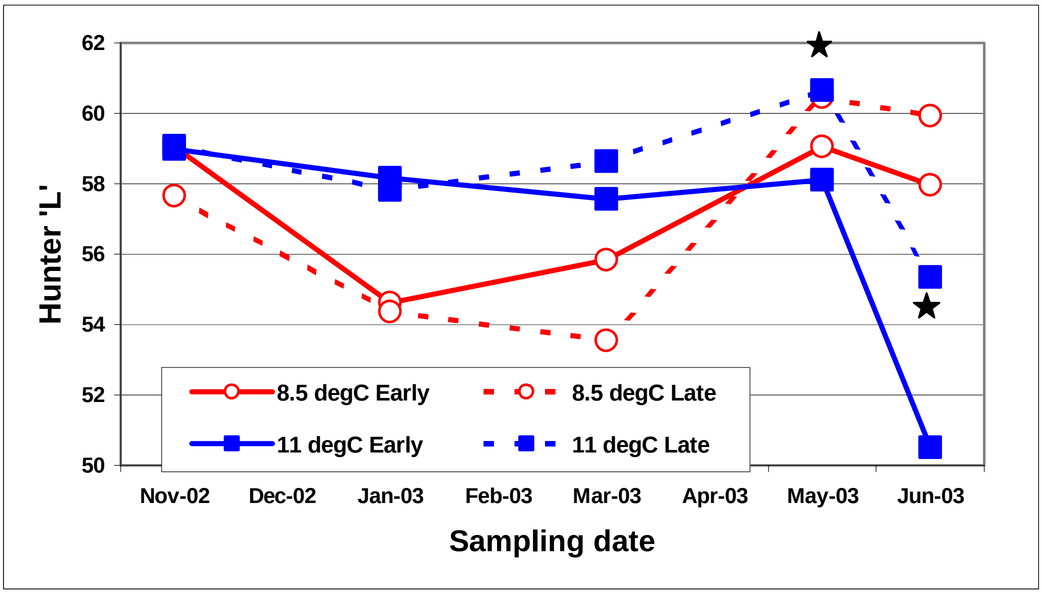

FIGURE 16. THE EFFECT OF PLANTING DATE TREATMENT ON FRY COLOUR (HUNTER 'L') OF CV SATURNA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (*P*=<0.05).

Planting date affected the weight of fry defects during storage in Saturna in both seasons. In year 1, early planting gave rise to fewer fry defects during storage up to March (Figure 17). This situation had reversed by the end of storage in June with fewer fry defects associated with the late planting field treatment. In year 2, the weight of fry defects remained below 5% until the last assessment in June when defects exceeded 30% in all treatments (except late planted crops stored at 8.5°C).

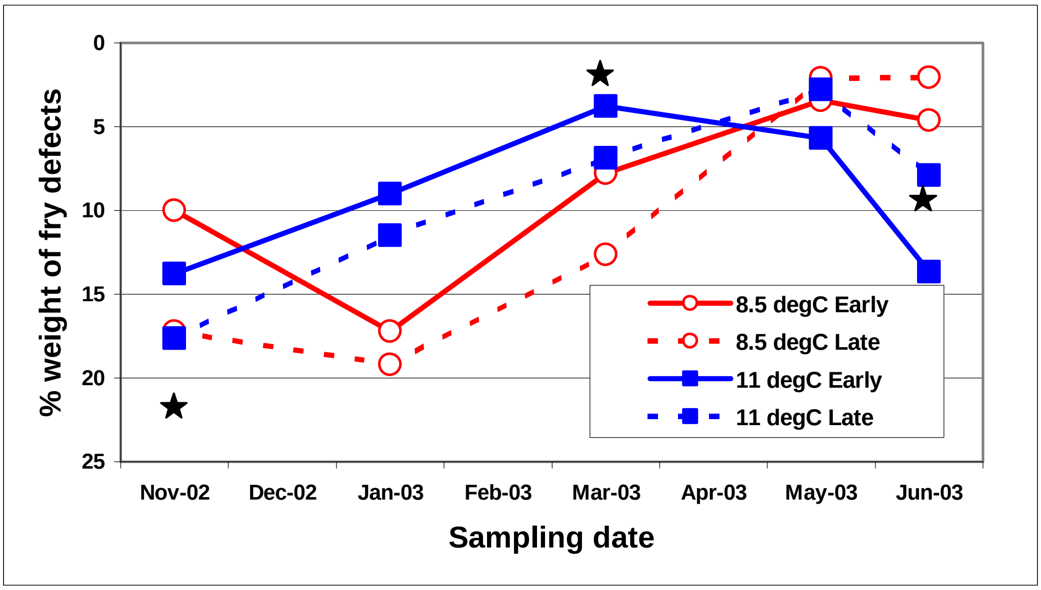

FIGURE 17. THE EFFECT OF PLANTING DATE TREATMENT ON FRY DEFECTS (% WEIGHT) OF CV SATURNA DURING STORAGE AT 8.5°C AND 11°C DURING YEAR 1. ★ INDICATES SIGNIFICANT TREATMENT DIFFERENCES AT THE ASSESSMENT DATE MARKED (P=<0.05).

2.3.3 Storage temperature

Storage of Maris Piper at 11°C resulted in an improvement in quality throughout Year 1 (Figure 18). In Year 2, storage at 11°C led to lighter fry colours until assessment in May, but deteriorated markedly after this (Figure 19). Although generally of a commercially acceptable standard, quality of crops was better in Year 2.

While it cannot be validated statistically, there was evidence of interactions between storage temperature and the different field treatments in the two seasons. In year 1, chitting of seed generally resulted in only marginal effects on processing quality, but in year 2, while chitting resulted in poorer fry colour at the end of storage at both temperatures, the rate of deterioration in fry colour was particularly rapid during storage at 11°C. A similar effect occurred in response to planting date treatments. In year 1, early planting resulted in fry colours that were only slightly darker than those from late-planted seed. In year 2, there was a similar, small improvement from late planting but with a marked and rapid deterioration in fry colour at the end of storage at

11°C. This suggests that, for long term storage in some seasons, processing quality may be improved if practices are adopted that 'conserve' physiological age.

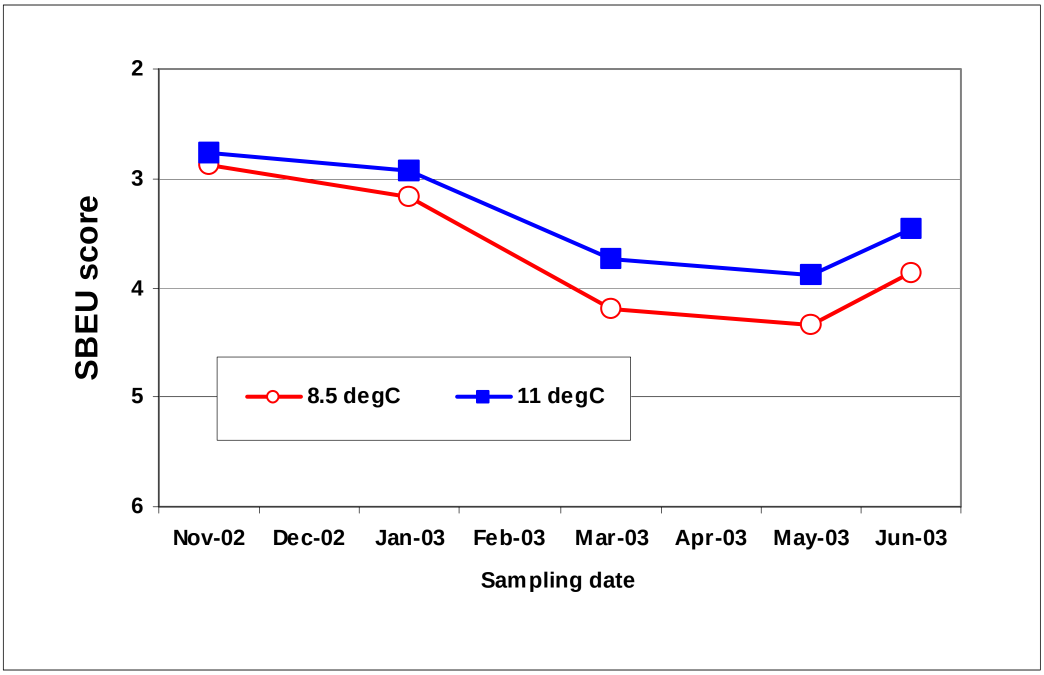

FIGURE 18. MEAN FRY COLOUR (SBEU SCORE) OF MARIS PIPER DURING STORAGE AT 8.5°C AND 11°C IN YEAR 1.

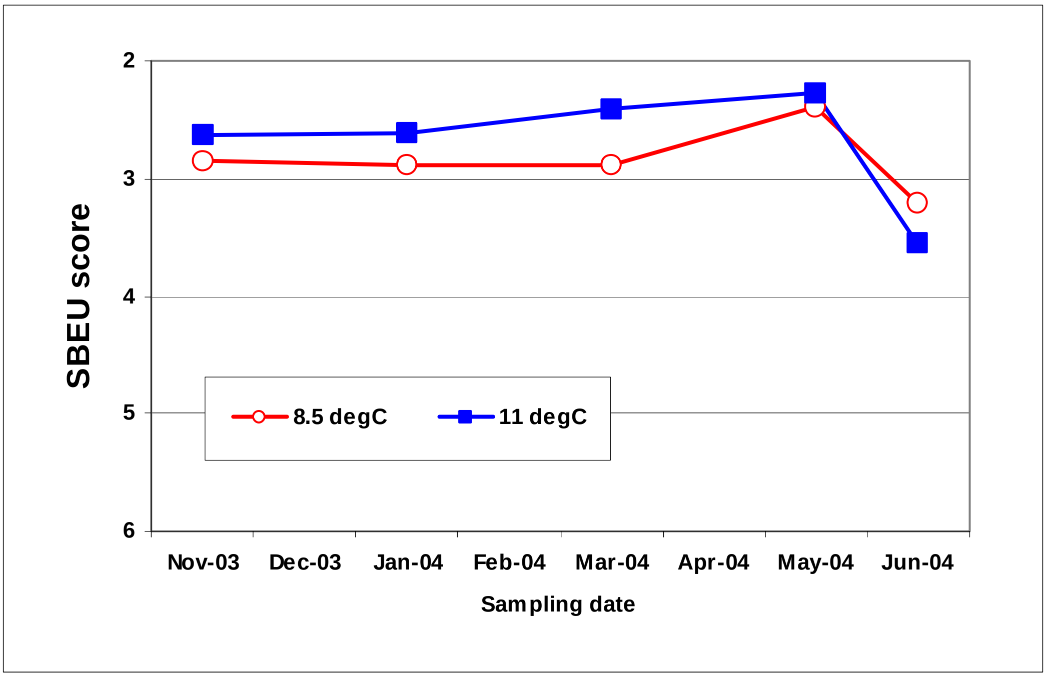

FIGURE 19. MEAN FRY COLOUR (SBEU SCORE) OF MARIS PIPER DURING STORAGE AT 8.5°C AND 11°C IN YEAR 2.

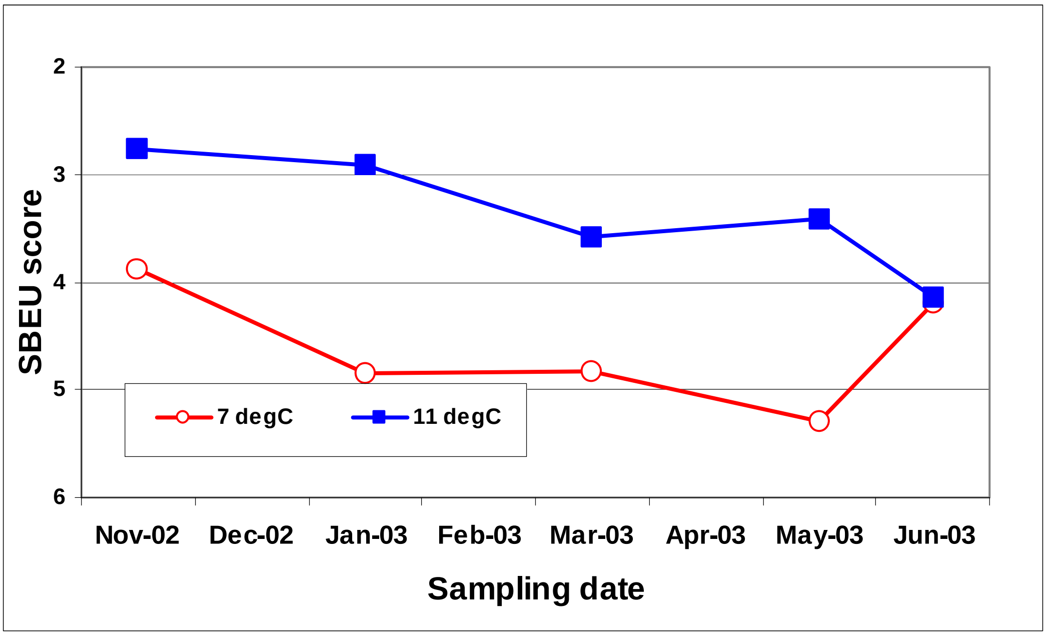

FIGURE 20. MEAN FRY COLOUR (SBEU SCORE) OF RUSSET BURBANK DURING STORAGE AT 7°C AND 11°C IN YEAR 1.

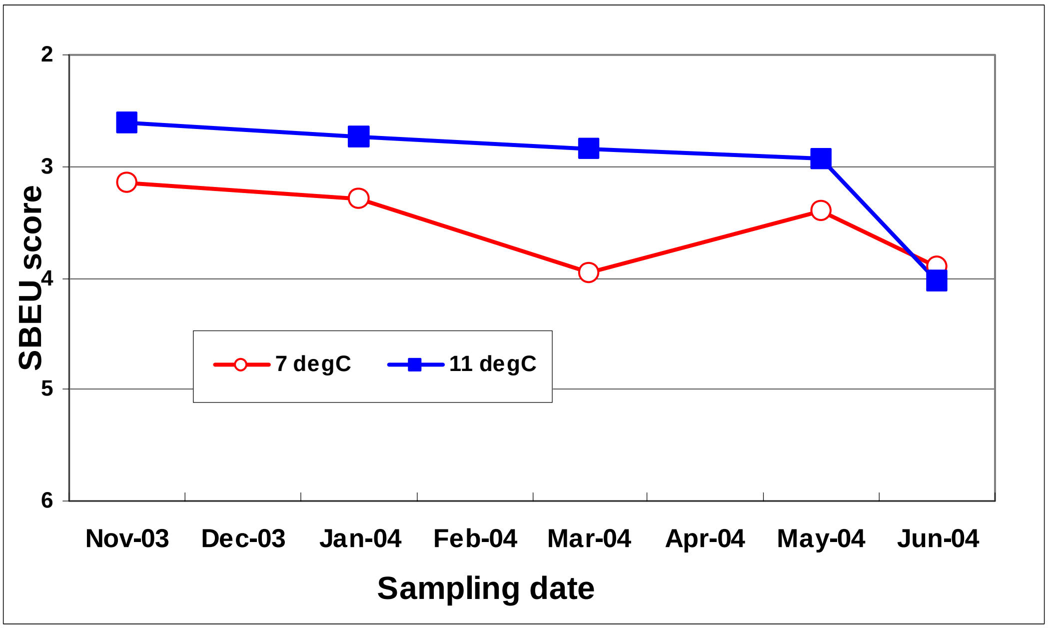

FIGURE 21. MEAN FRY COLOUR (SBEU SCORE) OF RUSSET BURBANK DURING STORAGE AT 7°C AND 11°C IN YEAR 2.

Although it remained of an acceptable standard, the fry colour of Russet Burbank was poor during storage at 7°C in Year 1 (Figure 20). Fry colour was markedly improved during storage at 11°C in this season, except at the end of storage where quality was similar to that of crop stored at 8.5°C.

In Year 2 (Figure 21), when fry colour was generally lighter, storage at 11°C also resulted in an improvement in colour but differences between 8.5°C and 11°C were less pronounced.

In both seasons, fry defects in Lady Rosetta remained at low levels during storage until March, and were unaffected by storage temperature (Figures 22 and 23). The level of defects increased progressively during the May-June period but were largely unaffected by storage temperature.

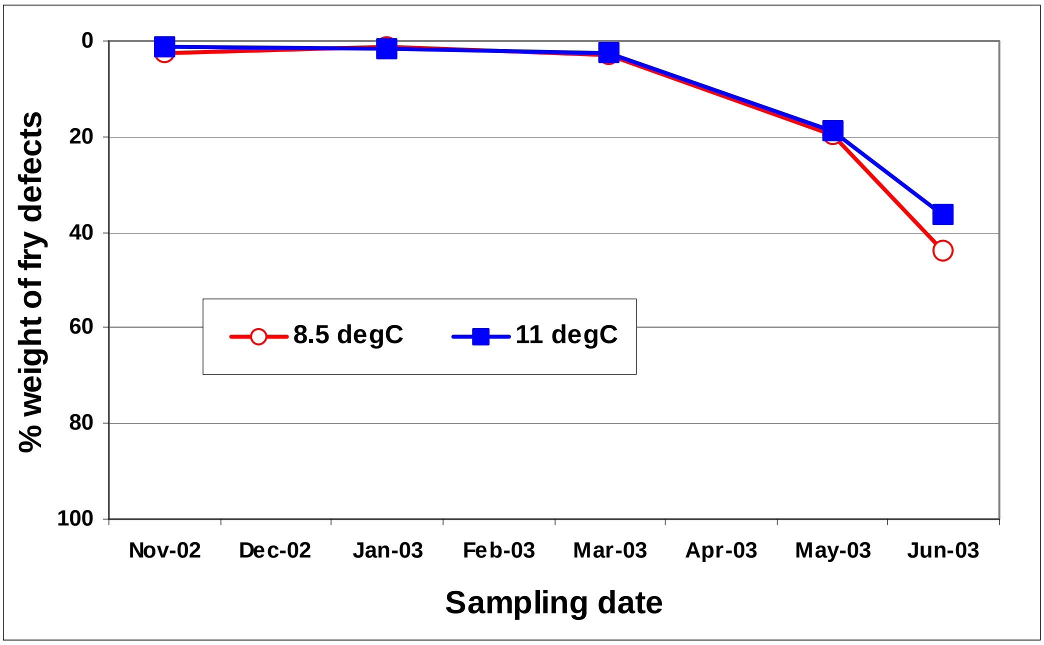

FIGURE 22. FRY DEFECTS (% WEIGHT) OF LADY ROSETTA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 1.

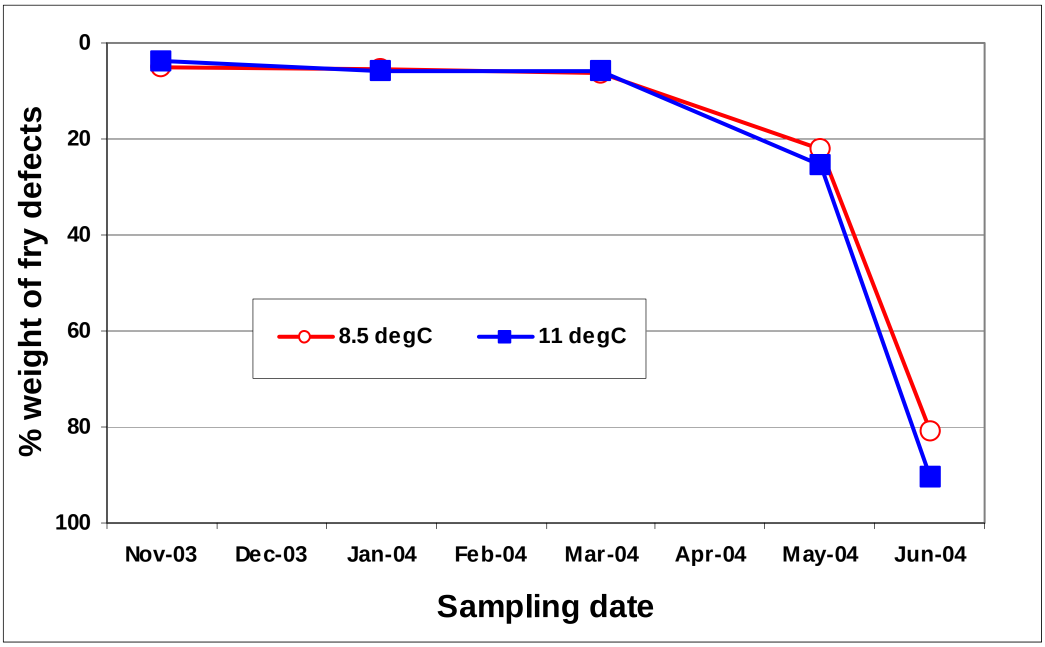

FIGURE 23. FRY DEFECTS (% WEIGHT) OF LADY ROSETTA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 2.

Storage of Lady Rosetta at 8.5°C resulted in a deterioration in fry colour to a commercially unacceptable quality (Hunter L <58) by January in Year 1 (Figure 24). Storage at 11°C maintained quality at an acceptable level until March, but gave rise to unacceptable quality after this. Fry colour of crops in Year 2 was generally lighter (Figure 25). Although storage at 11°C resulted in an improvement in quality, differences between the two temperatures in Year 2 were less pronounced. Storage under both temperature regimes resulted in a rapid deterioration in fry colour after March in the second season.

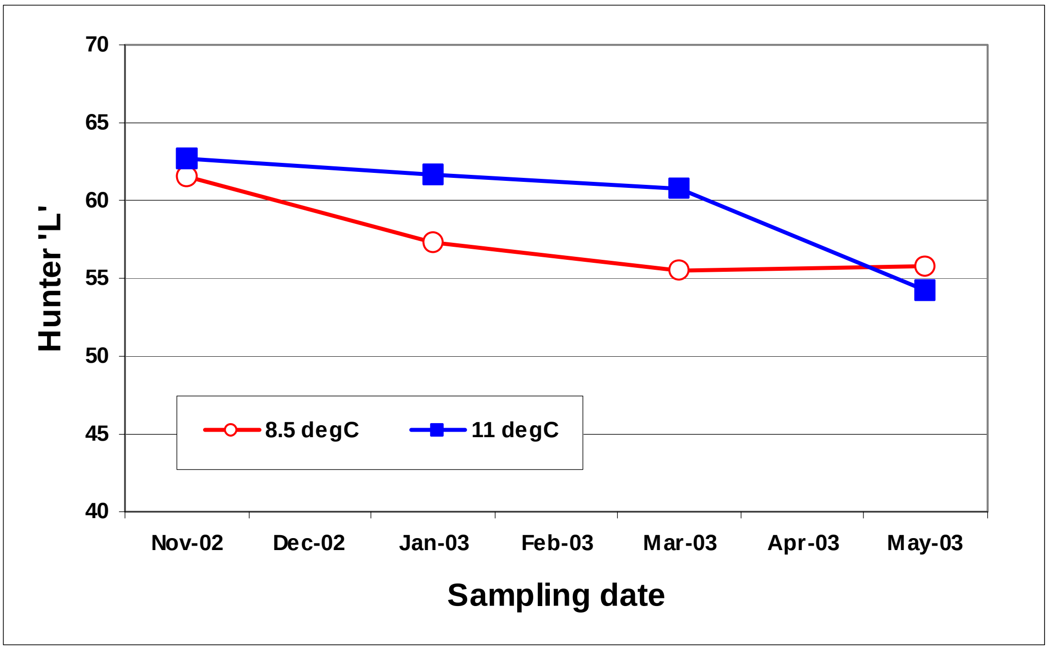

FIGURE 24. FRY COLOUR (HUNTER L) OF LADY ROSETTA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 1.

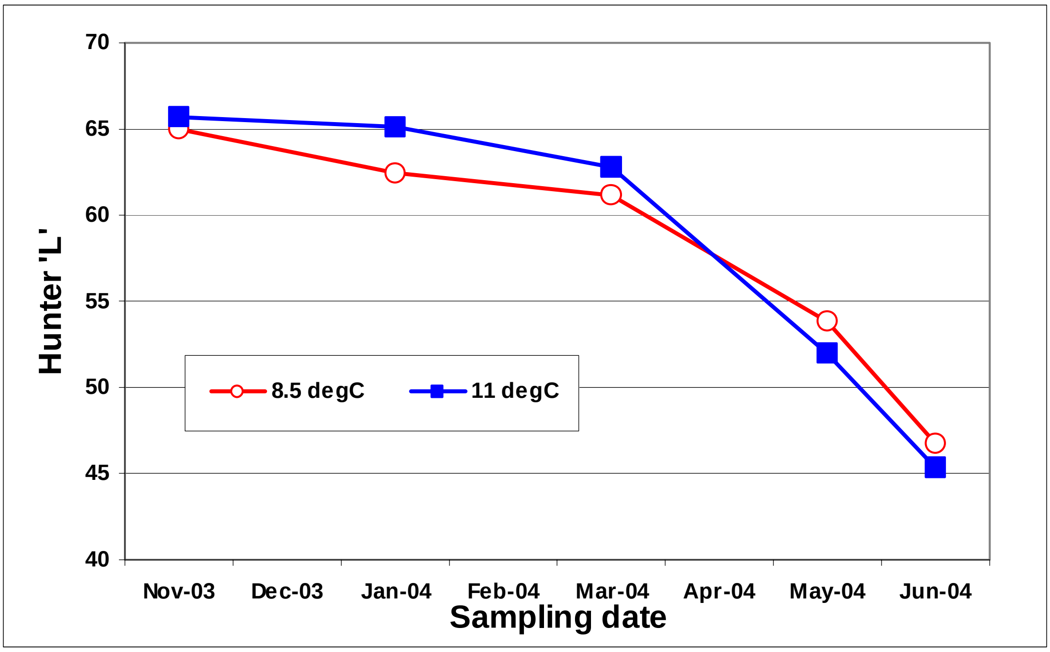

FIGURE 25. FRY COLOUR (HUNTER L) OF LADY ROSETTA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 2.

The effect of storage temperature on fry defects of Saturna is shown in figures 26 and 27 for Years 1 and 2 respectively. Fry defects occurred at relatively high levels during early storage in 2002/3 and declined as the season progressed. In Year 2, fry defects occurred at low levels until the end of storage (June), when there was a marked increased, particularly during storage at 11°C.

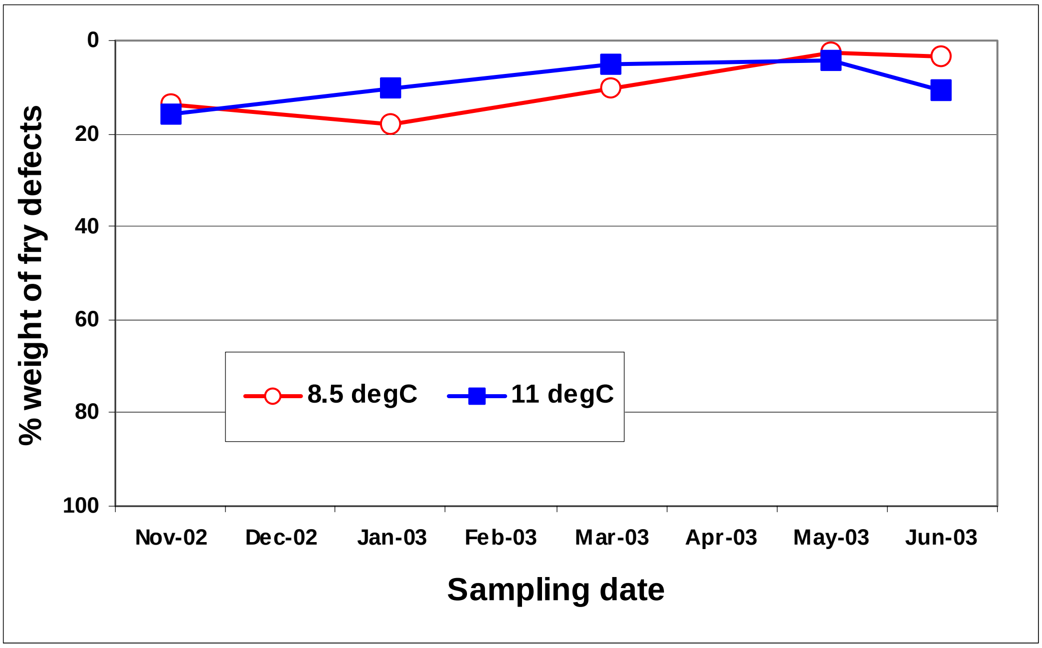

FIGURE 26. FRY DEFECTS (% WEIGHT) OF SATURNA DURING STORAGE AT 8.5°C AND 11°C DURING YEAR 1.

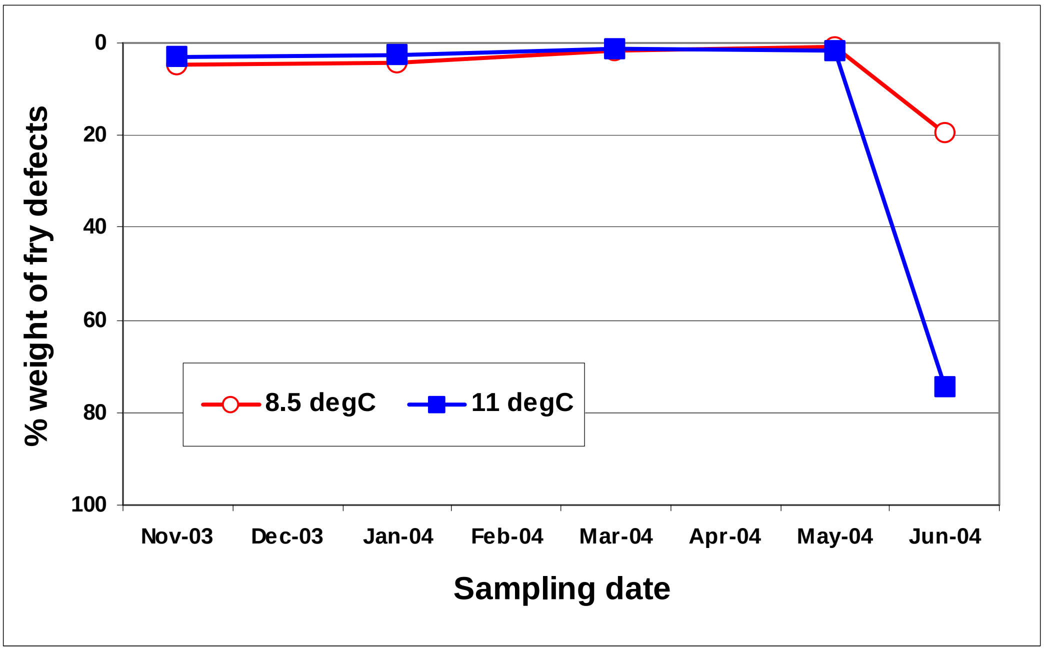

FIGURE 27. FRY DEFECTS (% WEIGHT) OF SATURNA DURING STORAGE AT 8.5°C AND 11°C DURING YEAR 2.

Storage of Saturna at 8.5°C resulted in deterioration of fry colour in Year 1 (Figure 28), with unacceptable colour by January, though there was an improvement in quality again (to an acceptable standard) late in storage. Storage at 11°C maintained fry colour at an acceptable standard until May, but resulted in unacceptable fry colour (L<58) at the final sampling occasion.

In Year 2, storage at 8.5° and 11°C resulted in acceptable fry colour during storage until May, with lighter colour from the warmer temperature (Figure 29). Quality at the end of storage (June) was poor, irrespective of storage temperature, though deterioration was more rapid in samples stored at 11°C.

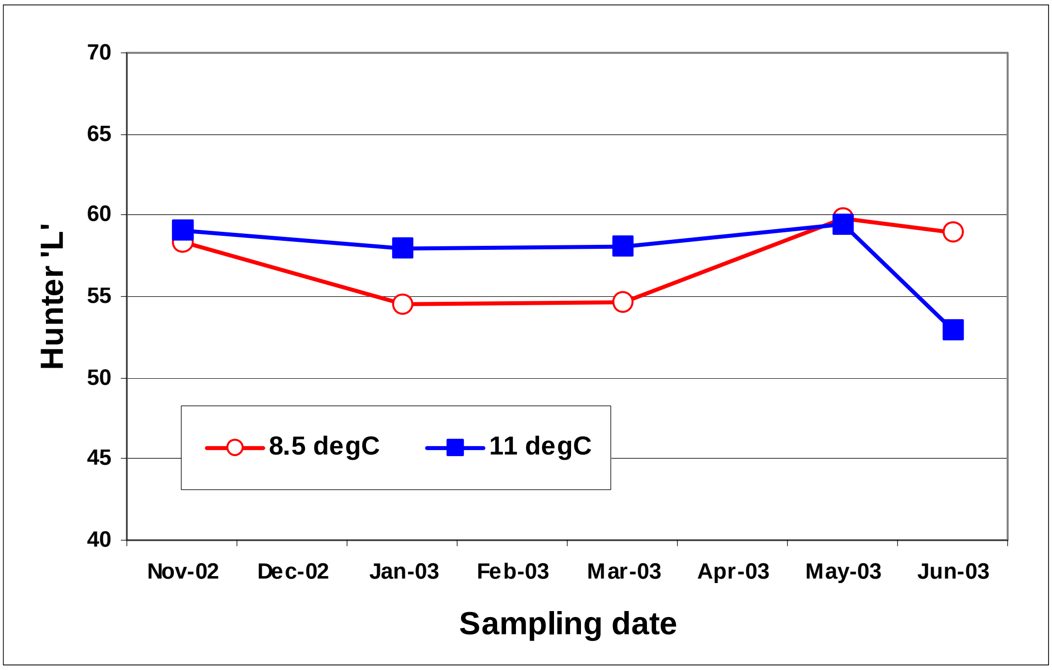

FIGURE 28. FRY COLOUR (HUNTER L) OF SATURNA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 1.

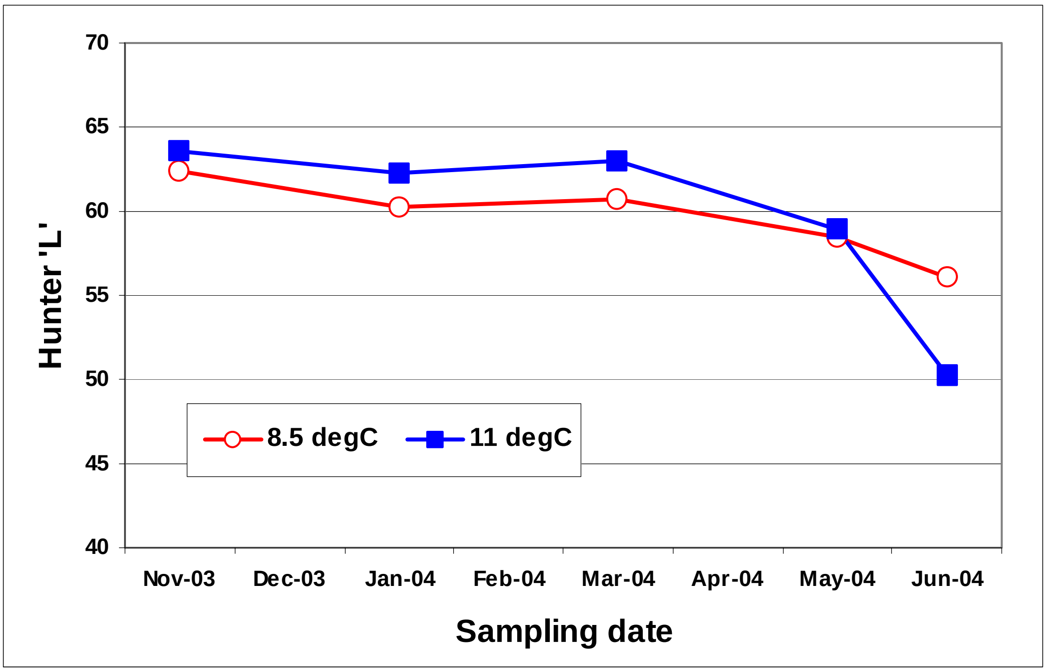

FIGURE 29. FRY COLOUR (HUNTER L) OF SATURNA DURING STORAGE AT 8.5°C AND 11°C IN YEAR 2.

2.3.4 Relationship between the physiological characteristics of the crop in the field and storage quality

In addition to the factorial ANOVA, further analyses were conducted to study the relationship between physiological characteristics of the crop in the field and the subsequent storage quality of the produce. The purpose of this exercise was to establish whether physiological characteristics of the crop in the field, which are indicators of crop maturity, may act as predictive indicators of storage quality. Regression analyses were conducted to investigate the relationships between canopy cover towards the end of the season and sugar concentration in the tuber at defoliation and at harvest. This is of interest as tuber sugar concentrations approaching harvest are thought to be related to processing quality during long term storage.

The relationships tested are itemised below.

Green canopy cover at defoliation against:

a) Tuber sucrose concentration at defoliation
b) Tuber glucose concentration at defoliation
c) Tuber fructose concentration at defoliation
d) Total tuber reducing sugar concentration at defoliation
e) Tuber sucrose concentration at harvest
f) Tuber glucose concentration at harvest
g) Tuber fructose concentration at harvest
h) Total tuber reducing sugar concentration at harvest

These regressions were repeated using a measure of the rate of senescence prior to defoliation as an alternative indicator of crop 'maturity' at harvest. The rate of senescence was calculated as the gradient of a line between the last recorded date of 100% canopy cover, and the cover at the time of defoliation (expressed as % canopy cover senescence per day). The results of these regressions indicated that there were no reliable relationships between the rate of canopy decline and tuber sugar concentration at defoliation or harvest. The regression analyses are included in the Annex.

Further correlation analyses were conducted to investigate the relationship between sugar measurements before storage and the quality of tubers during storage. Fry colour, and weight of fry defects (for crisping varieties only), were taken as the indicators of quality during storage. Data from each sampling occasion were correlated separately against all the tuber sugar concentration parameters described above. Additionally, the relationship between crop cover data at defoliation and storage quality was also investigated.

These analyses generated a substantial number of correlation coefficients, none of which provided evidence of a useful link between storage quality and the parameters measured prior to storage.

2.4 Discussion

The aim was to identify relationships between characteristics that can be measured easily prior to harvest, and the storage potential of the crop. These measurements included green canopy cover at defoliation and tuber sugar concentrations at harvest.

The seed maturity factor gave rise to differences in the longevity of the canopy, however, these differences were inconsistent and relatively small. Mature seed was also associated with an increased total and ware yield in Saturna (year 1). However, as this increase was not associated with a corresponding effect on canopy cover during growth, it is possible that the yield effect was due to chance or other factors not identified in the field. Other effects of this treatment on sugar concentration at defoliation and harvest suggest some influence of this factor on crop development. However these effects were also inconsistent and, as processing quality during storage was unaffected by this treatment, it is likely that the effects of this treatment were limited by the relatively small ‘maturity’ difference achieved during the seed production phase.

Both seed chitting and early planting date decreased green canopy cover at defoliation producing highly significant effects (P<0.001) in both years and in all varieties except Russet Burbank. With this variety the chitting treatment was only 50 day degrees, compared with 250 to 350 day degree for the other varieties studied. Consequentially the effect of this main treatment in this variety was limited. Ware yield was significantly affected by seed chitting in only one variety in one year. In contrast early planting affected yields in all varieties in at least one year of the study.

Measurements of the crops up to and including harvest therefore suggest that ranking order of impact of the three field treatments on crop ‘maturity’ entering store were planting date > seed chitting > seed maturity. The assessments of processing quality during storage suggest the same ranking order of treatment effect.

The main indicators of processing quality during long-term storage are fry colour and fry defects in crisps. Fry colour is largely controlled by the reaction of reducing sugar (glucose and fructose) with amino-N compounds (Maillard reaction), which gives rise to a brown colouration of the product. There have been many attempts made to relate the concentration of Maillard reaction substrates, measured at harvest, with the long-term storage potential of the crop. The most encouraging studies (Sowokinos 1978) identified a relationship between tuber sucrose concentration during the growing season, and quality during storage and subsequently suggested a Sucrose Rating System. This approach has been developed into the Chemical Maturity Monitoring model which has been adopted by a number of companies in the US and UK. It is known that tuber sucrose concentrations decline as tubers ‘mature’. Although sucrose does not directly contribute to Maillard browning, it serves as a substrate for reducing sugar production via the action of the enzyme invertase.

In the study reported here, tuber sucrose, fructose and glucose were measured at defoliation and at harvest. Although their concentrations were affected by all the field treatments, they were found to be unrelated to storage quality despite extensive analysis of the data.

In general, processing quality during storage was adversely affected by field treatments that enhanced tuber maturity at harvest (i.e. chitted seed, early planted). Although these differences were often small in commercial terms, they were significant and more pronounced towards the end of storage when senescent sweetening may have been implicated. However, in previous studies using the same varieties (BPC project ref. 807/196), treatments that enhanced the length of the growing season were associated with good storage quality. Those experiments were conducted during seasons where wet springs delayed the planting dates tested, so that the late planting date treatments resulted in very short growing seasons. It is therefore reasonable to conclude that planting date can operate to either enhance or limit storage potential and that this effect is likely to be dependent on season.

Fry colours were generally superior where tubers were stored at the higher temperature of 11°C. However, towards the end of storage, processing quality deteriorated rapidly in both crisping varieties at this higher temperature. This indicates that senescent sweetening occurred earlier at the higher temperature, limiting the duration of storage.

The weight of fry defects appeared less dependent on storage temperature than field treatment, in variety Lady Rosetta. During late storage (after March) the difference in the weight of fry defects between tubers stored at 11^{o} and 8.5^{o}C was only *c*. 2%, whereas the difference between early and late planted crops was *c*. 19%. This is of interest as, in general, storage temperature had a greater effect on fry colour than the field treatments.

Planting date did not have a consistent effect on the level of fry defects for much of the storage season. It is likely that other (uncontrolled) factors were also involved in determining levels during this period. During long term storage, however, beyond around March, early planting was consistently associated with elevated levels of fry defects suggesting that fry defects associated with senescent sweetening were directly related to the planting date treatments imposed.

Whilst seasonal effects were noted, it must be stressed that processing quality in the two seasons in which this work was undertaken (2002/3 and 2003/4) were very different, despite similar planting dates and length of growing season. Agronomic factors which could be controlled, such as water supply and fertiliser rates, were also the same in both years. Despite this, the differences in fry colour between seasons exceeded field treatment differences.

Factors that could have contributed to these seasonal differences include:

a) accumulated temperature;
b) solar radiation;
c) field location/aspect;
d) previous cropping;
e) soil condition.

The effects of these cannot be viewed in isolation as they are confounded with, and interact with, each other. Therefore, the causes of seasonal differences cannot be attributed to specific factors.

It was recognised at the outset of this work that there would be interacting seasonal factors that affect processing quality. These factors also directly affect crop growth and development. Therefore, the aim of this work was to identify crop parameters that reflect these interacting seasonal factors and which relate to processing quality. However, despite the introduction of new treatments—e.g. seed maturity—such predictive crop parameters were not found. A continued lack of understanding of tuber 'maturity' remains a major obstacle to further progress.

Our hypothesis is that, for each crop, there is an optimum 'maturity' for best processing quality. Progress towards this optimum will be influenced by the rate of crop development during the season. In growing seasons when early growth is slow, planting late delays crop development further, so at harvest the crop may be immature (the optimum maturity stage is not reached) and unsuitable for long-term storage. In seasons when early growth is rapid, tubers at harvest may be more mature than the optimum, but late planting would decrease maturity, bringing it closer to the optimum, and improving storage potential.

Whilst broad messages can be drawn from these findings in terms of the storage potential of a particular crop, the results alone do not provide an accurate method of predicting storage quality on their own.

2.5 References

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