SUGAR CHANGES IN THE POTATO CULTIVARS 'RUSSET BURBANK' AND 'SHEPODY' STORED AT LOW TEMPERATURES WITHOUT SPROUT INHIBITOR

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BY

ESTHER GATHONI GICHOHI

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ABSTRACT

Gichohi, Esther Gathoni, MSc., The University of Manitoba, September 1993. Sugar changes in the potato cultivars 'Russet Burbank' and 'Shepody' stored at low temperatures without sprout inhibitor.

The processing quality of Russet Burbank and Shepody potatoes after storage at 4 to 8°C was assessed to determine the potential of low temperature storage as a substitute for chemical sprout inhibitors. Russet Burbank and Shepody tubers were preconditioned at 15°C for 2 weeks before lowering the temperature to the final storage temperatures of 4, 6, or 8°C in 1990/91 and 5, 6, or 8°C in 1991/92. In both years and in both cultivars, reducing sugar concentration increased over the storage period when storage temperature was lowered to 8, 6, 5 or 4°C, with higher increases at the lower temperatures. Sucrose concentration increased in Russet Burbank tubers stored at 4°C, while sucrose concentration in Russet Burbank and Shepody tubers stored at 6 or 8°C declined during storage. When Shepody tubers were cooled to 5 or 4°C, there was rapid accumulation of sucrose which later declined. Russet Burbank tubers stored at 6 or 8°C had sugar concentrations that would give acceptable french fry colour after processing over most of the storage period in 1990/91. Tubers stored at 4°C were not acceptable for french fry processing over the entire storage period. Shepody tubers stored at 8°C in 1990/91 had sugar concentrations that were acceptable for processing while tubers stored at 4 or 6°C were not acceptable for the entire storage period. Placement into 18°C for

4 weeks was successful in lowering reducing sugar concentrations to acceptable levels in Russet Burbank tubers stored at 4°C in 1990/91. However reconditioning after 33 weeks in storage rendered them unacceptable for processing because of excessive sprout development. Reconditioning at 18°C for 4 weeks did not lower sugar concentration in Shepody tubers stored at 4 or 6°C to acceptable levels for processing. In 1991/92, Russet Burbank tubers stored at 8°C had acceptable sugar concentration over the entire storage period. Two weeks of reconditioning either by immediate placement into 18°C or by gradual warming to 18°C was for the most part successful in lowering sugar concentration to levels acceptable for processing in tubers stored at 5 or 6°C. Shepody tubers stored with or without MH60 at 8°C were acceptable for processing up to 15 weeks after harvest. Application of MH60 led to significantly higher levels of reducing sugar concentration compared to tubers without MH60 in stored Shepody tubers but not in Russet Burbank tubers.Shepody tubers stored at 5 or 6°C did not have acceptable sugar levels over the entire storage period. A 2 week fast or gradual reconditioning did not lower sugar concentration to acceptable levels. Glucose, fructose and total reducing sugars were significantly correlated with fry colour but the closeness of the correlation varied depending on the cultivar and the presence or absence of sprout inhibitor and is discussed.

1.1 INTRODUCTION

Manitoba produces 19 000 ha of potatoes with a farm gate value of $48M of which 80% is processed as french fries, chips, and other processed products. The seasonal nature of potato production in Canada and other northern production regions necessitates the use of cold storage in order to provide raw material for year round processing. Generally, chemical treatments to control sprouting and minimize disese are required to ensure long term storage. However issues such as acceptable processing quality and food safety must be addressed if the potato processing industry in Manitoba is to continue to develop.

Potatoes used in the processing industry for making french fries and chips must meet rigid specifications with regard to quality of raw product entering the plant. Excessive sprout growth which can occur within a few months of harvest is unacceptable for processing and must be minimized. Tubers with high reducing sugars, glucose and fructose, will result in unacceptable darkening during frying. The darkening is due to non-enzymatic browning known as the Maillard reaction in which reducing sugars interact with amino acids during high temperature frying.

Sprouting reduces the acceptability of stored potatoes for processing due to weight and nutrient loss, as well as softening, during storage for up to 12 months. Sprouting also results in a temporary increase in reducing sugars and sucrose. Chemical sprout inhibitors such as isopropyl N-(3-chlorphenyl carbamate) (CIPC) and maleic hydrazide (MH) are widely used in North America on potatoes to maintain fresh or processing quality. In

recent years issues relating to food safety have heightened consumer awareness about the use of chemicals in foods. Excessive amounts of potentially hazardous chemicals are clearly undesirable in a foodstuff, particularly in one which is widely consumed in comparatively large quantities. Use of chemical sprout inhibitors leads to unavoidable residue of the chemicals on the tuber after storage and becomes a potential environmental contaminant.

Storage of potatoes at low temperatures prolongs the dormancy period and delays or prevents sprouting. However, temperatures below 10°C result in an excessive accumulation of sugars, with greater accumulation the lower the temperature. Therefore, for medium and long term storage of processing potatoes, temperatures of 7-8°C for french fries and 9-10°C for chips are used together with chemical sprout inhibitors to ensure acceptable processing quality.

The objective of this study was to examine the effects of low storage temperature on accumulation of sugars and sprout development in the potato cultivars Russet Burbank and Shepody which are used in Manitoba for processing as french fries. The reconditioning treatments needed to remove the sugars accumulated during low temperature storage to improve the processing quality was determined. Based on this information, recommendations on using low temperature storage as an alternative to chemical sprout inhibitors were developed. The effect of the sprout inhibitor MH60 (Royal MH60, Uniroyal Chemical, Elmira,ON), on the sugar composition of potato tubers was also examined. Relationships between fry colour and sugar concentration were determined.

2. LITERATURE REVIEW

2.1 Introduction

2.1.1 History and description of the potato

The potato (*Solanum tuberosum* L.) is an annual plant belonging to the family Solanaceae. It is generally agreed that the domesticated potato species originated in the Peruvian Andes of South America. The tuber of the potato is a modified stem which usually develops below ground as a consequence of swelling of the subapical portion of the stolon with simultaneous accumulation of reserve material (Coleman, 1987). Each 'eye' of the potato tuber consists of a rudimentary scale leaf, often discernible only as a slight ridge, with three or more axillary buds which are usually not growing at the time of harvest but will grow to produce new stems and foliage under suitable conditions (Burton, 1989).

2.1.2 Carbohydrate metabolism in potato tubers

The polymeric carbohydrate starch constitutes approximately 70% to 85% of tuber dry weight (Davies, 1990). For most non-photosynthetic cells of higher plants, carbon for biosynthesis and energy is obtained as sucrose from photosynthetic cells (ap Rees, 1988). In the potato tuber, sucrose is partitioned between storage starch, structural polysaccharides, storage as sucrose or hexose, and entry into the respiratory pathways. About 50% to 70% of the sucrose carbon goes to the starch and 5% to 10% goes to

structural polysaccharides (Oparka, 1985). The rest of the carbon is divided between respiration and storage as sucrose or hexose.

The location of sucrose in potato tubers has not yet been demonstrated, but by analogy to other storage tissues, ap Rees and Morrell (1990) suggest that it is highly likely most of the sucrose is in the vacuole with a relatively small amount in the cytosol. In developing tubers, initial metabolism of sucrose proceeds via sucrose synthase where sucrose is converted to fructose and UDPglucose. In developing tubers, invertase is not sufficiently active to mediate more than a small fraction of sucrose breakdown to glucose and fructose (Morrell and ap Rees, 1986). Sucrose synthase activity declines as tubers mature on the plants (Pressey, 1969). UDPglucose is further converted to glucose-1-P (G1P) via the action of UDPglucose pyrophosphorylase, while fructose is converted to fructose-6-P via the action of fructokinase. The whole sequence takes place in the cytosol.

From the cytosol, carbon may be transported across the plastid membrane into the amyloplast as 3-carbon compounds via a phosphate translocator protein in exchange for Pi (Sowokinos et al., 1985). The alternative hypothesis suggests that 6-carbon compounds enter the amyloplast, and is more likely for developing potato tubers (ap Rees and Morrell, 1990). In the amyloplast, the action of ADPglucose pyrophosphorylase on G1P forms ADPglucose. Alkaline inorganic pyrophosphate acts on ADPglucose to form starch.

In stored tubers, starch breakdown is most likely phosphorolytic (Sowokinos, 1990) resulting in formation of G1P (or glucose-6-P). G1P may enter the cytoplasm via

the hexose-P, Pi-translocator protein located in the inner membrane of the amyloplast. 3-Phosphoglyceladehyde (3PGA) may also be formed and transported across the amyloplast membrane (Mohabir and John, 1988). In the cytoplasm, G1P may undergo glycolysis and oxidative reactions and/or be utilized for gluconeogenic reactions, yielding the free sugars sucrose, glucose and fructose (Sowokinos, 1990). In stored and sprouting tubers, sucrose hydrolysis most likely occurs via the action of invertase (Davies, 1990) and acid invertase activity predominates (Pressey and Shaw, 1966; Ross and Davies, 1991). Although it is suggested that sucrose is stored in the vacuole, there is little information on storage site or movement in and out of the vacuole for the reducing sugars glucose and fructose. There is evidence however that sucrose hydrolysis often accompanies sugar accumulation in storage (Pollock and ap Rees, 1975; Richardson et al., 1990).

2.2 Processing quality

2.2.1 Sucrose and reducing sugar

Colour development during the frying process has been attributed to the Maillard reaction. The Maillard browning reaction involves the interaction of amino compounds, including all amino acids comprising natural proteins, and reducing sugars during the thermal processing and storage of foods (Timm et al., 1968; Shallenberger et al., 1959; Mazza, 1983; Pritchard and Adam, in press). Upon frying, the aldehyde and ketone groups of the reducing sugars glucose and fructose react nonenzymatically with amino

groups of amino acids present in the potato tubers.

Harvesting of potato tubers usually takes place at chemical maturity, a point at which tubers have reached maximum starch and minimum sugar content (Burton, 1989; Iritani, 1981). Once the rhizome connection between the tuber and the plant is broken, tuber carbohydrate metabolism may change considerably (Oparka et al., 1988). When tubers are chemically immature at harvest, (high sucrose), reducing sugars accumulate soon after harvest. Sowokinos (1978) found that the higher the sucrose content was at the time of lifting the greater the reducing sugars accumulation during storage.

In mature tubers, sucrose increase occurs before that of reducing sugars when potatoes are stored at low temperatures. At 10°C, sucrose is the main sugar to be lost (Isherwood, 1973). In immature tubers, sucrose and the hexoses all tend to change in a parallel manner, and may not be in separate compartments. Sucrose does not participate in the Maillard browning directly but it serves as a substrate for reducing sugar production via the storage activated enzyme invertase (Pressey, 1969). Timm et al. (1968) and Clegg and Chapman (1962) have reported that high concentrations of sucrose enhanced the darkening of chips. Shallenberger (1959) used filter papers soaked in sucrose and amino acid to simulate potato slices and observed colour development at temperatures used to fry potato chips. Sucrose may be hydrolysed during frying to yield fructose and glucose which could then participate in the Maillard reaction to produce the brown colour during the frying process (Coffin et al., 1987).

Sugar content is closely related to the colour produced during the processing procedure (Habib and Brown, 1956). The potato processing industry uses reducing sugar

levels as a predictive test of the suitability of material for processing, since reducing sugars are normally the limiting factor in colour development (Marquez and Anon, 1986). Sugars contribute a small fraction of dry matter in tubers, usually up to 3%. Maximum permissible reducing sugar levels in tubers used for french fries is about 4.0-5.0 mg g^{-1} and 3.5 mg g^{-1} for the nonreducing disaccharide sucrose (van Es and Hartmans, 1981). Pritchard and Adam (in press) found the best relationship between fry colour and sugars to be that given by glucose. They gave the maximum permissible glucose level for maximum bonus payment for colour to be 1.6 mg g^{-1} in Russet Burbank and 1.2 mg g^{-1} in Shepody. Mazza (1983) also found reducing sugars to be closely related to chip colour, and also found that a multiple regression involving other factors that affect chip colour gave a better correlation coefficient of determination. Although reducing sugars are the most important factor determining fry colour, their importance in some cases may be limited by the amount of free nitrogen present in the tuber. Habib and Brown (1956) observed that reconditioning resulted in disappearance of various amino acids especially the basic amino acids lysine, histidine and arginine. Ashoor and Zent (1984) reported that tuber amino acid composition affected the intensity of the Maillard browning.

2.2.2 Sprouting

Potato tubers contain free amino acids and soluble sugars potentially available for sprout growth, but continued growth prior to onset of photosynthesis will depend on mobilization of polymeric reserves to satisfy both structural and functional requirements

(Moorby, 1978). This leads to shrivelling due to weight loss and appearance of sprouts, which represents a loss of income to growers or retailers and presents technological problems for potential manufacturers as the tubers become more difficult to peel (van Es and Hartmans, 1981). Processors prefer potato tubers with no sprouts but usually sprouts of 10 cm or less are tolerated (Carnation Foods, personal communication). When sprouts reach 15 cm or more, scrubbers in the processing line are likely to become blocked.

Sprouting markedly reduces the acceptability of potato tubers due to weight and nutrient loss, as well as tuber softening. Sprouting also leads to a transient rise in sucrose and reducing sugars glucose and fructose (Edelman and Singh, 1969; Richardson et al., 1990). The majority of the dry weight lost during sprouting (80-90%) appears to be due to translocation of carbohydrates to shoots and roots, while respiratory losses of transported carbon by rapidly growing shoots is extensive (Davies, 1990). Edelman and Singh (1969), working on the variety Duke of York, found that the starch content of tubers fell to zero 13 weeks after sprouting had started. The tissues were still fully turgid at this stage but, a few days after disappearance of starch the tuber suddenly collapsed. At this time the tuber had contributed practically all of its dry matter to the growing sprouts. Dry weight of the tuber fell by 75% and total storage carbohydrates by about 90%.

2.3 Dormancy

2.3.1 Definition of dormancy

There has been considerable debate as to the correct interpretation of dormancy duration and release in potato tubers (Coleman, 1987). One view is that the potato tuber has no true dormancy since microscopic growth occurs continuously from harvest. Rather, appearance of the sprouts indicates the first macroscopic growth feature. Goodwin (1967) suggested that growth of the tissues is stopped at lifting or death of the mother plant and buds enter a dormant period. Burton (1989) regards dormancy as beginning at onset of tuber initiation and ending with resumption of active bud growth under favourable growing conditions. Most writers refer to a bud which is not growing due to internal factors as resting and one not growing due to environmental factors as dormant. Burton (1978) described buds as dormant if they were not growing for any reason. He however recognized a state where buds would not grow even under favourable conditions and referred to such buds as endodormant.

2.3.2 Regulation of dormancy

In nature, environmental factors cue plants to changes in the seasons so that they can make adaptations that will favour survival through periods of unfavourable weather (Nooden and Weber, 1978). Dormancy in deciduous fruit trees and other woody perennials of the temperate zones is a phase of development that occurs annually and

enables plants to survive the cold winters. Potato tubers have an inherent dormancy period whose duration depends on several factors, and especially on variety, storage, and growing conditions (Thomson et al., 1980; Rama et al., 1986). When the dormancy period is over the tubers start sprouting.

The development, maintenance and release of dormancy in buds involves a complex interaction of a number of factors, ranging from environmental to genetic (Nooden et al., 1978). Dormancy release appears to be a gradual process with continuous, albeit slow bud growth and development during the dormant phase (Davidson, 1958). Hemberg, cited by Coleman (1987), hypothesized that inhibitors are the primary cause of dormancy. Specifically he viewed inhibitor- B complex as responsible for both initiating and maintaining tuber dormancy through undefined multiple modes of action. With the onset of rapid bud growth (ie. dormancy release) the inhibitor-B complex decreases rapidly although there is no evidence of a specific threshold concentration of abscisic acid (ABA: a major component of inhibitor B) in the tuber below which sprouting will occur (Coleman, 1987).

Exogenously applied cytokinins (kinetin and zeatin) are capable of breaking tuber dormancy and simultaneously reducing the inhibitor-B complex. In the majority of situations investigated, inhibited buds were found to contain low auxin and high cytokinin levels (van Staden and Dimalla, 1978). Exogenous gibberellins (GA) generally terminate dormancy in potato tubers and may play an important role as endogenous regulators of bud dormancy and development (Coleman, 1987). GA was hypothesized to regulate reserve mobilization through changes in intracellular compartmentation. This proposed

role of GA parallels embryo synthesized GA in aleurone layer cells of cereal seeds. Ethylene as an endogenous growth regulator for plants is well established, but its role in dormancy of potato tubers remains unclear (Rylski et al., 1974).

2.4 Methods of controlling sprouting

In order to meet both fresh market and processing industry demands, potatoes are stored for several months. After rest and dormancy, the potato tuber exhibits compulsive growth or sprouting with elevated temperatures common to the spring season. Controlling of rest and dormancy is the essence of storage research. Sprouting in potato tubers can be inhibited by low temperature, irradiation, or chemical sprout inhibitors (Burton and Wilson, 1978; Yada et al., 1991; Liu et al., 1990). Recently, modified atmosphere storage has been explored (Schwobe and Parkin, 1990) to extend storage life of potato tubers.

2.4.1 Chemical sprout inhibitors

Chemicals shown to be effective inhibitors of potato sprouting include isopropyl N-(3-chlorphenyl carbamate) (CIPC), maleic hydrazide (MH), tetrachloronitrobenzene (TCNB) and the methyl ester of naphthalene acetic acid (MENA) (Liu et al., 1990; Coxon and Filmer, 1983; Yada et al., 1991). Sprouting can be inhibited partially or completely if these chemicals are applied properly.

With the exception of MH, all these materials are applied after harvest as dusts, dips, and fumigants. Maleic hydrazide is sprayed onto plant foliage several weeks before harvest (Timm et al., 1959; Weiss et al., 1980). MH is translocated from foliage into tubers and it accumulates in the region of the eyes where it becomes fixed. MH applied to the foliage of the potato cultivars Norchip and Kennebec potatoes had no detrimental effect on marketable and total yields of potatoes. It was effective in suppressing sprout growth and had no effect on the fructose, glucose, and sucrose content of tubers at harvest or after 6 months in storage (Yada et al., 1991). Generally, MH caused no change in chip colour compared to untreated controls. However application of MH earlier in the growing season is likely to result in lower potato yields.

CIPC is the most widely used sprout inhibitor in North America and is normally applied through the ventilation system after vaporising at high temperature. It can also be applied to potatoes going into storage as a dust or liquid. CIPC is very effective in controlling sprout development and an emulsifiable formulation is also used to treat potatoes coming out of storage to control sprouting in marketing channels.

However, there are concerns about high concentrations of CIPC in the peeled potato. In the Netherlands the maximum permitted residue of CIPC in the peeled potato tuber is 0.5 mg a.i. kg^{-1} (Coxon and Filmer, 1983). In commercial application, a greater range of residue concentrations is likely to be encountered because of uneven distribution of the CIPC formulation. Although use of sprout inhibitor may discourage sprout degradation and therefore lead to minimum sugar accumulation (Khurana et al., 1967), both CIPC and MH are reported to increase nonenzymatic browning during processing

of potato tubers (Mondy et al., 1967; Mueller and Mondy, 1977). This may be due to changes in other compounds such as phenolics, also shown to be positively related to fry colour (Ponnampalam and Mondy, 1986). CIPC also interferes with development of the periderm and may slow down wound healing, leading to higher incidence of *Erwinia carotovora* (soft rot), *Fusarium, Penicillum and Aspergillus*.

2.4.2 Natural sprout inhibitors.

The role played by naturally occurring sprout inhibitors is not yet resolved. Meigh et al. (1973) identified three active inhibitors of sprouting released by potato tubers: benzothiozole, 1,4-dimethylnaphthalene and 1,6-dimethylnaphthalene. Further work identified two additional endogenous growth inhibitors as dimethylalanine and dibenzothiophene (Coleman, 1987). The roles of these substances as functional inhibitors remains unresolved due to the low estimated rate of production. It is believed that inhibition of growth is due to the multiple, synergistic interactions among the volatile substances.

2.4.3 Temperature Control

A potato tuber is a hydrated, highly perishable commodity that is extremely responsive to its environment. Starch in potato tubers is frequently converted to undesirable high concentrations of the reducing sugars glucose and fructose as a result of

stress experienced during growth and/or storage (Sowokinos, 1990). Aspects of cellular regulation that may be influenced by stress include: hormones, membrane structure and function, compartmentalization and concentration of key ions, substrate, enzymes and other effectors and enzyme synthesis and/or enzyme activity. It is well known that the best means of decreasing metabolic processes in potato tubers is to store them at low temperature (Owings et al., 1978; Burton and Wilson, 1978).

Storage at temperatures above 10°C usually encourages rotting, water loss, senescent sweetening and sprouting. Storage of potato tubers of most processing potato cultivars at temperatures below 9-10°C results in substantial increase in the reducing sugars glucose and fructose. The normal compromise to ensure processing quality is reached is to store potatoes for mid to long term storage at 7-8°C for french fries and 9-10°C for potato chips after curing them at 15°C and 95% RH for two weeks (Alberta Agriculture, 1987).

2.4.3.1 Low temperature sweetening

Temperature is a key factor in the control of potato starch content (Hagen et al., 1991). The synthesis of starch in potato callus was observed by Mohabir and John (1988) to be optimum at 21.5°C.

Accumulation of sucrose and the reducing sugars glucose and fructose has been observed when potato tubers are stored at low temperatures, especially at storage temperatures below 5°C (Samotous and Schwimmer, 1962; Coffin et al., 1987). Sucrose

is the principal form in which carbon is delivered to the tuber, and almost certainly, an intermediate in the formation of hexose from starch (Pollock and ap Rees, 1975). During the loss of starch at low temperature, sucrose is produced first followed by the accumulation of reducing sugars. Sucrose represents the major part of the sugar increase at 2°C while at 10°C sugars are converted to starch. During the synthesis of starch, sucrose is the main sugar to be lost (Isherwood, 1973).

The biochemical mechanism of low temperature-induced sweetening in potato tubers is not conclusively established. Ability of stress to lead to sugar accumulation is likely to be due to a shift in the balance between starch synthesis and degradation, respiration, sucrose formation and sucrose hydrolysis (Sowokinos, 1990). However the effects of cold on potato metabolism are likely to be so complex that it is improbable that there is a single cause of sweetening. Growing conditions have been reported to influence potato processing quality (Iritani, 1981; Owings et al., 1978). Morrell and ap Rees (1986) found appreciable variation in hexose content, not only between varieties and between tubers of the same variety grown under different conditions, but even between tubers of the same variety grown under the same conditions. Time of harvesting processing potatoes is important because immature potatoes contain high amounts of sucrose (Samotus and Schwimmer, 1962) and are likely to accumulate high concentrations of reducing sugars in storage. Sowokinos (1978) has suggested that sucrose rating (SR) at harvest could be used to predict acceptability of stored potato tubers for processing.

Restriction of glycolysis could lead to accumulation of hexose phosphates and their availability for gluconeogenic reactions. Pollock and ap Rees (1975), suggested that

cold lability of key glycolytic enzymes results in low temperature inhibition of glycolysis with subsequent accumulation of hexose phosphates and followed by sucrose synthesis. The enzymes phosphofructokinase and pyruvate kinase may play an important role in the accumulation of hexose phosphates (Dixon and ap Rees, 1980).

Starch grains of potato tubers are surrounded by a double membrane, typical of a plastid, that has been observed to separate at high sugar levels in senescent tubers (Isherwood, 1973) and to disintegrate or disappear during storage at low temperature (Ohad et al., 1971). Lipids in plant cellular membranes normally exist in a liquid-crystalline state and in this state enzymes associated with these membranes have their optimal activity and permeability under control (Salisbury and Ross, 1985). As the temperature is lowered in chilling sensitive plants, lipids in the cellular membranes solidify (crystallize) at a critical temperature determined by the ratio of saturated to unsaturated fatty acids (Graham and Patterson, 1982; Lyons, 1973). This change in state may lead to cracks or channels that lead to increased permeability (Salisbury and Ross, 1985), resulting in ions and other solutes leaking from chill-damaged cells or mitochondria. Workman et al. (1979) observed a transient increase in ion leakage during the first three days of potato tuber storage at 0°C which may have been the first indication of membrane damage. Enzyme activities would also be upset, and metabolites such as those produced in glycolysis would be expected to accumulate. If the temperature is raised soon enough, membranes return to the normal liquid-crystalline state (this phase being completely reversible) and the cell recovers (Salisbury and Ross, 1985). If the metabolite buildup and solute leakage are allowed to occur to any great extent however,

the cells are injured or killed.

The major portion of inorganic phosphate (Pi) is compartmentalized in the vacuole (Bieleski, 1973). Leakiness of the tonoplast membrane during cold stress could lead to elevated levels of Pi in the cytoplasm (Sowokinos, 1990). Translucent tuber tissue has been found to have elevated levels of Pi (Sowokinos et al., 1985), a stress response that could be analogous to that in low temperature stored tubers. Excess Pi could aid in G1P or 3PGA transport across the amyloplast membrane via a phosphate translocator protein which could lead to higher concentrations of cytoplasmic precursors of sucrose and reducing sugars (Sowokinos, 1990). Inorganic Pi is also a potent inhibitor of ADPglucose pyrophosphorylase and would lead to a decrease in starch synthesis. Pi also stimulates the formation of fructose-2,6-bisphosphate (fru-2,6-bisP), an important metabolic regulator of carbon partitioning in potato tubers. Fru-2,6-bisP may favour glycolysis and retard gluconeogenesis. High cytoplasmic levels of Pi however, also appear to simulate low cytoplasmic levels of fru-2,6-bisP (Sowokinos, 1990) and the elevated levels of Pi initiated by leaky membranes during cold stress, would favour formation of free sugar.

The enzymes UDPglucose pyrophosphorylase (UPPLase) and sucrose 6-phosphate synthase (SPSase) have been found to be important in regulating gluconeogenesis (Sowokinos, 1990). The concentration of UPPLase in nonphotosynthetic potato tubers is reported to be 10 to 20 times lower than its Km (Morrell and ap Rees, 1986) and is important in determining the rate of gluconeogenic reactions. Concentrations of both UPPLase and SPSase have been found to be highly correlated with glucose concentration, their activity increasing during low temperature storage at 3°C, compared to their activity

at the intermediate temperature of 9°C (Sowokinos, 1990). UPPLase and SPSase concentrations are also reported to have increased much more in Red Pontiac (a high sugar clone), when stored at 3°C, compared to the increase in the cold-resistant clone ND860-2, stored at the same temperature.

2.4.4 Modified atmosphere

Lower storage temperatures may be used for sprout control with the use of modified atmosphere (MA) to avoid low temperature sweetening, but results from research with potatoes have been varied (Sherman and Ewing, 1983). Carbon dioxide, oxygen and ethylene are some of the gases found to modify tuber sprouting.

Temporary (ie.one week) and partial anaerobiosis will break dormancy regardless of tuber age (Burton, 1989). Under anaerobic conditions there is no accumulation of sugars although there is evidence for the production of volatile end products of glycolysis such as ethanol and acetaldehyde (Samatous and Schwimmer,1963). Harkett (1971) found potatoes stored at 1°C and 3% oxygen or less accumulated less reducing sugars than those stored in air. Schwobe and Parkin (1990) found potato tuber response to modified atmosphere in terms of sugar accumulation to be cultivar dependent. Working with 3% oxygen, sucrose and hexose sugar accumulation was delayed in Onaway tubers and greatly reduced in ND860-2 tubers. In Norchip, tubers high in sucrose were maintained in the low oxygen atmosphere and hexose sugar accumulation was attenuated.

The effect of ethylene on sprouting and reducing sugar accumulation in potato

tubers was investigated by Haard (1971). Monona tubers produced much darker chips after ethylene treatment. Non-enzymatic browning of Kennebec chips was considerably less after storage exposure to 10ppm ethylene in storage before cold treatment. Schwobe and Parkin (1990) exposed Onaway and Norchip tubers to 1000 ppm ethylene at 3°C and found little practical benefit of the ethylene atmosphere in keeping reducing sugars from accumulating at low temperatures. However, in view of this experiment and that done by Haard (1971), effects of ethylene on reducing sugar accumulation may be concentration and/or cultivar dependent.

2.4.5 Irradiation

Sprout growth may be inhibited indefinitely by irradiating the tubers at sufficiently high dosage with gamma rays (Burton, 1989; Borsa and Mazza, 1989). However senescent changes, both sweetening and tuber breakdown are reported by Burton (1989) to be accelerated by gamma irradiation. After 16 months storage at 10°C, the great majority of tubers irradiated with 10,000 rad were found to be semi-liquid, though enclosed in an intact skin, and had completely black flesh when cut. There was only a slight incidence of breakdown in control tubers that received similar treatment but which were not irradiated. Irradiation also leads to perturbations or increases in the levels of total and reducing sugars (Borsa and Mazza, 1989; Liu et al., 1990). van Es and Hartmans (1981) also reported that gamma irradiation greatly increases the sucrose content of tubers as this sugar can no longer be translocated to the sprouts.

2.5 Reconditioning

Normally the build-up of sugars during cold storage can be reduced to acceptable levels by reconditioning the tubers (Owings et al., 1978; Schwobe and Parkin, 1990; Isherwood, 1973). This is done by storage of potato tubers at elevated temperatures of 15-21°C for varying lengths of time (Iritani and Weller, 1978). During reconditioning, tubers are exposed to high temperatures which converts most of the reducing sugars to starch and results in lightening of chip or french fry colour (Coffin et al., 1987), while some reducing sugars are utilized in respiration.

Sometimes french fry colour from cold stored tubers is not acceptable after reconditioning. Coffin et al. (1987) reported that Simcoe and Norchip tubers did not produce chips with acceptable colour after storage at 5°C even after reconditioning at 20°C for two weeks. For these cultivars, storage at 5°C might lead to a partially irreversible reconversion of reducing sugars to starch such that reconditioning was no longer an effective remedy. Liu et al. (1990) also found that the longer potatoes were stored at low temperatures, the less the sugar content was reduced during reconditioning and that longer reconditioning time periods removes accumulated reducing sugars but the extent of sugar removal decreases with the time until no further reduction occurs. Sugar accumulated as a result of senescent sweetening cannot be removed by reconditioning. The amyloplast membranes have been observed to separate at high sugar levels in senescent tubers (Isherwood, 1976) and this may represent irreversible damage to the membrane. Low temperature sweetening may be a result of changes in cell membrane

structure (Salisbury and Ross, 1985) and if the temperature is raised soon enough, membranes may return to normal. If metabolite buildup and solute leakage are allowed to occur to any great extent however, cells are injured or killed and reconditioning is not successful.

3.1 Experimental material

3.1.1 Field planting

Shepody and Russet Burbank potatoes were planted on wheat stubble on an Almassippi sandy loam soil at Graysville, Manitoba, on May 24, 1990 and on May 22, 1991 in a commercial field. Plant spacing was 42 cm within rows and 1 m between rows. The field used in 1990 planting had soil fertility of 119-27-242-269-0.6-0.5 kg ha^{-1} of N:P:K:S:Zn:Cu. The corresponding fertility levels for soil in the field used in 1991 were 82-46-375-15-0.4-0.2 kg ha^{-1}. Before planting, 101-0-146-11-4-1 kg ha^{-1} and 101-0-146-11-4-1 kg ha^{-1} of N:P:K:S:Zn:Cu was broadcast in 1990 and 1991, respectively. Additional fertilizer was applied at time of planting by banding at the rate of 26-121-0 kg ha^{-1} in 1990 and 54-0-134-6-0-0 kg ha^{-1} in 1991. Insecticide, fungicide, and irrigation water were applied by the producer. Maleic hydrazide (Royal MH60, Uniroyal Chemical, Elmira, ON), hereafter referred to as MH60, was applied for sprout inhibition to half of the plot on August 23, 1991, at the rate of 5.65 kg 500 L^{-1} of water ha^{-1}. Plots were harvested by hand on September 19, 1990 and with a small plot harvester on September 23,1991.

3.1.2 Storage management

After harvest, tubers were stored for two weeks at 15°C and 90% RH for

preconditioning. Temperature was then slowly decreased at the rate of 1°C per week to 8, 6, or 4°C in 1990/91 and to 8, 6, or 5°C in 1991/92 for long term storage. The decision to replace the 4°C storage temperature with 5°C in 1991/92 was reached after results from 1990/91 indicated excessively high reducing sugar concentrations when tubers were stored at 4°C. The 8°C temperature served as the control temperature. Tubers were stored until mid-June in both 1990/91 and 1991/92.

3.1.3 Experimental design and sampling

In 1990/91, the experiment was a nested design in which sampling week was nested against storage temperature. The 6°C storage temperature was established two weeks after the 8°C temperature and two weeks before the 4°C storage temperature. The sampling dates were therefore dependent on storage temperature. Sampling was done at harvest, at two weeks after harvest at the end of preconditioning, when the storage temperatures were established, and every four weeks thereafter. A factorial design was used in 1991/92 where the factors were temperature (8, 6, or 5°C), sampling date, and MH60 treatment. Sampling was done at harvest and, at two and four weeks after harvest. Thereafter sampling was at four week intervals. There were three replications for each storage temperature which were stored in one room at each temperature.

3.2 Determination of sugars by HPLC

3.2.1 Sample preparation

At each sampling time, five tubers were removed from each replication, peeled, and 1-2 cm removed from each end. Tubers were cut into longitudinal strips and a representative sample of approximately 200 g was weighed and passed through an Olympic fruit and vegetable juicer (Model No.1000). The pulp was rinsed with distilled water and the volume of the extract was brought up to 400 mL. The juice was stirred and left to settle at 4°C for about 1 h. Twenty mL of juice was pipetted out of the centre of the sample and stored at -20°C until analyzed.

3.2.2 Analysis

A modification of the high performance liquid chromatography (HPLC) method of Wilson et al. (1981) as described by Pritchard and Adam (1992) was used to determine levels of sucrose, glucose, and fructose.

Standards were prepared at the beginning of each HPLC analysis. About 250 mg of each of sucrose, glucose and fructose were dissolved in 25 mL of water. Ten mL of this solution was treated like each of the potato samples as described below.

The frozen potato juice samples were thawed and a 10 mL portion transferred into a centrifuge tube. Ten mL methanol was added to each sample and mixed on a vortex. The samples were then centrifuged at 15,000 rpm for 10 min. A 10 mL aliquot of the

supernatant was drawn and dried in a roto-evaporator at 45°C and was redissolved in 10 mL distilled water. Samples are filtered through a 2.5 cm Whatman glass micro-fibre filter and about 5 mL filtered through a C_{18} cartridge Sep-Pak (Waters, a Division of Millipore, Milford, MA). A 20-50 µl sample was analyzed on a Beckman Model 100A high performance liquid chromatograph equipped with an Altex 156 refractive index detector. The carbohydrate analysis column used was an Aminex HPX-87P (Bio-Rad Laboratories (Canada) Ltd., Mississauga, ON), with a mobile phase of distilled, filtered, degassed water at a flow rate of 0.6 mL min^{-1} which was operated at 85°C.

Detector signals were integrated as area peaks, which were directly related to sugar concentration. Sugar content for each sample was determined by the formula:

sugar conc (mg/g fresh weight) = (area sample/area standard) x (mg/mL of standard) x (volume sample juice/sample fresh weight)

3.3 Fry colour determination

Tubers used for sugar determination were also used for fry colour determination. After peeling, the sample of five tubers was sliced longitudinally and five slices removed from the middle of each tuber to make a total of 25 slices. The slices were fried for 2.75 min at 190°C and the colour of each fry was visually assessed. The colour rating was compared to the USDA french fry potato colour chart (Anonymous, 1988). The chart ratings of 000, 00, 0, 1, 2, 3 and 4 were converted to a 1-7 rating with 1 being lightest (Appendix 11). Fry colour of the sample was given as the average colour of the 25 slices.

3.4 Reconditioning

In 1990/91, reconditioning started 17 weeks after harvest for the potato tubers stored at 4°C and 19 weeks after harvest for the tubers stored at 6°C. Two, five-tuber samples were removed from each storage every four weeks and placed in an 18°C storage. One sample was removed after 2 and the other after 4 weeks and analyzed for reducing sugar and fry colour. In 1991/92, reconditioning was only carried out for 2 weeks due to the excessive sprouting of tubers reconditioned for 4 weeks in 1990/91. In the fast reconditioning treatment, potato tuber samples were drawn from 5 and 6°C storage beginning 19 weeks after harvest and were stored at 18°C for 2 weeks. Thereafter until the end of storage, samples were removed to 18°C at 2 week intervals. In the gradual reconditioning treatment, samples were removed from the 5 and 6°C storage beginning 27 weeks after harvest and stored in a chamber where temperature was raised at the rate of 1°C per day to reach a maximum of 18°C. Samples were removed after 2 weeks of reconditioning and were analysed for sugars and fry colour.

3.5 Sprout assessment

Sprout growth of all samples was visually assessed in the stored potato tubers in both 1990/91 and 1991/92. Dates of visible sprouting and excessive sprout growth were recorded. Average sprout length of 10 cm or more was considered to be excessive sprout growth.

4. RESULTS AND DISCUSSION

4.1 Storage Temperature Effect on Sugar Levels

The normal storage conditions for Russet Burbank and Shepody potato tubers used for french fry processing in Manitoba is a holding temperature of 7 to 8°C and in combination with sprout inhibitor. In this study, the 8°C storage temperature was used as the control. During the 1990/91 storage season, tubers which had not been sprout inhibited were used. Due to the excessive accumulation of reducing sugars in potato tubers stored at 4°C in 1990/91, the 4°C storage temperature was replaced with 5°C in 1991/92. In 1991/92, tubers treated with the sprout inhibitor MH60 in addition to tubers without sprout inhibitor were used in the study.

4.1.1 Russet Burbank

The effect of storage temperature and sampling week on concentrations of sucrose, glucose and fructose of tubers stored at 4, 6 or 8°C in 1990/91 and at 5, 6 or 8°C in 1991/92 were highly significant ($P< 0.01$) (Table 1). Sucrose concentration in both 1990/91 and 1991/92 generally decreased during storage at 6 or 8°C, and increased at 4 or 5°C (Fig 1 and 2). The reducing sugar (glucose and fructose) concentration, slowly increased during storage with more accumulation occurring the lower the temperature. There was a very rapid rise in the concentration of reducing sugars at the 4°C storage

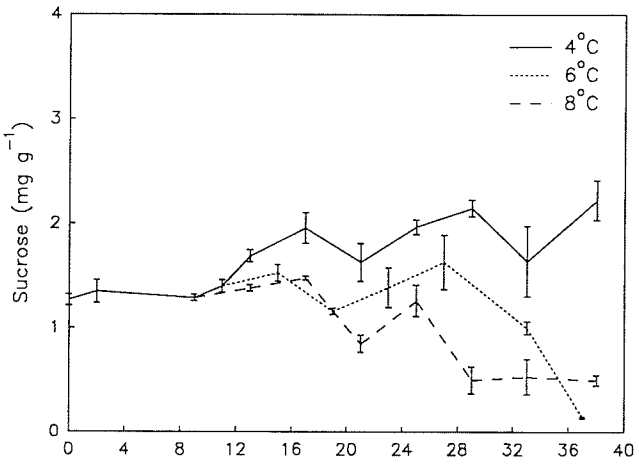
Table 1. Analysis of variance for sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Russet Burbank potatoes sampled during storage 4, 6 or 8°C in 1990]/91 or stored with or without sprout inhibitor in 1991/92 (only significant results are shown).

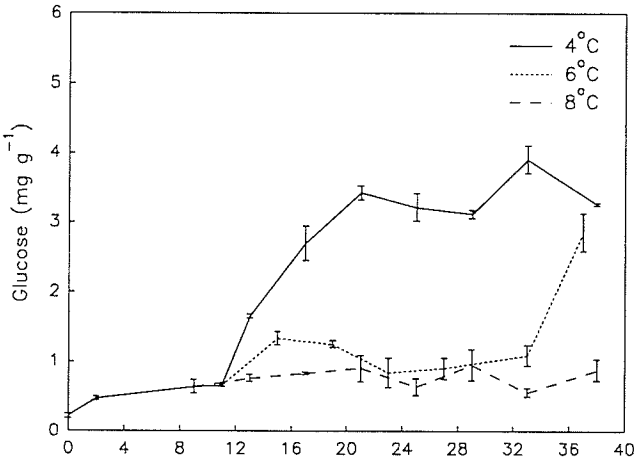
		Mean square		
Source	df	Sucrose	Glucose	Fructose
1990/91				
Temp	2	3.582**	17.779**	8.883**
Sweek*(temp)	28	0.452**	2.669**	3.232**
Error	62	0.089	0.095	0.062
C.V.%		22.57	23.68	15.42
1991/92				
Temp	2	3.930**	21.064**	17.456**
Sweek	12	0.495**	6.978**	13.515**
Sweekxtemp	24	0.243**	1.275**	1.478**
Error	139	0.108	0.170	0.274
C.V.%		28.9	34.2	43.5

** = significant at $P < 0.01$

*sweek = sampling week

Fig 1. Sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Russet Burbank potato tubers stored without sprout inhibitor at 4, 6 or 8°C in 1990/91.


4°C
6°C
8°C
Sucrose (mg g^{-1})
0
1
2
3
4
0 4 8 12 16 20 24 28 32 36 40


4°C
6°C
8°C
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0 4 8 12 16 20 24 28 32 36 40

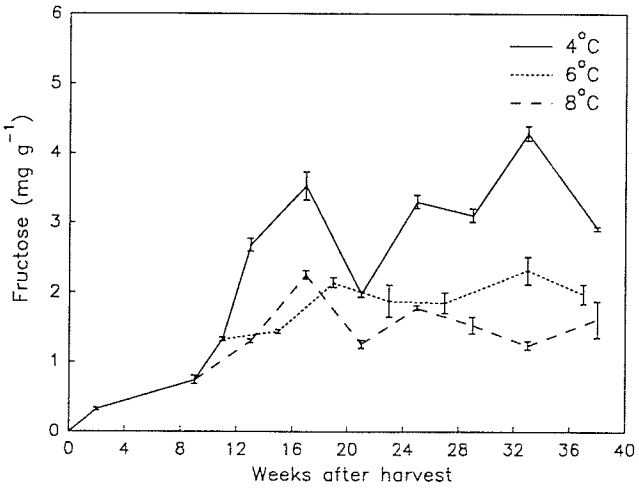
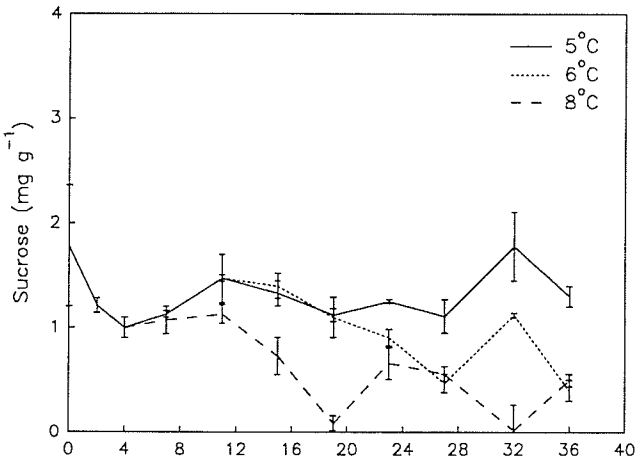
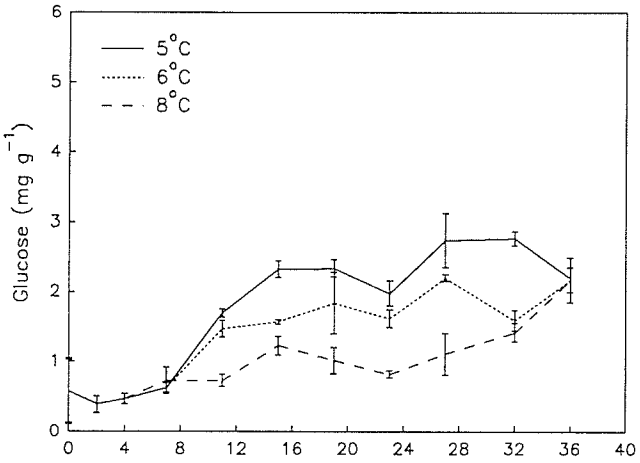
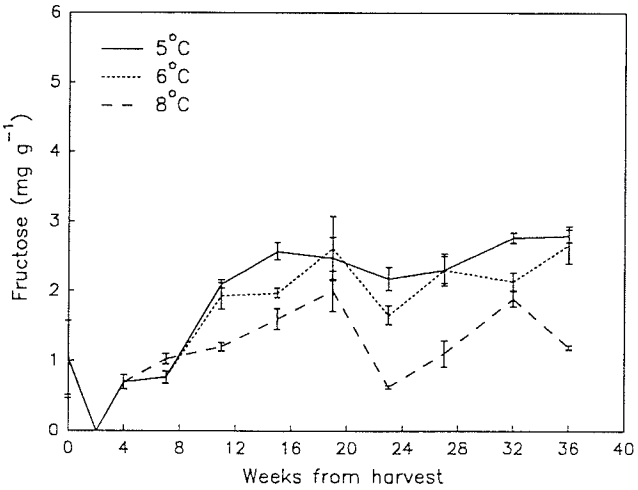

4°C
6°C
8°C
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0 4 8 12 16 20 24 28 32 36 40
Weeks after harvest

Fig 2. Sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Russet Burbank potato tubers stored without sprout inhibitor at 5, 6 or 8°C in 1991/92.


5°C
6°C
8°C
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40


5°C
6°C
8°C
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


5°C
6°C
8°C
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

temperature, and the concentration remained high until the end of the study.

In 1990/91, sucrose concentration in tubers stored at 8°C declined from 1.27 mg g^{-1} at harvest to 0.50 mg g^{-1} 38 weeks after harvest. The glucose concentration increased slightly from 0.22 mg g^{-1} at harvest to 0.88 mg g^{-1} 38 weeks after harvest. Fructose concentration increased the most and reached a maximum of 2.25 mg g^{-1} 17 weeks after harvest (Fig 1). The trend in change of sugar concentration of tubers stored at 6°C was similar to that in tubers stored at 8°C, but the concentrations were slightly higher. Sucrose concentration declined while concentration of the reducing sugars generally increased at 6°C. In tubers stored at 4°C, concentration of all three sugars, sucrose glucose and fructose, increased rapidly from harvest and remained high over the entire storage period. Accumulation of sucrose and the reducing sugars glucose and fructose has been observed when potatoes are stored at low temperatures, especially at storage temperatures below 5°C (Samotous and Schwimmer, 1962; Coffin et al., 1987). There was a very significant increase in the concentration of glucose and fructose as the temperature was lowered from 6 to 4°C. The high reducing sugar concentration at 4°C was considered excessive and unacceptable for processing, and reconditioning (discussed later in section 4.3) was not successful in lowering the sugars to acceptable levels. Consequently, in the second year of the study, 5°C was substituted for the 4°C storage temperature.

In 1991/92 both sprout inhibited and non-sprout inhibited tubers were used in the study. Treatment of Russet Burbank potato tubers with MH60 did not significantly affect sucrose and reducing sugar concentrations ($P=0.56$). Other researchers have obtained

similar results with different cultivars. Yada et al. (1991) found that sucrose, glucose and fructose concentrations of Norchip and Kennebec tubers treated with MH60 compared to untreated tubers were the same at harvest and after 6 months in storage. Highlands et al. (1952) also reported similar sugar concentration for MH60 treated and untreated tubers of the cultivars Kennebec and Katahdin. Therefore only data from non-MH60 treated tubers is presented and discussed below.

In 1991/92 the changes in sugar concentration in response to different storage temperatures were similar to those in 1990/91. Storage at 5°C resulted in the highest sugar accumulation compared to tubers stored at 6°C and 8°C (Fig 2). A sampling week x temperature interaction was observed for the three sugars (Table 1). This interaction occurred for sucrose since the sucrose concentration in tubers stored at 8°C declined, with increased sucrose at lower temperatures. Reducing sugars increased over time but there was a greater increase the lower the temperature. This interaction could not be determined in 1990/91 because sampling week was nested against storage temperature.

In both 1990/91 and 1991/92, generally an increase in reducing sugar accumulation was observed at the time of sprouting (Fig 1 and 2). Sprouting was evident after 27 weeks at 8°C and at 33 weeks when tubers were stored at 6°C in both years. A rise in sugar content in potato tubers associated with break of dormancy has been reported by Edelman and Singh (1969), Richardson et al. (1990) and by van Staden and Dimalla (1978).

The glucose concentration that gives acceptable french fry colour for the cultivar Russet Burbank grown in Manitoba to be was determined to be 1.62 mg g^{-1} (Section 4.4).

Potatoes will still be suitable for frying when the glucose concentration is >1.62 mg g^{-1}, but bonus payments may be reduced (Appendix 11). If this concentration of glucose is used as the point of maximum return for the producer, storage of potato tubers at 8°C in 1990/91 would have given acceptable fry colour over the entire storage period (Fig 1). Tubers stored at 6°C had acceptable glucose for most of the storage period but tubers stored at 4°C had glucose concentration above 1.62 mg g^{-1} for the entire storage period. In 1991/92 tubers stored at 8°C had acceptable glucose concentrations over the entire storage period (Fig 2). Tubers stored at 6°C also had glucose concentration below 1.62 mg g^{-1} for most of the storage period, while tubers from 5°C storage had glucose concentration above 1.62 mg g^{-1} after 10 weeks in storage which would have occurred at about the time when storage temperature had reached 5°C (Fig 2).

4.1.2 Shepody

The response of Shepody to storage temperature was similar to that of Russet Burbank with higher sugar accumulation at lower temperatures. Shepody however responded with much greater sugar increases as compared to Russet Burbank when stored at the same temperature.

Temperature had highly significant effects on sucrose, glucose and fructose levels, while sampling week significantly affected sucrose and glucose concentrations in 1990/91 (Table 2). Sucrose remained relatively stable for the first several weeks of storage at 8°C, then declined throughout storage (Fig 3). However, as tubers were cooled to 4°C, there

was a sharp increase in sucrose, which later declined (Fig 3). The reducing sugars glucose and fructose generally increased with higher accumulation at lower temperatures. A very rapid increase in fructose occured at the time that the high sucrose concentration that had accumulated began to decline. At 4°C reducing sugar concentration was

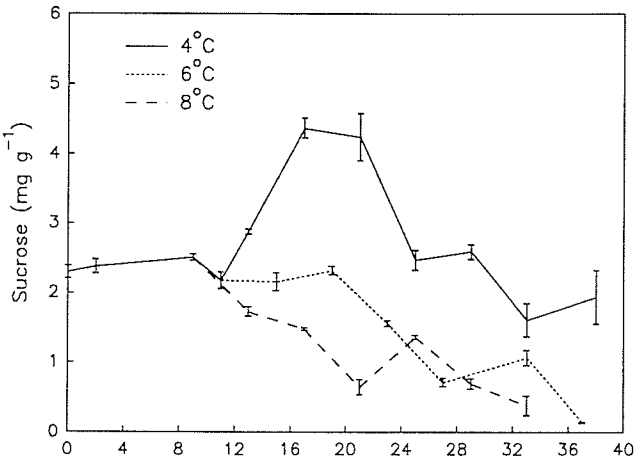
Table 2. Analysis of variance for sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Shepody potato tubers stored without sprout inhibitor at 4, 6 or 8°C in 1990/91.

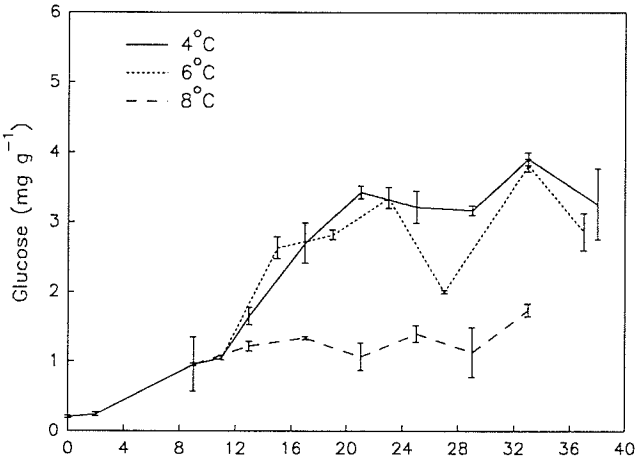
		Mean Square		
Source	df	Sucrose	Glucose	Fructose
Temp	2	12.105**	42.384**	21.018**
Sweek*(temp)	27	2.094**	8.027**	6.221
Error	60	0.111	0.185	0.094
C.V.%		16.586	19.436	14.035

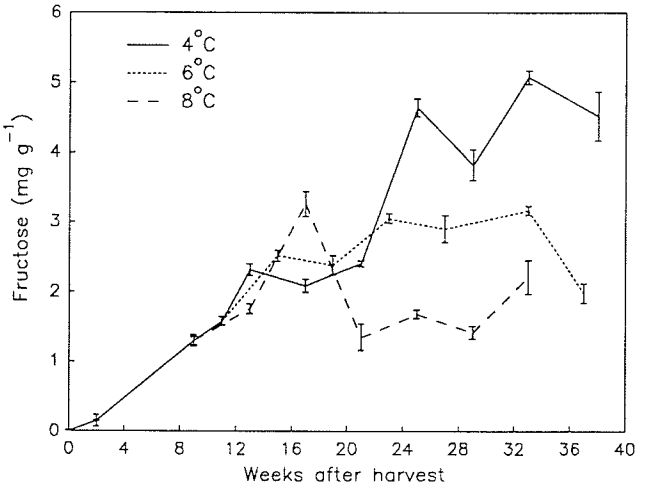
** = significant at $P < 0.01$

*sweek = sampling week

Fig 3. Sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Shepody potato tubers stored without sprout inhibitor at 4, 6 or 8°C in 1990/91.


4°C
6°C
8°C
Sucrose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


4°C
6°C
8°C
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


4°C
6°C
8°C
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks after harvest

excessively high and therefore, this temperature would not be feasible to use for long term storage of this cultivar. A storage temperature of 5°C replaced 4°C in the second year of study. Low temperature sweetening (accumulation of free sugars when potato tubers are stored at temperatures below 9-10°C, especially below 5°C), is well documented in existing literature (Coffin et al., 1987; ap Rees et al., 1981; Pressey and Shaw, 1966). In order to determine if sprout inhibitor application affects the response of tubers to storage temperature, MH60 was applied for sprout inhibition in 1991/92. MH60 did not have a significant effect on the sucrose concentration in the stored Shepody tubers (Table 3). Sucrose concentration increased rapidly early in storage to reach a maximum about 10 weeks after harvest in both MH60-treated and untreated tubers and then declined to a minimum 36 weeks after harvest for tubers stored at 5 or 6°C (Fig 4 and 5). However, in tubers without MH60, sucrose declined sharply as reducing sugars increased, while in MH60-treated tubers, sucrose remained high for several weeks before declining (Fig 4 and 5).

MH60 treatment had a significant effect on the level of glucose (Table 3). There was greater glucose accumulation at all temperatures for MH60-treated tubers compared to tubers with no MH60 application over most of the storage period (Fig 4 and 5). There was a temperature x MH60 and sampling week x MH60 interaction for fructose. Accumulation of fructose at 5 and 6°C storage was higher in MH60 treated tubers and MH60 treatment led to higher sugar accumulation between 12 and 28 weeks after harvest (Fig 4 and 5).

Table 3. Analysis of variance for sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Shepody potato tubers stored at 5, 6, or 8°C in 1991/92.

		Mean Square		
Source	df	Sucrose	Glucose	Fructose
Temp	2	7.846**	28.174**	24.144**
MH60	1	0.440	3.110**	0.142
TempxMH60	2	0.591	0.157	1.086**
Sweek*	10	0.461**	26.745**	18.709**
SweekxTemp	20	0.938**	1.710**	1.532**
SweekxMH60	9	0.183	0.575	0.952**
SweekxMH60xtemp	18	0.095	0.600*	0.558
Error	125	0.112	0.347	0.214
C.V.%		23.4	30.7	27.7

* = significant at $P < 0.05$

** = significant at $P < 0.01$

*sweek = sampling week

Fig 4. Sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Shepody potato tubers stored without sprout inhibitor at 5, 6 or 8°C in 1991/92.

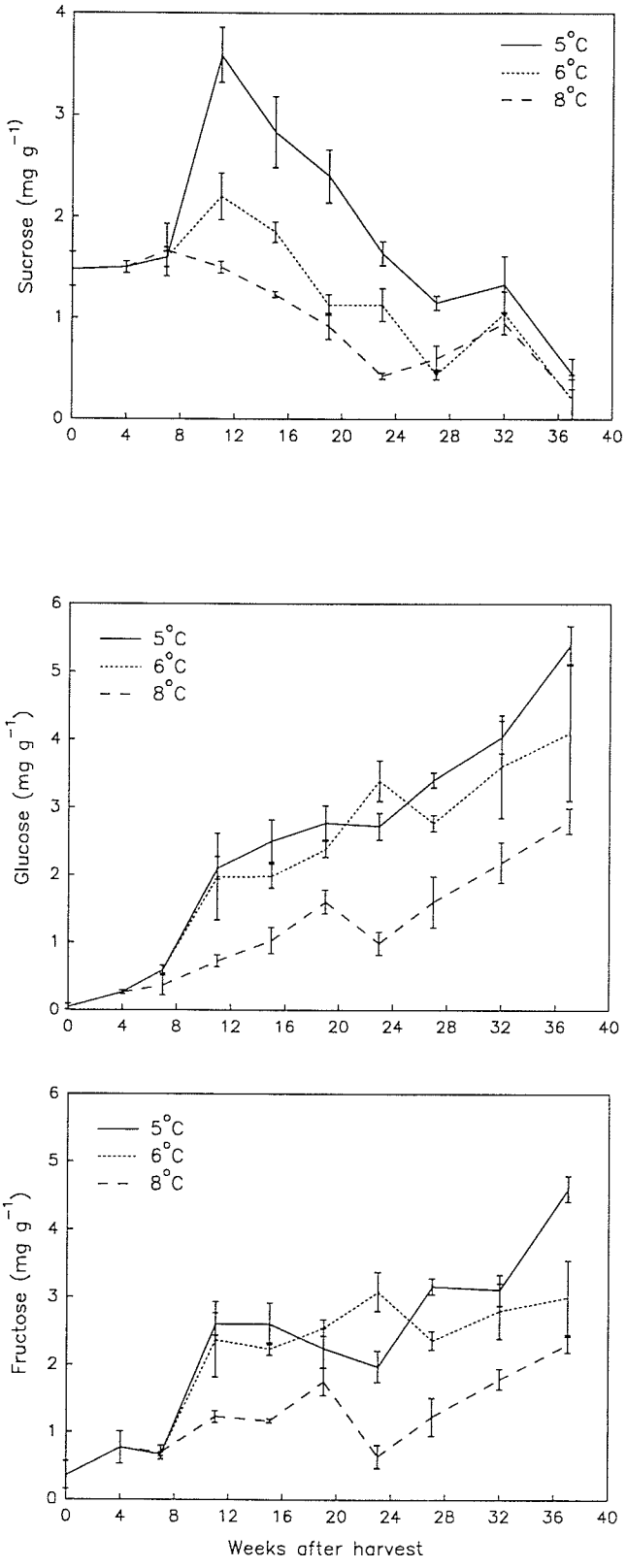
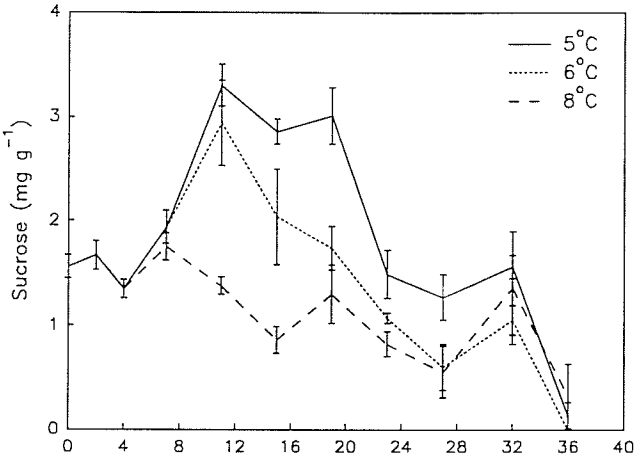
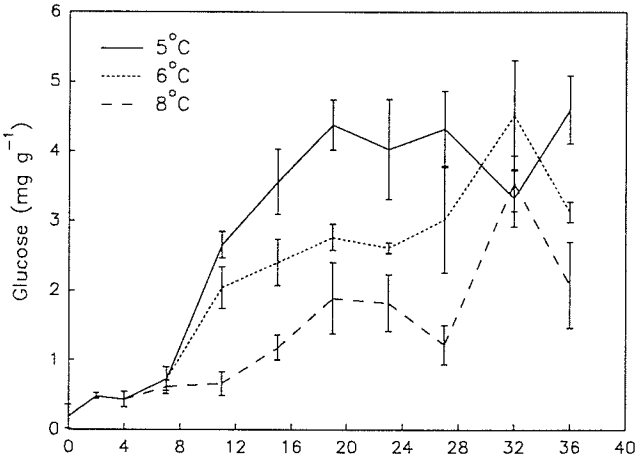
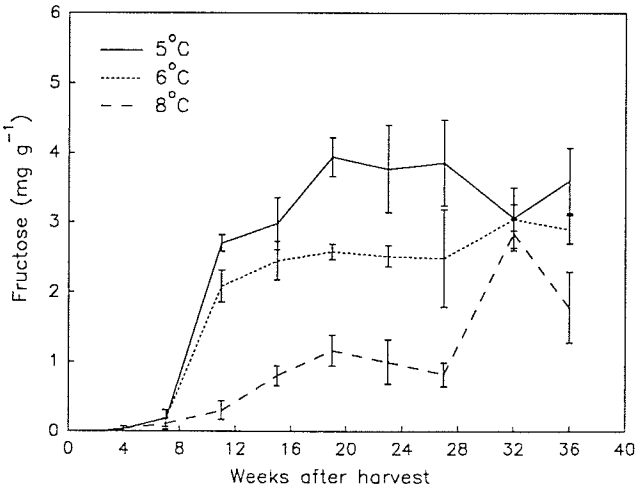

Sucrose (mg g^{-1})
Glucose (mg g^{-1})
Fructose (mg g^{-1})
5°C
6°C
8°C
Weeks after harvest

Fig 5. Sucrose, glucose and fructose concentration (mg g^{-1} fwt) of Shepody potato tubers stored with sprout inhibitor at 5, 6 or 8°C in 1991/92.


5°C
6°C
8°C
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40


5°C
6°C
8°C
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


5°C
6°C
8°C
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks after harvest

In general both the reducing sugars had a similar response to both temperature and MH60 treatment. In tubers stored at 5°C, there was greater increase in glucose and fructose earlier in storage in MH60 treated tubers (Fig 4 and 5). Reducing sugar concentration in tubers without sprout inhibitor increased steadily to above 5 mg g^{-1} for glucose and 4 mg g^{-1} for fructose at 36 weeks. In the MH60 treated tubers, a maximum of about 4 mg g^{-1} for both sugars was reached at about 19 weeks in storage, declined until 32 weeks, then slowly started to rise in the presence of MH60. In tubers with no MH60, and stored at 6 or 8°C, reducing sugar concentration increased steadily to 36 weeks after harvest. There was a sharp increase then a decline in reducing sugar at about time of sprouting (at 18 weeks and 20 weeks for tubers stored at 8 or 6°C, respectively) (Fig 4). In MH60-treated tubers stored at 8 and 6°C, reducing sugar concentration increased gradually during most of the storage period, increased sharply at 32 weeks and then declined (Fig 5).

The mechanisms that control carbohydrate metabolism in Shepody potato tubers appear to differ in the presence of sprout inhibitor and need to be clarified. The difference may be related to the membrane structure when sprout inhibitor is applied. Mondy et al. (1967) reported that in MH60-treated tubers there was a significant increase in saturated fatty acids and a decrease in unsaturated fatty acids in cell membrane lipids.

Yada et al. (1991) and Highlands et al. (1952) have reported similar sugar concentrations of MH60 treated and untreated tubers in storage. Yada et al. (1991) however found that tubers from untreated plants of the cultivar Kennebec produced significantly lighter coloured chips after 6 months in storage than did tubers from MH60

treated plants. Desprouting, CIPC treatment and gamma irradiation to prevent sprout development have been reported to increase the sucrose content of potato tubers as this sugar is no longer translocated to the sprouts (van Es and Hartmans, 1981). MH60 treatment may be expected to lead to an increase in sucrose and reducing sugars (from hydrolysis of sucrose) for the same reasons.

In 1990/91, Shepody tubers stored at 4 or 6°C had glucose concentration above 1.3 mg g^{-1} over the entire storage time (Fig 3), while tubers stored at 8°C had acceptable glucose concentration below 1.3 mg g^{-1} up to 16 weeks in storage. French fries from tubers with glucose concentration >1.3 mg g^{-1} would have a fry colour which would not be eligible for maximum bonus payment (Section 4.4). In 1991/92 Shepody tubers stored at 5°C and 6°C had glucose levels above 1.3 mg g^{-1} for the entire storage period whether or not sprout inhibitor was used (Fig 4 and 5). MH60 treated and untreated tubers stored at 8°C had glucose levels higher than 1.3 mg g^{-1} after 16 weeks in storage at which time maximum payments for colour would not be obtained and steps to improve colour would be necessary.

4.2 Temperature and Sprout Growth

Sprout growth was visually assessed and measurements of sprout length were taken during the storage. Apical dominance and physical appearance of the sprouts were observed and are presented in the appendix but will not be discussed (Appendix 7). The time in weeks from harvest to first visible signs of sprouting of both Russet Burbank and Shepody was very similar in the two years of the study (Table 4 and 5).

Generally, in both cultivars and in both years, the lower the storage temperature, the more sprout development was delayed. Almost all stored processing potatoes in Manitoba are sprout inhibited in storage and sprouting does not therefore become a problem. There is no clear definition as to the maximum sprout development which is acceptable to the processors. There is preference for tubers without sprouts but sprouts of up to 10cm in length are acceptable (Carnation Foods Ltd, Carberry, personal communication). When sprouts are >10 cm in length, the scrubbers in the processing line will likely become blocked.

In this study, average sprout length was assessed as one parameter of acceptability of potato tubers for processing. However the number and thickness of the sprouts was found to vary depending on the cultivar and time of assessment (Appendix 7). Russet Burbank had few, long and thin sprouts while Shepody produced thick sprouts that generally became branched towards the end of the storage season. Average sprout length therefore may not be the most appropriate indicator to assess acceptability of tubers for processing. The sprouts perhaps should have been removed and weighed for a more

precise estimate of sprout development.

Russet Burbank stored at 4, 5 and 6°C had acceptable sprouts up to end of the study (Table 4). In the 8°C treatment, the degree of sprout development was acceptable up to 33 weeks after harvest in 1990/91 although the first visible signs of sprouting occurred after 27 weeks. Shepody had a shorter dormancy period than Russet Burbank. Dropping storage temperature from 8 to 6 and 4°C delayed sprouting by 4 weeks and 16

Table 4. Time in weeks after harvest of first sprout appearance and excessive sprout length (> 10 cm) in Russet Burbank tubers stored without sprout inhibitor in 1990/91 and 1991/92.

Storage temp(°C)	Time to initial sprouting (weeks)		Time to sprout length >10cm (weeks)	
	1990/91	1991/92	1990/91	1991/92
4	>38	-	>38	-
5	-	37	-	>37
6	33	33	>38	na
8	27	27	33	na

na - not assessed

weeks, respectively, in 1990/91 while dropping temperature from 8 to 6 and 5°C delayed sprouting by 3 and 15 weeks, respectively, in 1991/92 (Table 5). Time of acceptable sprout length was not extended by dropping the temperature from 8 to 6°C. When temperature was dropped to 4°C, in 1990/91 there was no sprout development up to the end of the study (Table 5). Burton (1989) observed that, in general, the higher the storage temperatures ranging from 4-21°C, the shorter the rest period (state where buds do not grow even under favourable conditions) after harvest.

Table 5. Time in weeks after harvest of first sprout appearance and excessive sprout length (> 10 cm) in Shepody tubers stored without sprout inhibitor in 1990/91 and 1991/92.

Storage temp(°C)	Time to initial sprouting (weeks)		Time to sprout length >10cm (weeks)	
	1990/91	1991/92	1990/91	1991/92
4	33	-	>38	na
5	-	33	-	na
6	21	21	29	na
8	17	18	29	na

na - not assessed

4.3 Reconditioning

Reconditioning studies were conducted to determine whether sugars accumulated during storage at low temperatures could be lowered to acceptable levels for processing. Reconditioning, by exposure of tubers to high temperatures, lowers sugars by conversion of free sugars back into starch and by utilization of some sugars in respiration.

In 1990/91, potato tubers were reconditioned for a period of 2 or 4 weeks. Tubers were removed from storage and placed directly into 18°C storage. In 1991/92, the 4 week reconditioning time was omitted due to excessive sprouting that occured in tubers in 1990/91. Reconditioning was done by placing tubers removed from storage either directly into 18°C storage or by gradually raising the temperature by 1°C per day up to 18°C. Therefore tubers in the latter treatment had reached 18°C approximately 2 days before sampling.

4.3.1 Russet Burbank

As discussed above (section 4.1.1), in 1990/91 tubers stored at 4°C had glucose levels above 1.62 mg g^{-1} over the entire storage period, while tubers stored at 6°C had acceptable glucose for most of the storage period. Tubers with glucose concentration above 1.62 mg g^{-1} would result in fry colours which are not acceptable for maximum bonus payments by the potato processing industry in Manitoba (Section 4.4). Although

glucose levels were considered acceptable at 6°C, the ratio of glucose to fructose varied depending on temperature, with higher fructose concentration at 6 and 8°C. At 8°C storage temperature, fructose concentration fluctuated but was much higher than glucose concentration in the first few weeks of storage (Fig 1). Therefore, reconditioning was done for tubers stored at both 4 and 6°C (Table 6), but it was not necessary to recondition tubers stored at 8°C as they had acceptable glucose levels over the entire storage period.

Reconditioning began 17 weeks and 19 weeks after harvest for tubers stored at 4 and 6°C, respectively, in 1990/91 and samples were taken every 4 weeks for the remainder of the storage period. Reconditioning tubers from both 4 and 6°C for 2 weeks was not always successful in lowering sugar concentrations to acceptable levels for processing (Table 6). A 4 week fast reconditioning was for the most part successful in reducing the glucose concentration to below 1.62 mg g^{-1} (Table 6) and was found to be successful in lowering reducing sugar concentration to that which would give acceptable fry colour for tubers from both 4 and 6°C after 33 weeks storage. However excessive sprout growth of more than 10 cm rendered the tubers unacceptable for processing after 33 weeks in storage at 4 or 6°C with reconditioning (Appendix 7) although there was no sprouting before reconditioning. Burton (1989) noted that storage of potato tubers at temperatures unfavourable for growth may alter the tuber composition so much that, on subsequent transfer to a temperature favourable to growth, the rate of sprout growth is far greater than for tubers stored continuously under favourable conditions.

In 1991/92, tubers stored at 5 and 6°C were reconditioned by direct placement into 18°C (fast), or by gradual warming to 18°C. Fast reconditioning started 19 weeks

Table 6. Mean sucrose, glucose and fructose (mg g^{-1} fwt) in Russet Burbank potato tubers stored without sprout inhibitor at 4 or 6°C in 1990/91 after reconditioning by direct placement into 18°C.

Temp(°C)	Weeks after harvest	Recondition time in weeks	Sucrose	Glucose	Fructose
4	17	0	1.96±.18	2.70±.28	3.53±.23
		2	1.48±.05	1.82±.05	1.81±.02
		4	1.13±.03	1.23±.08	1.37±.10
	21	0	1.63±.21	3.43±.12	1.98±.04
		2	1.38±.04	1.37±.11	1.87±.04
		4	0.84±.13	0.74±.18	1.79±.24
	25	0	1.97±.08	3.22±.23	3.30±.12
		2	1.82±.08	1.14±.04	2.62±.20
		4	1.03±.26	0.82±.04	1.78±.16
	29	0	2.15±.09	3.12±.07	3.11±.11
		4	1.06±.12	1.47±.04	1.62±.04
	33	0	2.23±.22	3.91±.23	4.29±.12
		4	1.00±.19	0.73±.02	1.93±.16
6	19	0	1.16±.03	1.25±.06	2.14±.08
		2	0.90±.14	0.76±.10	0.66±.06
		4	1.13±.04	0.36±.03	2.19±.10
	23	0	1.39±.22	0.84±.24	1.88±.26
		2	1.46±.10	0.50±.02	1.27±.05
		4	1.09±.06	0.76±.06	1.51±.06
	27	0	1.63±.21	0.90±.17	1.85±.18
		2	1.01±.05	0.47±.01	1.22±.06
	33	0	1.00±.07	1.09±.17	2.32±.23
		4	0.93±.11	0.65±.04	1.84±.20

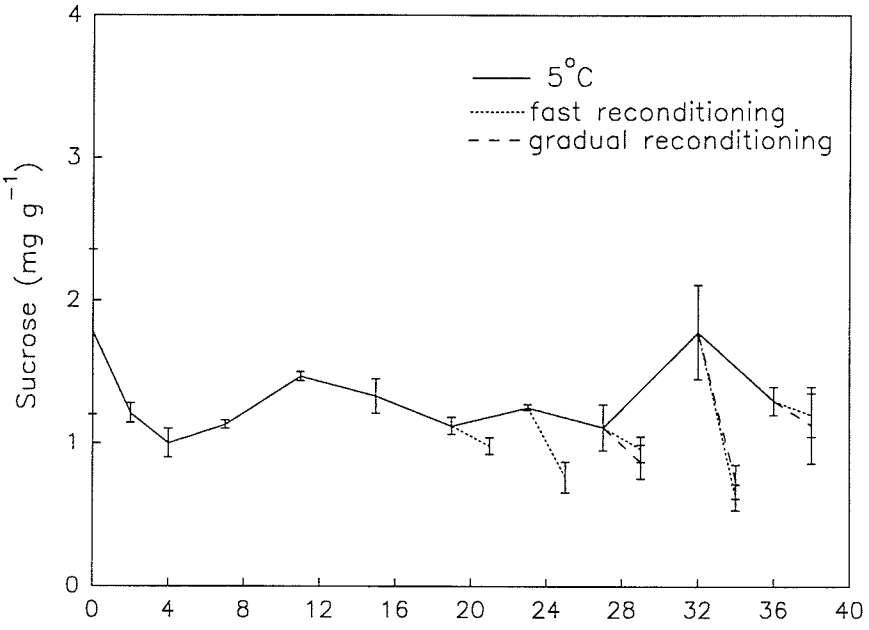
after harvest for tubers stored at 5 and 6°C. Gradual reconditioning started 27 weeks after harvest. Raising the temperature rapidly presents technical problems in commercial storage because of the large bulk of product that is stored. Therefore, slow changes in temperature would occur during the warming period. Problems of disease due to moisture condensing on the surface of the cold tubers would also occur if large volumes of warm air are used to warm the pile.

Generally, both fast and gradual reconditioning lowered the sugar concentrations, except after 32 weeks when sucrose and fructose concentrations actually increased in tubers which had been stored at 6°C (Fig 6, 7 and 8). This increase in sucrose and fructose concentration could have been due to senescent sweetening (Burton and Wilson, 1978). A 2 week fast or gradual reconditioning led to a reduction in sucrose concentration, although in most cases it was not significant (Fig 6). Glucose concentration was significantly reduced by reconditioning, fast or gradual, of tubers stored at 5 or 6°C (Fig 7). Only gradual reconditioning at 37 weeks did not result in acceptable glucose concentration in tubers stored at 5°C. Fast reconditioning resulted in significantly lower fructose concentrations and was usually more effective than gradual reconditioning in lowering sugars in tubers stored at 5 or 6°C.

4.3.2 Shepody

In 1990/91, tubers stored at 4°C did not have acceptable glucose concentration of

Fig 6. Sucrose concentration (mg g^{-1}) of Russet Burbank potato tubers stored at 5 and 6°C without sprout inhibitor in 1991/92, after reconditioning by placement directly into 18°C (fast) or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40

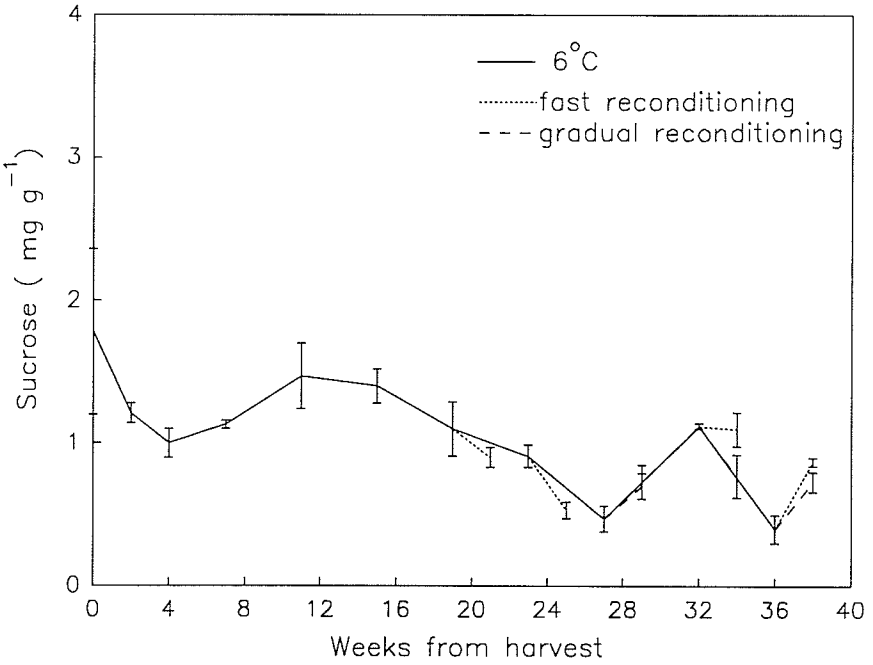
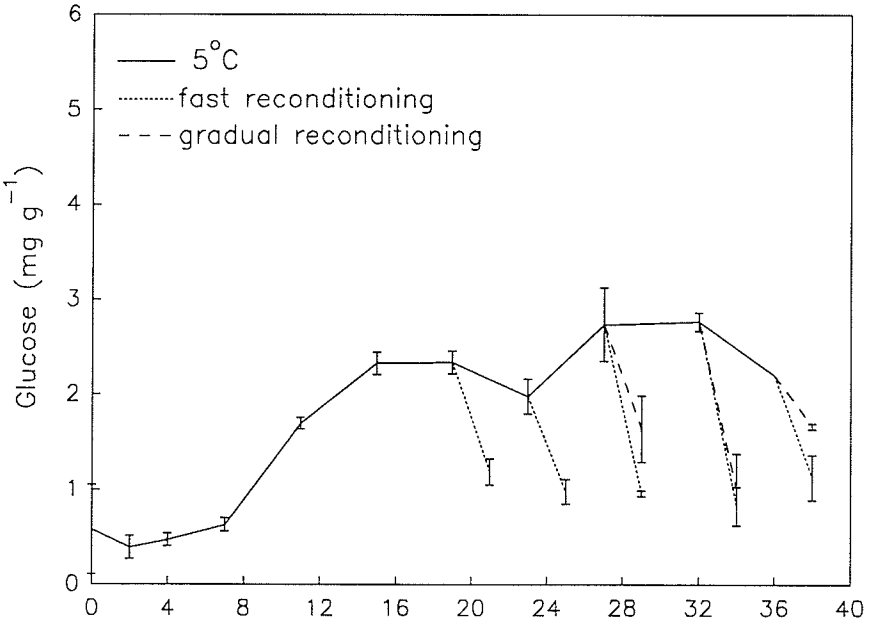

6°C
fast reconditioning
gradual reconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

Fig 7. Glucose concentration (mg g^{-1} fwt) of Russet Burbank potato tubers stored without sprout inhibitor at 5 and 6°C in 1991/92, after reconditioning by placement directly into 18°C(fast) or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40

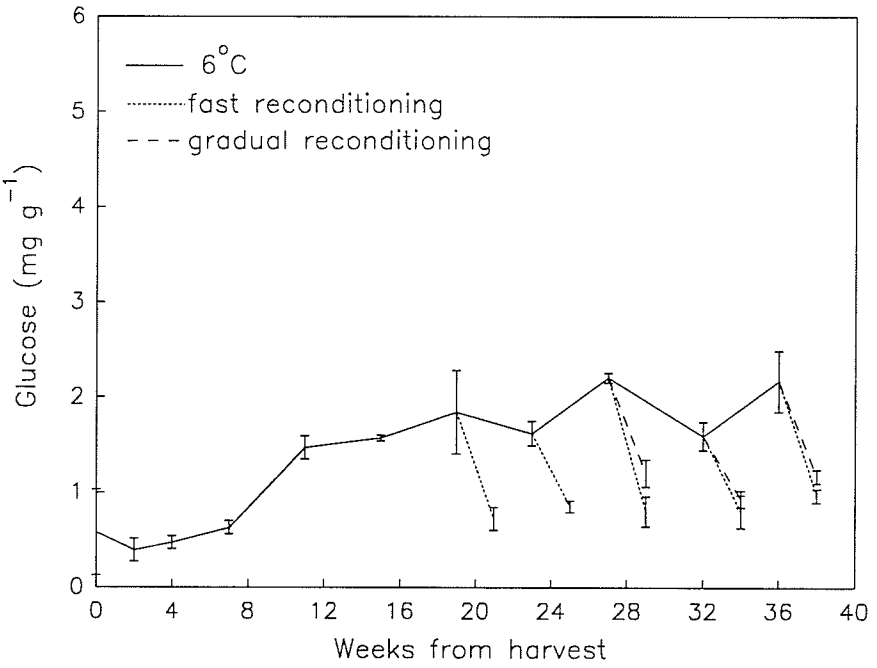
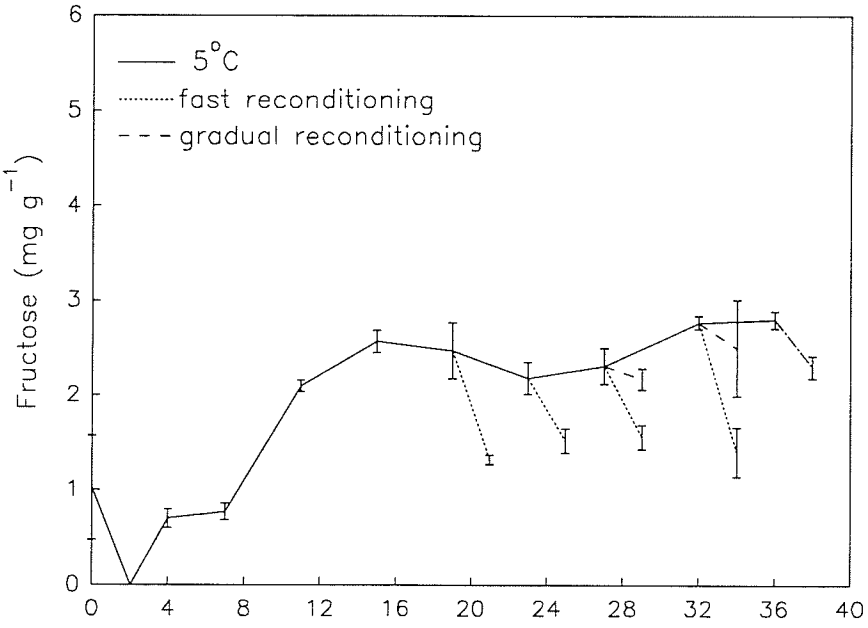
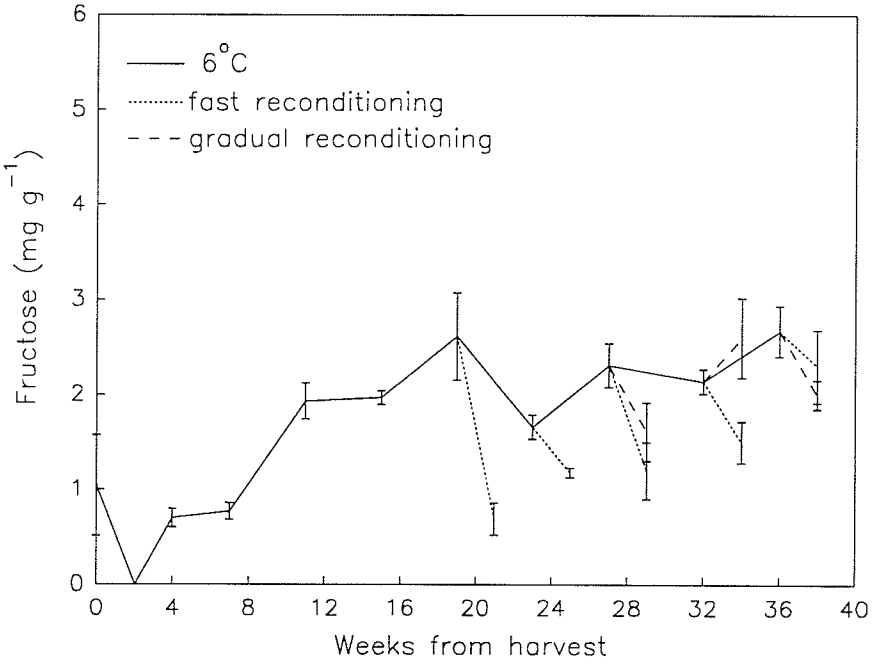

6°C
fast reconditioning
gradual reconditioning
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

Fig 8. Fructose concentration (mg g^{-1}fwt) of Russet Burbank potato tubers stored without sprout inhibitor at 5 and 6°C in 1991/92, after reconditioning by placement directly into 18°C (fast) or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


6°C
fast reconditioning
gradual reconditioning
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

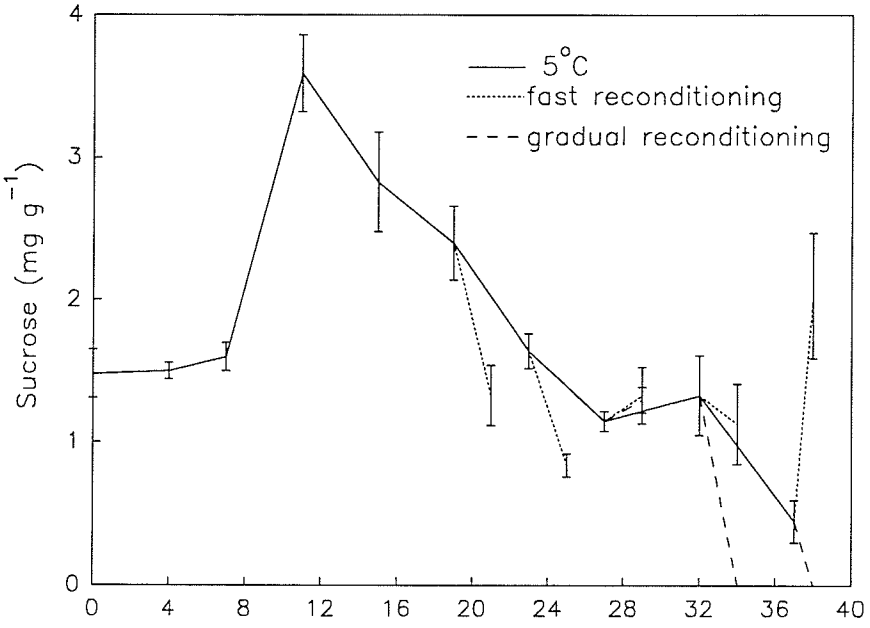
1.3 mg g^{-1} (Section 4.4) for the entire storage period (Fig 3). Tubers stored at 6°C had acceptable glucose concentration up to 15 weeks after harvest, while those stored at 8°C had acceptable glucose concentration up to 33 weeks after harvest. Therefore reconditioning was done for tubers stored at 4 or 6°C. Samples were removed from the storage and placed directly into 18°C for either 2 or 4 weeks. Although fast reconditioning for 2 or 4 weeks resulted in lower sucrose, glucose and fructose concentrations for tubers stored at both 4 or 6°C (Table 7), it was not consistently successful in lowering the glucose concentration to below 1.3 mg g^{-1}, the concentration above which fry colour is darker than that eligible for maximum bonus payment. Ohad (1971) observed a disintegration of the amyloplast membranes after tubers were stored at 4°C for 12 days and suggested that cold-induced sugar increase may be a result of amyloplast membrane damage. For the cultivar Shepody, storage at 4 or 6°C might lead to a partially irreversible reconversion of reducing sugars to starch such that reconditioning is no longer an effective remedy to lower sugars.

Generally, fast or gradual 2 week reconditioning in 1991/92 did not consistently reduce sucrose concentration (Fig 9). After 27 weeks in storage, reconditioning (especially fast) led to an increase in sucrose. The high temperature used in fast reconditioning early in storage (18°C) may have accelerated the senescence process. Glucose concentration was significantly reduced by both fast and gradual reconditioning in tubers stored at 5 or 6°C, fast reconditioning resulting in a lower sugar concentration than gradual reconditioning (Fig 10). However, the reduction in glucose concentration was not sufficient to render tubers acceptable for french fry processing. The longer the

Table 7. Mean sucrose, glucose and fructose (mg g^{-1} fwt) in Shepody potato tubers stored without sprout inhibitor at 4 or 6°C in 1990/91 and reconditioned by direct placement into 18°C.

Temp (°C)	Weeks after harvest	Reconditioning time in weeks	sucrose	glucose	fructose
4	17	0	4.37±.16	6.40±.33	6.24±.10
		2	1.65±.02	2.98±.04	2.98±.11
		4	1.02±.02	2.34±.08	1.47±.05
	21	0	4.24±.39	4.94±.10	2.40±.05
		2	1.31±.03	1.93±.12	3.05±.09
		4	1.77±.06	1.01±.25	2.47±.25
	25	0	2.47±.17	5.36±.26	4.70±.15
		2	1.89±.01	1.72±.14	3.10±.07
		4	1.40±.15	0.69±.10	1.72±.07
	29	0	2.59±.13	4.83±.09	3.82±.26
		4	1.41±.09	2.14±.05	2.69±.08
	33	0	1.61±.28	5.30±.11	5.08±.12
		4	1.20±.19	1.62±.54	3.14±.20
6	19	0	2.32±.06	2.83±.08	2.19±.16
		2	0.95±.09	1.63±.11	1.05±.05
		4	1.36±.11	1.36±.03	1.42±.04
	23	0	1.56±.05	3.35±.17	3.05±.08
		2	1.19±.08	1.58±.27	2.15±.08
		4	0.62±.05	0.37±.04	1.11±.03
	27	0	0.71±.07	2.00±.03	2.90±.22
		4	0.87±.09	1.35±.05	2.34±.02
	33	0	1.07±.13	3.83±.11	3.17±.07
		4	0.35±.06	1.44±.12	1.40±.05

Fig 9. Sucrose concentration (mg g^{-1} fwt) in Shepody potato tubers stored without sprout inhibitor at 5 or 6°C in 1991/92 after reconditioning by placement directly into 18°C (fast) or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40

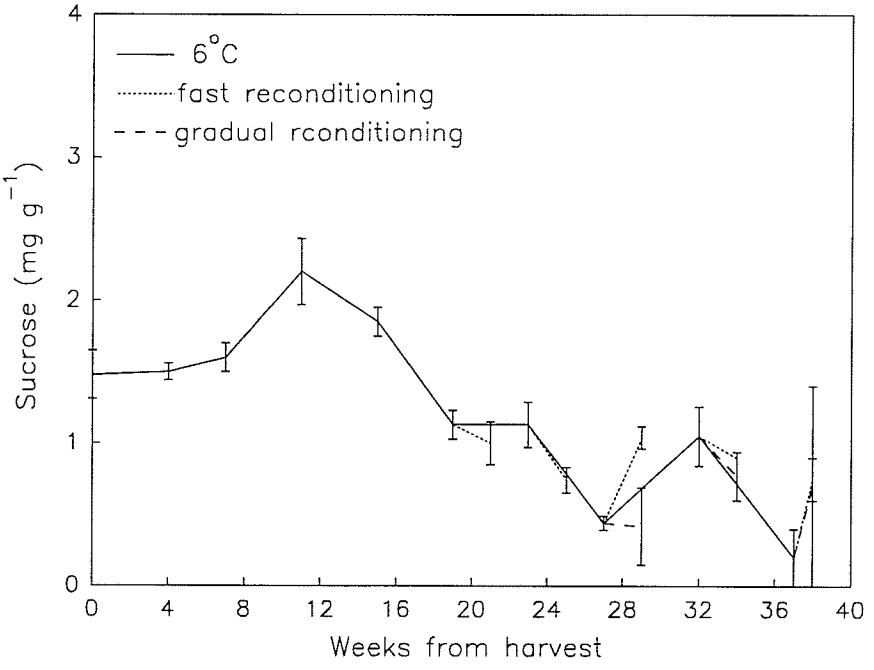
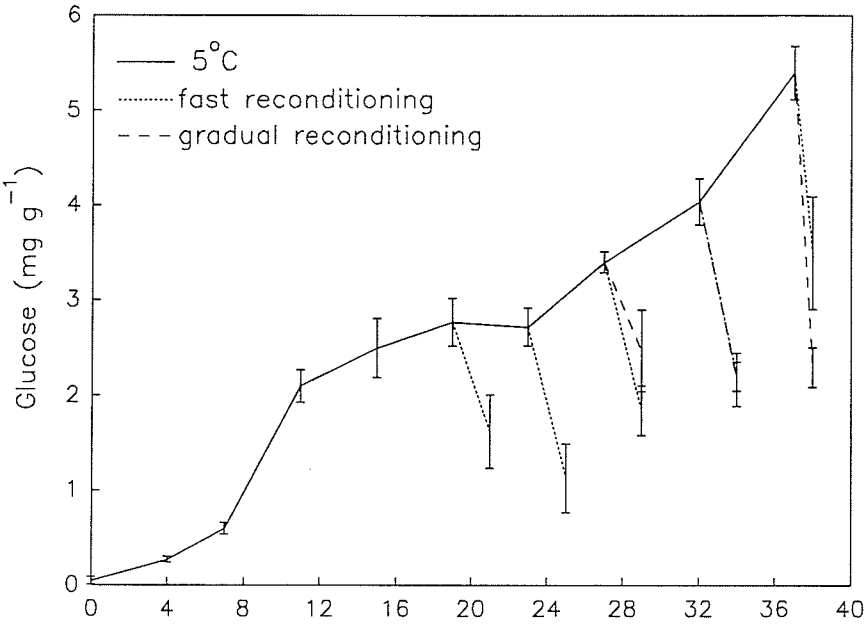
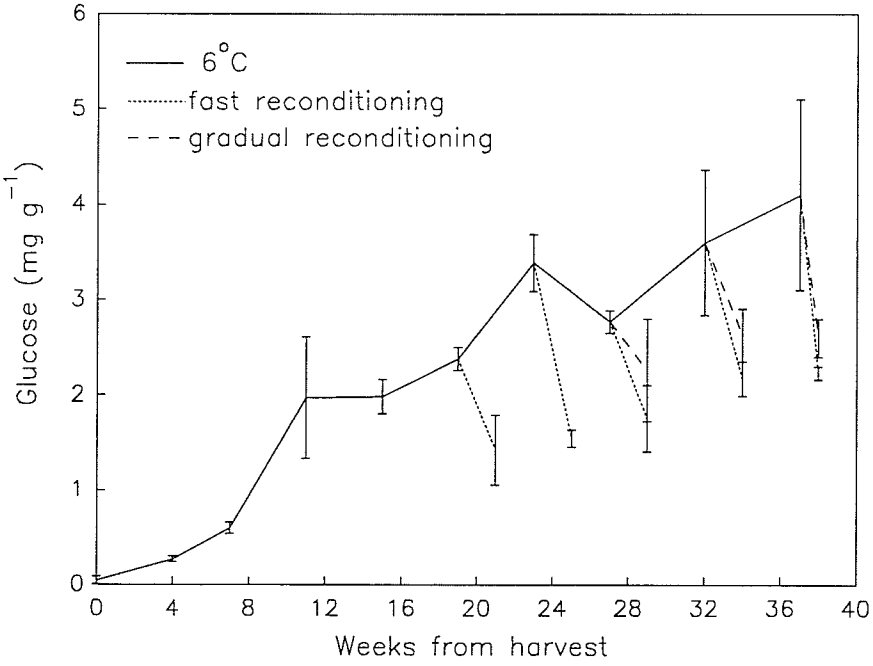

6°C
fast reconditioning
gradual rconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

Fig 10. Glucose concentration (mg g^{-1} fwt) in Shepody potato tubers stored without sprout inhibitor at 5 or 6°C in 1991/92, after reconditioning by placement directly into 18°C (fast) or by gradual warming of tubers.

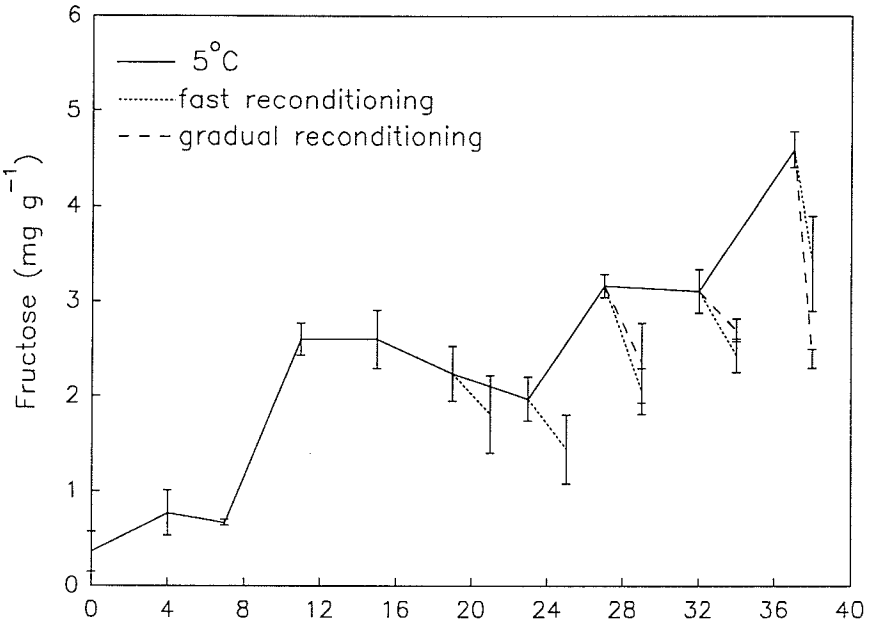

5°C
fast reconditioning
gradual reconditioning
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


6°C
fast reconditioning
gradual reconditioning
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

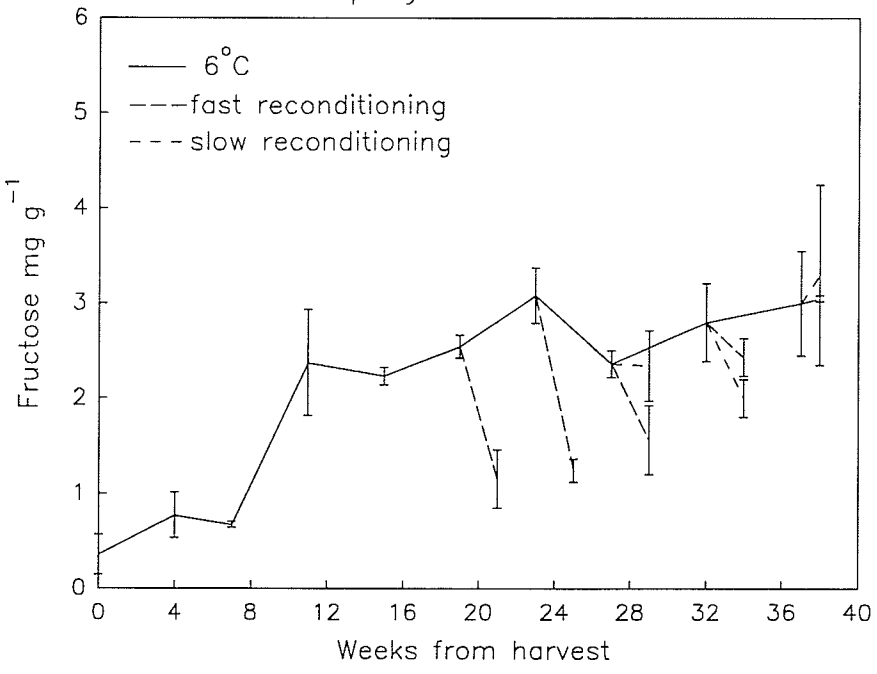
tubers stayed at low temperatures, the greater the increase in reducing sugars, and this caused reconditioning to become less successful. When tubers are stored at low temperature for long periods, the process of low temperature sweetening may become partially irreversible (Salisbury and Ross, 1985; Coffin et al., 1987). Generally, fructose concentration was significantly reduced by both fast and gradual reconditioning (Fig 11), but again the reduction was less later in storage.

Shepody tubers stored at 5 or 6°C with sprout inhibitor had similar response to reconditioning as those tubers stored without sprout inhibitor (Appendix 8, 9 and 10). Sucrose concentration was not reduced over most of the reconditioning time periods. Both glucose and fructose concentrations were significantly reduced in both fast and gradual reconditioning, but not sufficiently to produce french fries with colours eligible for maximum bonus payment. Fast reconditioning was more effective in lowering the sugar concentration, and it became more difficult to lower the sugar concentration by reconditioning with longer storage time at lower temperatures.

Fig 11. Fructose concentration (mg g^{-1} fwt) in Shepody potato tubers stored without sprout inhibitor at 5 or 6°C in 1991/92, after reconditioning by placement directly into 18°C or by gradual warming of tubers.



Shepody 1991 No Mh60



4.4 Sugar Levels and Fry Colour

Relationships between fry colour and sugar concentrations were determined in 1991/92, for both Russet Burbank and Shepody potatoes including data from 5, 6, and 8°C storage. Data for sprout and non-sprout inhibited tubers were combined for Russet Burbank when determining fry colour-sugar relationships because MH60 treatment did not significantly affect the sugar levels. However, for Shepody, MH60 treatment had a significant effect on sugar levels. Therefore, relationships between fry colour and sugar levels were determined separately for Shepody tubers with sprout inhibitor and Shepody tubers without sprout inhibitor.

4.4.1 Russet Burbank

The total number of observations made in determination of fry colour relationships to sugar levels in Russet Burbank tubers was 119. Total reducing sugar had the best relationship to fry colour (Table 8). The reducing sugars glucose and fructose also had good correlations to fry colour. Though sucrose was significantly correlated to fry colour, the coefficient of determination (r^2) was low.

In Manitoba, a fry colour of 3.5 on a scale of 1-7, in which 1 is light and 7 is dark, is the maximum rating (darkest colur) eligible for maximum benefit, or bonus payment to the farmer. This 1-7 scale is equivalent to 000 - 4 on the USDA french fry colour chart (Anonymous, 1980; Appendix 11). When colour is above 3.5, the grower

Table 8. Relationships between fry colour and sucrose, glucose, fructose, or total reducing sugars.

Sugar	Regression equation	r^2	Range of sugar conc in sample (mg g^{-1} fwt)	Sugar conc for fry colour = 3.5
Russet Burbank				
Sucrose	Y = 3.209+0.259x[a]	0.01**	0.30 - 2.95	-
Glucose	Y = 2.041+0.902x	0.58**	0.15 - 5.48	1.62
Fructose	Y = 2.149+0.747x	0.50**	0.00 - 3.47	1.81
Total red sugar	Y = 1.948+0.453x	0.60**	0.15 - 7.16	3.43
Shepody (no MH60)				
Sucrose	Y = 4.033+0.139x	0.01n.s.	0.20 - 3.8	-
Glucose	Y = 2.685+0.629x	0.51**	0.00 - 5.6	1.3
Fructose	Y = 2.766+0.638x	0.32**	0.20 - 4.60	1.15
Total red sugar	Y = 2.545+0.355x	0.47**	0.20 - 10.2	2.70
Shepody (with MH60)				
Sucrose	Y = 4.04+0.347x	0.09**	0.00 - 3.30	-
Glucose	Y = 2.957+0.586x	0.49**	0.20 - 4.60	0.93
Fructose	Y = 2.931+0.712x	0.60**	0.00 - 4.00	0.80
Total red sugar	Y = 2.901+0.33x	0.55**	0.20 - 8.60	1.82

n.s. not significant

** significant at $P < 0.01$

[a] Y = fry colour on scale of 1-7 and x = sugar concentration

either does not receive maximum bonus or gets paid at less than the contract price. Fitting the fry colour of 3.5 to the regression equations (Table 8) gives the maximum acceptable concentration of glucose, fructose and total reducing sugars in the potato processing industry in Manitoba. These concentrations compare to those documented in existing literature (Pritchard and Adam, in press; van Es and Hartmans, 1987). Tubers with sugar concentrations above those calculated would be accepted for processing, but would receive less than maximum bonus.

4.4.2 Shepody

4.4.2.1 Non-sprout inhibited

The number of observations made in determining the relationships between sugar levels and fry colour in non-sprout inhibited Shepody tubers was 57. Sucrose contribution to fry colour was not significant (r^2= 0.01) (Table 8). Glucose had the best correlation with fry colour, and total reducing sugar and fructose also contributed significantly to fry colour.

4.4.2.2 MH60 treated tubers

The number of observations made in the determination of the relationships between sugar levels in Shepody tubers with sprout inhibitor and fry colour was 59.

Sucrose was very poorly related to fry colour (Table 8). Fructose was the sugar best correlated to fry colour. Total reducing sugar and glucose also had good correlations to fry colour.

The use of sprout inhibitor in Shepody tubers used in the determination of fry colour resulted in a change in the level of fructose contribution to fry colour. The correlation between fructose and fry colour changed from $r^2 = 0.32$ when sprout inhibitor was not used to $r^2 = 0.60$ when sprout inhibitor was used. The use of sprout inhibitor also led to improved correlation between total reducing sugars and fry colour (r^2 changed from 0.47 to 0.55). This latter change may be a direct result of increased fructose contribution to fry colour. Glucose contribution to fry colour remained almost unchanged with r^2 of 0.51 and 0.49 for non-sprout and sprout inhibited Shepody, respectively.

4.4.3 Reconditioned Russet Burbank and Shepody

In Russet Burbank and Shepody potato tubers that had undergone the reconditioning process, of the sugars (sucrose, glucose, fructose or total reducing sugars), only sucrose in Shepody had a significant correlation with fry colour. However the r^2 was low at 0.08 (Table 9). Reconditioning generally lowered the sugars to similar levels regardless of the sugar concentration at the beginning of the reconditioning period. This resulted in limited variability in sugar concentration within the tuber samples used for fry colour determination after reconditioning. Any relationship between fry colour and sugars

cannot be properly determined within such a narrow range of sugar concentration values.

Table 9. Regression coefficients of fry colour and sucrose, glucose, fructose, or total reducing sugar in reconditioned Russet Burbank and Shepody tubers stored at 5 and 6°C and reconditioned fast or gradually for 2 or 4 weeks in 1991/92.

Sugar	Regression coefficient (r^2)	
	Russet Burbank	Shepody
Sucrose	$0.03^{n.s}$	0.08^{*}
Glucose	$0.02^{n.s}$	$0.03^{n.s.}$
Fructose	$0.00^{n.s.}$	$0.03^{n.s}$
Total red sugar	$0.01^{n.s.}$	$0.03^{n.s}$

* significant at $P < 0.05$

n.s. not significant

However the breakdown in correlation between fry colour for reconditioned tubers was reported by van Es and Hartmans (1981) and Coffin et al. (1987). They suggested that the breakdown may be attributed to different amino acid composition, and amount and

composition of the starch fraction of reconditioned tubers. The enzymes involved in the starch-sugar pathway may also change. Ashoor and Zent (1984) found that the intensity of the Maillard reaction may change when different amino acids are present. Such changes could therefore lead to different relationships between the reducing sugar concentration and fry colour depending on how tubers are handled before frying.

4.4.5 Conclusion

Sucrose was found to have a poor relationship with fry colour in the two cultivars. This is in agreement with Mazza (1983) who found the relationship between sucrose and fry colour to be poor and highly variable. Pritchard and Adam (in press), also found sucrose to be of little importance in predicting fry colour.

Glucose, fructose and total reducing sugars all had highly significant relationships with fry colour, the best relationship between any of the sugars and fry colour depending on the cultivar and the presence or absence of sprout inhibitor. The r^2 for the relationships between total reducing sugars and fry colour varied from 0.47 to 0.60. The r^2 for glucose and fry colour ranged from 0.49 to 0.58 while r^2 for fructose and fry colour varied from 0.32 to 0.6. Pritchard and Adam (in press) found glucose to have the best correlation to fry colour in stored Russet Burbank tubers ttreated with MH60 while Mazza (1983) found total reducing sugars to have a better relationship to fry colour than the individual reducing sugars. Glucose, fructose, or total reducing sugars could be used in predicting the fry colour in stored Russet Burbank and Shepody potato tubers, by

selecting the sugar most closely correlated to fry colour. However Mazza (1983), reported highly variable results in different growing conditions and seasons. Therefore the relationships between fry colour and sugars may vary when tubers grown under different environmental conditions.

5.1 GENERAL DISCUSSION

The common practice in Manitoba is to store potato tubers for french fry processing at a temperature of 8°C in combination with sprout inhibitor to maintain optimum processing quality with respect to french fry colour. In recent years however, issues relating to food safety have heightened consumer awareness about the use of chemicals in foods, making it necessary to look for alternative methods of storing potatoes without the use of sprout inhibitor. Other storage methods that have been found to be effective in prolonging the dormancy of potato tubers include low temperature storage, irradiation, and recently, the use of modified atmosphere storage has been explored.

Irradiation has been found to inhibit sprout development in stored potato tubers (Borsa et al., 1990; Liu et al., 1990), but consumer perception of irradiated foods is still a problem. In addition, handling the process of irradiation on a small scale presents a lot of difficulties. On the other hand, modified atmosphere storage is expensive and is currently only used for storing produce that gives high returns per unit volume, such as apples. Low temperature storage is a viable alternative, and most commercial storage facilities already have temperature regulation equipment in place. However, most potato cultivars used for french fry processing accumulate significant amounts of reducing sugars when stored at temperatures below 7°C (Coffin et al., 1987; Isherwood, 1976). Elevated levels of reducing sugars in tuber tissue result in finished products which are dark coloured and commercially unacceptable (Habib and Brown, 1956; Mazza, 1983; Pritchard and Adam, in press).

Accumulation of reducing sugars at low temperatures could be avoided by the use of cultivars that do not accumulate reducing sugars to excessive concentrations at low temperatures. Two North Dakota State University breeding clones, ND860-2 and ND2221-6, possess physiological characteristics for the maintenance of low reducing sugar levels when they are kept in low temperature storage of 3-4°C (Ehlenfeldt et al., 1990). However a lot of work needs to be done to combine this characteristic with desirable french fry quality and agronomic characteristics. Low temperature storage, in combination with reconditioning prior to marketing, was therefore examined in this study for its effectiveness in prolonging the dormancy period and maintaining reducing sugar concentration at levels acceptable for french fry processing. The two potato cultivars Russet Burbank and Shepody are used in Manitoba for processing into french fries and were evaluated in this study.

A long term storage temperature of 4, 5 or 6°C for Russet Burbank and 4 or 5°C for Shepody was found to be effective in controlling sprout development because tubers stored at these temperatures had minimal or no sprout development up to the end of storage. Russet Burbank tubers stored at 8°C had excessive sprout development (>10 cm sprout length) at 33 weeks after harvest, while Shepody stored at 8 or 6°C had excessive sprout development at 29 weeks. Storage of Russet Burbank tubers at 5 or 6°C without sprout inhibitor delayed sprouting by 10 and 6 weeks, respectively, compared to storage at 8°C without sprout inhibitor. Tubers stored at 4°C did not sprout up to the end of the study at 38 weeks after harvest. Storage of Shepody tubers without sprout inhibitor at 6°C delayed sprouting by 3-4 weeks compared to storage at 8°C. Tubers stored at 5°C

sprouted 12 weeks later than tubers stored at 8°C, while tubers stored at 4°C did not sprout up to the end of the study at 38 weeks after harvest. Similar results have been discussed by Burton (1959). He states that, in general, the higher the storage temperature, ranging from 4-21°C, the shorter the endodormant or rest period after harvest.

Low temperature storage, though successful in delaying sprout development, led to serious concerns about the rapid increase in the concentration of free sugars (sucrose, glucose and fructose), especially at 4 and 5°C. This phenomenon of low temperature sweetening is well documented in existing literature (Burton, 1958; Gould et al., 1979; Samotous and Schwimmer, 1962; Coffin et al., 1987). There were cultivar differences in the way Russet Burbank and Shepody responded to temperature. Shepody responded with much higher sugar increases when stored at the same temperature as Russet Burbank. Shepody also had much higher sucrose accumulation in the first few weeks in low temperature storage that subsequently declined. This initial increase in sucrose content has been reported by Ewing et al. (1971) and Coffin et al. (1987) and may have led to accumulation of very high levels of reducing sugars later in storage as sucrose is hydrolysed to give glucose and fructose in stored potato tubers (Isherwood, 1973). Generally, storage temperature below 8°C resulted in an increase in reducing sugars in both Russet Burbank and Shepody.

A fry colour rating of 3.5, on a scale of 1-7, 1 being light and 7 being dark, was considered the acceptable colour of processed french fries, earning growers the maximum bonus (Appendix 11). However, when the fry colour is > 3.5, growers still get paid, but earn less than the maximum bonus. When fry colour is > 5.5 growers are paid at less

than the contract price. Based on this, Russet Burbank tubers stored at 6 or 8°C had sugar concentrations that would have given acceptable french fry colour for most of the study period while tubers stored at 4 or 5°C were not acceptable for processing over most of the storage period. Use of the sprout inhibitor MH60 in Russet Burbank did not result in significantly different sugar concentrations compared to tubers not treated with a sprout inhibitor.

During reconditioning, tubers are exposed to high temperatures which converts most reducing sugars to starch, while some reducing sugars are used up in respiration (Burton and Wilson, 1978; Iritani, 1981; Liu et al., 1990). For Russet Burbank tubers stored at 4°C in 1990/91, a 4 week fast reconditioning period lowered sugar concentrations to acceptable levels throughout the study period. However excessive sprout development became a problem at 32 weeks after harvest. In 1991/92, a 2 week fast or gradual reconditioning generally lowered the sugar concentrations in tubers stored at 5 or 6°C. Time to excessive sprout development was not assessed in 1991/92. However based, on results obtained in 1990/91 on excessive sprout development in tubers stored at 4°C and reconditioned for 4 weeks, it can be assumed that tubers stored at 5°C and reconditioned for 2 weeks in 1991/92, would not have excessive sprout development up to 32 weeks after harvest.

Shepody tubers stored at 4, 5, or 6°C were not acceptable for french fry processing because of excessive accumulation of sugars which could not be removed with reconditiioning. Shepody tubers stored with sprout inhibitor responded differently to temperature compared to tubers stored without sprout inhibitor. In MH60-treated tubers,

reducing sugars increased rapidly earlier in storage compared to tubers not treated with MH60, while reducing sugars in non MH60-treated tubers increased steadily to the end of the storage period. The mechanisms controlling carbohydrate metabolism in the two treatments seem to differ and needs clarification. In tubers treated with MH60, reducing sugars accumulated rapidly and remain high in tubers stored at 5°C, while they increased gradually in tubers with no sprout inhibitor. Sucrose in MH60-treated tubers stored at 5°C increased rapidly and remained high for a few weeks before declining, while sucrose in tubers without MH60 increased rapidly and declined sharply. At 6 and 8°C storage temperatures, reducing sugars increase in tubers with no MH60 application at about the time of sprouting, while an increase in reducing sugars occured later in tubers treated with MH60.

Generally, Shepody tubers stored with or without sprout inhibitor at 4, 5 or 6°C in both 1990/91 and 1991/92 had unacceptable sugar concentrations for french fry processing over most of the storage period. In 1990/91, a 4 week fast reconditioning period did not lower sugar levels sufficiently for processing in tubers stored at 4 or 6°C. In 1991/92, a 2 week fast or gradual reconditioning was not successful in lowering sugar concentrations to acceptable levels in tubers stored at 5 or 6°C with or without sprout inhibitor. This inability to remove free sugars accumulated during low temperature storage by raising the storage temperature has been reported for cultivars other than Shepody by Iritani and Weller (1971) and Coffin et al. (1987). Studies could be done to investigate the effect that a longer reconditioning time has on lowering sugar concentrations. However, excessive sprout development is likely to be a major problem

for longer reconditioning times in Shepody tubers.

In the study on the relationship between sugars and fry colour, the regression coefficients obtained compared well to those documented in existing literature. However, the role of fructose in fry colour development seems unpredictable, and changes when sprout inhibitor is used in Shepody. This variability in the role of fructose may become more clear if studies are done over a period of several years. That sucrose seems to have a very poor correlation with fry colour is reported by others studying the relationship (Mazza, 1983; Pritchard and Adam, in press). Individual reducing sugars as well as total reducing sugars were found to be closely related to fry colour. Although reconditioned tubers gave lighter coloured french fries, there was lack of correlation between fry colour and sugar levels. It was observed that sugars were reduced to a very narrow range of concentrations after reconditioning, irrespective of the concentration before reconditioning. It may not have been possible to obtain a correlation because sugar concentration values were not spread over a wide range in reconditioned tubers. High correlation coefficients are difficult to obtain when all values are grouped into a small area. Reconditioning may also change the composition or concentration of other factors involved in development of fry colour, such as amino acids (Habib and Brown, 1956; van Es and Hartmans, 1981)

In conclusion, Russet Burbank potato tubers could be stored without sprout inhibitor at 6°C for 38 weeks and at 8°C for 33 weeks after harvest and still produce acceptable french fries when processed. When tubers were stored at 5°C without sprout inhibitor, a 2 week reconditioning period was necessary starting at 17 weeks after harvest to improve the fry colour. Tubers stored at 4°C required a 4 week reconditioning period

starting at 17 weeks after harvest but excessive sprout development became a problem during reconditioning at 33 weeks after harvest. Shepody tubers stored at 8°C without sprout inhibitor may have acceptable sugar concentrations throughout the storage period depending on the planting season. Conditions during the growing period seem to influence sugar accumulation in storage (Burton and Wilson, 1978; Iritani,1981), and tubers stored at 8°C in 1990/91 had acceptable sugar levels over the entire storage period while tubers stored at the same temperature in 1991/92 only had acceptable sugar levels up to 15 weeks after harvest. Tubers stored without sprout inhibitor at 5 or 6°C and reconditioned for 2 weeks in 1991/92 generally had unacceptable sugar levels while tubers stored without sprout inhibitor at 4 or 6°C in 1990/91 did not have acceptable sugar concentrations even with a 4 week reconditioning period.

In this study, the cultivar Russet Burbank was stored without sprout inhibitor for over 30 weeks at temperatures as low as 4°C, and acceptable sugar concentrations were obtained with reconditioning. Generally, the cultivar Shepody did not store as long at low temperature and give acceptable french fry colour. Storage of potatoes at low temperatures has many advantages and, in addition to delaying sprout development, senescent sweetening and growth of disease organisms are inhibited. Low temperature storage without the use of chemical sprout inhibitor in the cultivar Shepody may have to be used in combination with other management practices for it to be successful in maintaining french fry processing quality in the long term. Studies may be done on the use of modified atmosphere or of natural sprout inhibitors in combination with low temperature storage.

Sprout development was not properly assessed in this study, and perhaps a better assessment would have been possible if the sprouts had been removed and weighed. In commercial storage, most of the sprouts that may develop usually fall off during handling and transportation to the processing plant, which makes it more difficult to assess potato tuber acceptibility for french fry processing on sprout development.

The reducing sugars, glucose and fructose, and the total reducing sugars were found to be correlated to fry colour and could be used to predict the fry colour in commercial storage. The use of reducing sugars in predicting fry colour may not be possible in reconditioned tubers.

6.1. MOISTURE AND HIGH TEMPERATURE STRESS

6.1.1 Introduction

The growth and yield of potatoes is particularly sensitive to drought, especially in the later stages of the growing season (Jones and Johnson, 1958). Short stress periods during tuber bulking may result in formation of misshapen tubers (Nichols and Ruf, 1967). Such short periods of stress are common in Manitoba during the growing season, where over 40% of potatoes are grown without irrigation. When irrigating, differential watering and the high temperatures experienced in the summer could lead to stress conditions. The frequency of tuber quality defects (second growth, translucent ends, growth cracks, shape defects, high sugar concentration and low dry matter content) can greatly increase in tubers grown under heat and stress (van Loon, 1986). The objective of this study was to examine possible changes in sugar concentration of stored Russet Burbank and Shepody tubers grown under short term heat and moisture stress common in the Manitoba growing conditions.

Materials and methods

1991

Tubers of cvs Shepody and Russet Burbank were planted on June 1st, 1991 in 30 litre pots containing an Almassippi sandy loam soil. The plants were grown in a growth

room and the soil watered to field capacity after planting and sensors to monitor the moisture content were inserted to 12 cm depths. Plants were well watered, with soil moisture content maintained at 3 to 20 centibars. Temperature of 22°C day/16°C night and 16 hour photoperiod was maintained. Stress conditions were introduced on September 16, 1991. To stress plants, soil moisture was reduced to 46 to 82 centibars, while temperature was raised to 30°C day/22°C night. Plants were divided into four treatment combinations: (a) moisture and heat stress, (b) normal moisture, heat stress, (c) normal temperature, moisture stress and (d) normal temperature, normal moisture.

Problems

There was compaction of soil in the containers, so that most of the water drained down the sides. To avoid this a cardboard box was put around the plant to perpetuate an even water spread, which led to water stagnating around the root region. Soil in treatments with no moisture stress was too wet for proper root development. In moisture stress treatments, the soil took a long time drying down.

The sudden high temperature in heat stress treatments led to leaf senescence after a few days. The stress environment was planned for 2 weeks but the growth room broke down after 10 days. Russet Burbank performed very poorly in the growth room conditions, producing few or no tubers. In the next planting therefore, only Shepody was planted.

Results

Potatoes were harvested on September 26, 1991 and preconditioned at 15°C for 2 weeks. Tubers were then transferred to 8°C storage for 3 weeks. Samples were taken at harvest, 2 weeks after harvest and at 5 weeks after harvest. Analysis for sugar content was done using high performance liquid chromatography (HPLC). The results showed no significant differences in sucrose, glucose or fructose levels for all three sample dates.

1992

Shepody tubers were planted on April 4, 1992. Growing conditions were maintained at 3 to 20 centibar moisture content, temperature of 22°C day/16°C night and 16 hour photoperiod up to July 7, 1992 when treatments began. To avoid sudden leaf senescence, temperature in heat stress treatments was raised to 26°C between 15.00 and 18.00 hrs every day for 2 weeks, and the rest of the growing conditions were maintained. After 2 weeks, temperature in heat stress treatments was raised to 30°C between 15.00 and 18.00 hrs. Tubers were harvested on August 5, 1992, preconditioned for 2 weeks at 15°C and stored at 8°C. Samples were taken after 2 weeks of high temperature, at harvest and at 4 weeks after harvest.

Results

Tubers from plants given 2 weeks high temperature had significantly lower sucrose concentrations ($P < 0.05$) than tubers with no heat stress. There were no differences in the level of reducing sugars. At harvest, tubers from plants kept under moisture stress for 2 weeks had significantly lower sucrose ($P < 0.05$) than tubers that did not have moisture stress but reducing sugars were not significantly different. Tubers stored for 4 weeks did not have significantly different sugar concentrations.

Conclusion and suggestions

This study would most likely succeed in the field. The problem of slow water drainage in the pots prevented moisture stress from occuring. The relative humidity and temperature regulation were different from those in stress conditions in the field and tubers may not have formed properly because the photoperiod was maintained at 16 hours thoughout the study.

Appendix 1. Mean sucrose, glucose and fructose concentration (mg g^{-1} fwt) in Russet Burbank potato tubers stored with sprout inhibitor at 5, 6 or 8°C in 1991/92.

Weeks after harvest	Temperature(°C) 8	6	5
sucrose			
0	1.46±.20	-	-
2	1.21±.07	-	-
4	0.85±.04	-	-
7	1.16±.15	1.20±.15	-
11	1.08±.07	1.47±.09	-
15	0.83±.03	1.38±.06	1.21±.02
19	0.68±.08	0.87±.03	1.79±.26
23	0.51±.06	0.94±.11	1.46±.07
27	0.51±.11	1.03±.03	1.36±.12
32	1.03±.03	1.13±.03	1.75±.16
36	0.50±.06	0.93±.07	1.27±.48
glucose			
0	0.25±.08	-	-
2	0.26±.15	-	-
4	0.35±.03	-	-
7	0.69±.08	0.83±.20	-
11	0.66±.06	1.18±.03	1.57±.08
15	0.77±.33	1.50±.03	2.56±.36
19	0.75±.17	1.38±.34	2.81±.25
23	0.83±.09	1.91±.09	2.61±.21
27	0.84±.20	2.04±.22	2.75±.10
32	1.21±.16	1.39±.07	3.69±.91
36	0.80±.09	1.67±.22	2.09±.03
fructose			
0	0.00±0	-	-
2	0.00±0	-	-
4	0.00±0	-	-
7	0.54±.26	0.54±.26	-
11	1.96±.26	1.49±.26	1.96±.26
15	2.40±.09	1.78±.09	2.40±.09
19	2.38±.29	0.94±.22	2.38±.29
23	2.61±.27	1.88±.17	2.61±.27
27	2.45±.15	1.72±.15	2.45±.15
32	3.47±.53	1.97±.08	3.47±.53
36	2.87±.13	3.13±1.32	2.87±.13

Appendix 2. Mean sucrose, glucose and fructose concentration (mg g^{-1} fwt) in reconditioned Russet Burbank potato tubers stored with sprout inhibitor at 5 or 6°C in 1991/92.

Temp(°C)	Weeks after harvest	Recondition type	sucrose	glucose	fructose
5	19	time 0	1.79±.26	2.81±.25	2.38±.29
		Fast	0.98±.10	1.19±.16	1.44±.25
	23	time 0	1.46±.07	2.61±.21	2.61±.27
		Fast	0.84±.09	0.84±.06	1.31±.03
	27	time 0	1.36±.12	2.75±.10	2.45±.15
		Fast	0.97±.04	0.78±.10	1.07±.24
		Gradual	0.91±.05	1.21±.11	2.01±.15
	32	time 0	1.75±.16	3.69±.91	3.47±.53
		Fast	1.00±.36	1.40±.35	1.90±.19
		Gradual	1.13±.03	0.87±.07	1.40±.06
	36	time 0	1.27±.48	2.03±.35	2.87±.13
		Fast	1.17±.03	0.90±.17	1.80±.20
		Gradual	0.97±.03	1.37±.03	2.50±.15
6	19	time 0	0.87±.03	1.38±.34	0.94±.22
		Fast	0.65±.09	1.24±.15	1.17±.10
	23	time 0	0.94±.11	1.91±.09	1.88±.17
		Fast	0.69±.02	0.78±.13	1.03±.17
	27	time 0	1.03±.03	2.04±.22	1.72±.15
		Fast	0.82±.03	0.92±.08	1.31±.06
		Gradual	0.96±.05	1.27±.18	1.61±.14
	32	time 0	1.13±.03	1.39±.09	1.61±.14
		Fast	0.62±.03	0.87±.07	1.40±.26
		Gradual	0.93±.03	1.27±.18	1.40±0
	36	time 0	0.93±.07	1.63±.22	3.13±1.32
		Fast	1.13±.07	1.00±.06	1.40±.13
		Gradual	0.70±.03	1.00±.17	1.97±.30

Appendix 3. Analysis of variance table for Russet Burbank stored at 5 or 6°C and reconditioned by direct placement into 18°C (fast) or by gradual warming in 1991/92.

		Mean square		
Source	df	Sucrose	Glucose	Fructose
Temp	1	2.221**	2.666*	1.229
Week	2	0.192n.s	0.810n.s	4.757**
Tempxweek	2	0.076n.s	0.642n.s	2.332*
Recon	2	1.904**	2.466**	0.876n.s
Tempxrecon	2	1.220**	2.818**	0.174n.s
Weekxrecon	4	0.455**	1.614**	0.188n.s
Tempxreconxweek	4	0.788**	0.847n.s	0.330n.s
Error	86	0.161	0.423	0.538
C.V.%		41.2	27.9	29.1

n.s not significant

* significant at $P < 0.05$

** significant at $P < 0.01$

Appendix 4. Analysis of variance for reconditioned Shepody stored at 5 or 6°C and reconditioned fast or gradually in 1991/92.

		Mean square		
Source	df	Sucrose	Glucose	Fructose
Temp	1	1.416**	1.390n.s	3.494**
Week	2	1.238**	4.317**	3.472**
Tempxweek	2	0.253n.s	0.786n.s	0.279n.s
Recon	2	1.198**	27.204**	5.985**
Temp*recon	2	0.866**	1.351n.s	1.243n.s
Week*recon	4	0.156**	0.435n.s	0.305n.s
Temp*week*recon	4	0.733n.s	1.226n.s	1.074*
Error		0.149	0.640	0.418
C.V.%		45.5	27.6	23.8

n.s not significant

* significant at P <0.05

** significant at P <0.01

Appendix 5. Least square mean comparisons between non reconditioned, fast and gradual reconditioned Russet Burbank tubers stored at 5, 6 or 8°C in 1991/92.

5°C	Pdiff			6°C	Pdiff	
	Lsmeans	fast	grad	Lsmeans	fast	grad
sucrose						
fast	1.27	-	-	0.84	-	-
gradual	0.63	**	-	0.76	ns	-
not recon	1.43	ns	**	0.85	ns	ns
glucose						
fast	2.19	-	-	2.09	-	-
gradual	2.58	ns	-	2.68	**	-
not recon	2.70	ns	ns	1.75	*	**
fructose						
fast	2.42	-	-	2.27	-	-
gradual	2.68	ns	-	2.57	ns	-
not recon	2.77	ns	ns	2.40	ns	ns

ns not significant

* significant at P< 0.05, ** significant at P< 0.05

Appendix 6. Least square mean comparisons between non reconditioned, fast and gradual reconditioned Shepody tubers from storage experiment in 1991/92.

	5°C	Pdiff		6°C	Pdiff	
	Lsmeans	fast	grad	Lsmeans	fast	grad
sucrose						
fast	1.27	-	-	0.84	-	-
gradual	0.63	**	-	0.76	*	-
not recon	0.97	ns	**	0.56	**	**
glucose						
fast	2.24	-	-	2.09	-	-
gradual	2.58	ns	-	2.68	*	-
not recon	4.18	**	**	3.57	**	**
fructose						
fast	2.45	-	-	2.27	-	-
gradual	2.68	ns	-	2.57	ns	-
not recon	3.57	**	**	2.40	**	ns

ns not significant

* significant at P< 0.05

Appendix 7 . Observations made on sprout development in Russet Burbank and Shepody potato tubers store at 4 or 6°C and reconditioned for 2 or 4 weeks in 1990/91.

Weeks after harvest	recondition time(weeks)	observations	acceptibility
Russet Burbank			
4°C			
23	2	No sprouts	acceptable
25	4	No apical dominance sprouts 1.5-2.0 cm	acceptable
27	2	partial apical dominance apical sprouts: 1.0 cm lateral sprouts: 0.5 cm	acceptable
29	2	no apical dominance sprouts: 2-4 cm	acceptable
33	4	no apical dominance numerous sprouts: 3-20 cm	borderline
38	4	2-5 thin, long sprouts 45-60cm	not acceptable
6°C			
25	2	no apical dominance peepers	acceptable
27	4	average 3, long sprouts 10-15 cm	borderline

29	2	partial apical dominance apical sprout: 5 cm average lateral: 0.5cm	acceptable
38	4	several, long, thin sprouts 25-40 cm	not acceptable

Shepody

4°C

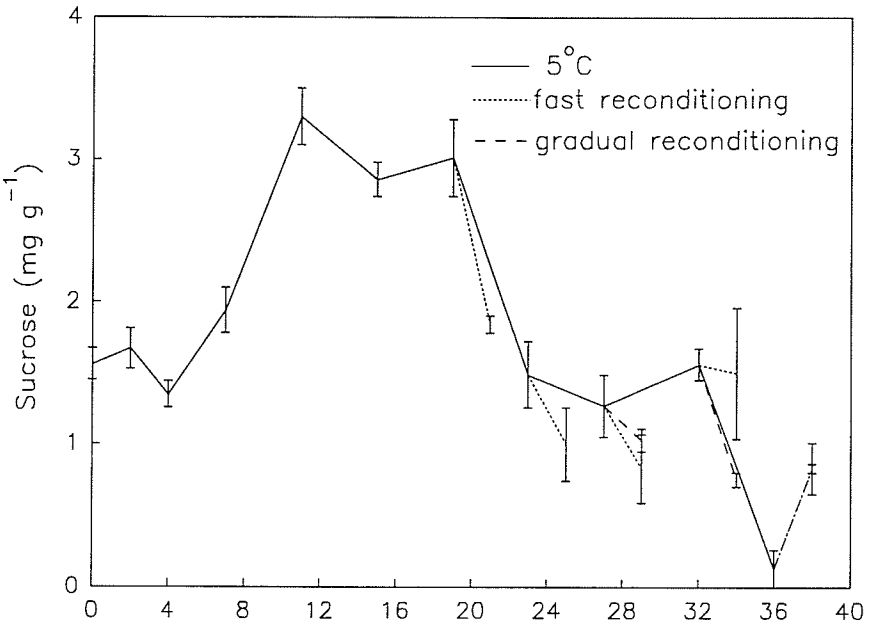
23	2	apical dominance apical sprout: 1.5 cm	acceptable
25	4	partial apical dominance apical sprout: 2.5 cm lateral sprout: 1.5 cm	acceptable
27	2	no apical dominance 2 to 4 sprouts per eye sprout length: 2.5 cm	acceptable
29	4	no apical dominance 5 to 9 sprouts per eye thick sprouts, 2-5 cm	acceptable
33	4	no apical dominance av sprout length: 11 cm numerous sprouts: 6-23 cm	borderline
38	4	thick, branched sprouts 15-20 cm	not acceptable

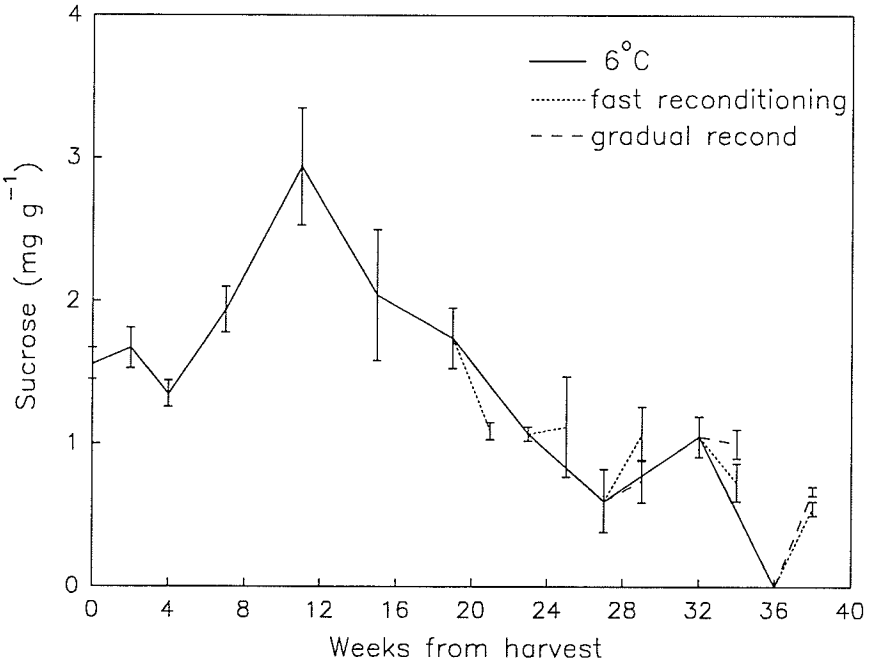
6°C

25	2	partial apical dominance apical sprouts: 1.5 cm lateral sprouts: 0.8 cm	acceptable
27	4	partial apical dominance av. 7 sprouts/eye thick sprouts, 1-3 cm	borderline

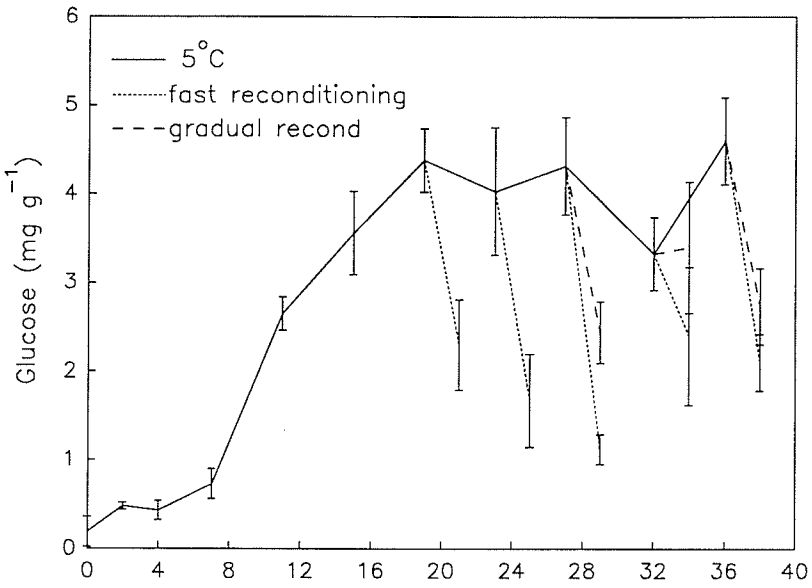
29	2	partial apical dominance apical sprout: 5 cm lateral sprout: 0.5 cm	acceptable
38	4	thick, branched sprouts 10-20 cm	not acceptable

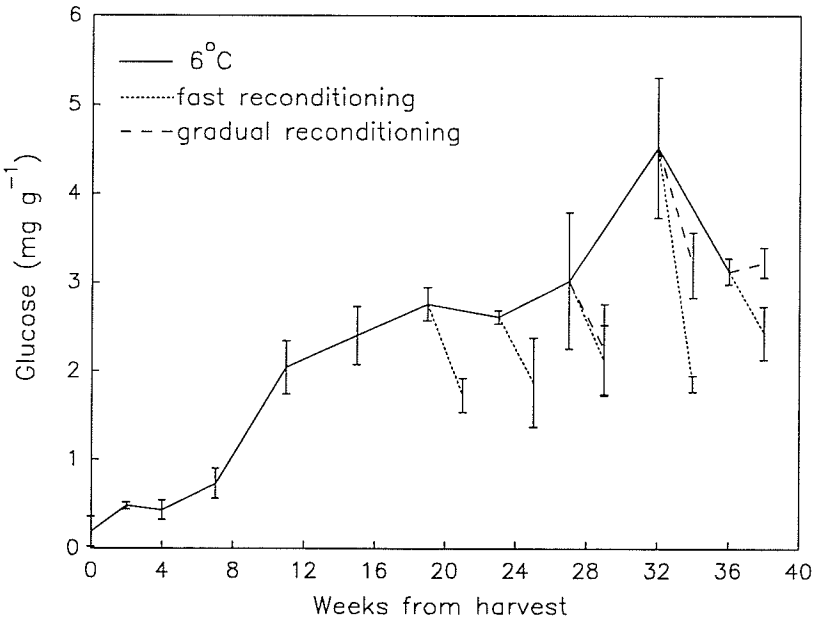
Appendix 8. Sucrose concentration (mg g^{-1} fwt) in Shepody potato tubers stored with sprout inhibitor at 5 or 6°C in 1991/92, after reconditioning by placement directly into 18°C or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40

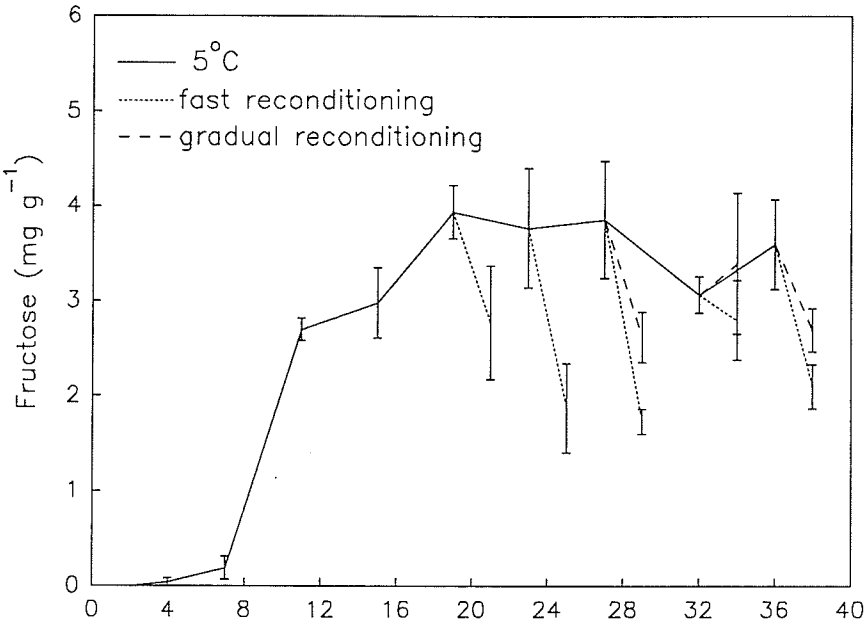

6°C
fast reconditioning
gradual recond
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

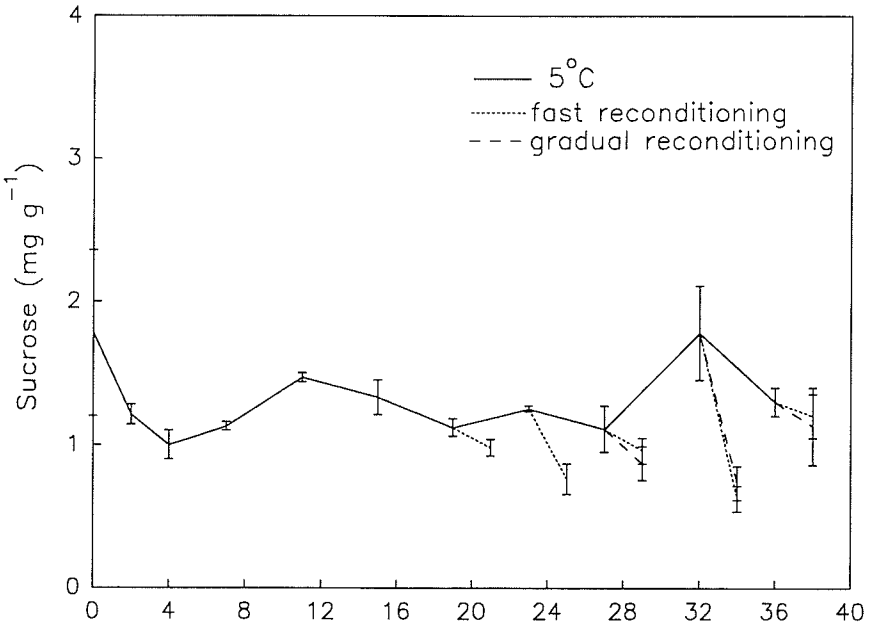
Appendix 9. Glucose concentration (mg g^{-1} fwt) in Shepody potato tubers stored with sprout inhibitor at 5 or 6°C in 1991/92, after reconditioning by placement directly into 18°C (fast) or by gradual warming of tubers.


5°C
fast reconditioning
gradual recond
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


6°C
fast reconditioning
gradual reconditioning
Glucose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40
Weeks from harvest

Appendix 10. Fructose concentration (mg g^{-1} fwt) in Shepody potato tubers stored with sprout inhibitor at 5 or 6°C in 1991/92, after reconditioning by placement directly into 18°C or by gradual warming of tubers.


5°C
fast reconditioning
gradual reconditioning
Fructose (mg g^{-1})
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
40


5°C
fast reconditioning
gradual reconditioning
Sucrose (mg g^{-1})
0
1
2
3
4
0
4
8
12
16
20
24
28
32
36
40

APPENDIX 11. FRENCH FRY COLOUR SCALES

USDA	000	00	0	1	2	3	4
U of M	1	2	3	4	5	6	7
Carnation	+2¢	+2¢	0 +2¢	1 +1¢	2 0	3 -1¢	4
McCain	+2.5¢	+2.5¢	1 +2.5¢	2 +1.5¢	3 0	4 -1.5¢	5

Bonus is determined on the colour of a small sample of fries whereby the number of fries with colour in a specific colour range is multiplied by the bonus value. Carnation scale: 18 fries of "0" colour and 2 fries of "1" colour gives a bonus of $(18x2^{¢})+2x1^{¢} = 38^{¢}$/cwt over contract price.

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