# THE EFFECT OF MATURITY, BRUISING, CHEMICAL TREATMENT (CIPC) AND $CO_2$ LEVELS IN STORAGE BINS ON RESPIRATION AND QUALITY OF PROCESSED POTATOES (*SOLANUM TUBEROSUM* L.)

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The Effect of Maturity, Bruising, Chemical Treatment (CIPC) and $CO_2$ Levels in Storage Bins on Respiration and Quality of Processed Potatoes (Solanum tuberosum L.)

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**DEDICATION**

To Mom and Dad

and

my brothers

Newton, Garneth, Moffat and Frank.

I love you all.

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**ABSTRACT**

Shamaila, M. Mawele. M.Sc., The University of Manitoba, October, 1985. The Effect of Maturity, Bruising, Chemical Treatment (CIPC) and $CO_2$ Levels in Storage Bins on Respiration and Quality of Processed Potatoes (Solanum Tuberosum L.). Supervisors: Drs. G. Mazza and L. La Croix.

Two potato cultivars, 'Norchip' and 'Russet Burbank' were used to study the changes that occur in potato tubers during growing season and through storage. In addition, the post harvest effects of bruising, chemical treatment (CIPC) and $CO_2$ build-up in storage bins on the quality of stored tubers were studied. The changes and quality parameters studied were respiratory rate ($CO_2$ evolution), sucrose and reducing sugar levels, chip colour and dry matter content.

It was found that the $CO_2$ evolution increased to a high value 8-14 hours after harvest and declined to an equilibrium level after about 48-50 hours in both cultivars. The total amount of $CO_2$ released by mature tubers was lower than that released by tubers harvested earlier in the growing season.

Bruising of potato tubers was found to increase the respiration rates. Bruised tubers respired at higher rates than intact tubers and the rate of respiration increased with the severity of bruising. Although the bruised immature tubers evolved more $CO_2$ than mature tubers, the effects of bruising were more pronounced as the tubers matured.

The sucrose content and reducing sugars of potatoes harvested early in the growing season were higher than those of tubers harvested late in the growing season. The chip colour in both cultivars remained relatively light and acceptable through the growing season while the dry matter content increased. In storage, the sucrose content continued to decline and the chip colour darkened with time. The reducing sugars drastically increased after sprout inhibitor treatment (CIPC) while the dry matter content did not change.

Closure of storage bins and application of sprout inhibitor (CIPC) resulted in increased $CO_2$ levels in the storage bins, increased reducing sugars of tubers and dark chips (lower Agtron units). A new higher $CO_2$ level was maintained in the storage bins even after regular ventilation was resumed.

Bruising of tubers at harvest resulted in increased sucrose content, dark chips and lower dry matter content both under short and long term storage. Bruised tubers showed blemishes and dark wounds at areas of impact and this contributed greatly to poor processed potatoes.

# Chapter I

## INTRODUCTION

Considerable progress has been made concerning potato (Solanum tuberosum L.) storage, but ideas still need to be tailored together. This will help provide the best storage conditions so as to prevent losses due to bruising, shrinkage, increased sugars and the detrimental influence of increased $CO_2$ levels in the bins, all of which affect the quality of processed potatoes. To solve these problems, we must study the biochemical and physiological changes that occur in tubers during the growing season and while in storage and, how these changes influence the quality of processed potatoes.

Many workers have found that as the tubers mature, their sugars decrease while the chip colour and dry matter content improves (Hope et al., 1960, Pressey, 1969, Iritani and Weller, 1977 and Mazza et al., 1983). The immature tubers, because of their high sugar content produce processed products of poor quality. It was therefore, a major research contribution when Sowokinos (1978) proposed a maximum harvest sucrose index of 2.8 mg sucrose/g tuber for tubers intended for long term storage. Lately, another physiological parameter, respiration rate, has been receiving great attention as an indicator of maturity of tubers as well as injury inflicted onto the tubers. Since the rate of $CO_2$ release can be measured, it can be used to assess the quality, developmental process or injury of such tubers. Consideration of both

$CO_2$ release by tubers and the harvest sucrose index could enhance the accuracy of estimating the maturity level of tubers and the influence of these factors on stored potato tubers.

Bruising of tubers from mechanical damage during harvesting and subsequent handling is a major cause of deterioration in processing quality and losses of potatoes during storage and processing. Bruising may occur during the handling operation from the field to the processing plant and, it occurs as a result of impact at harvesting or upon handling and by pressure contacts in storage. The discolored areas formed due to bruising create problems at processing time since they cannot be easily trimmed down. Field conditions such as available potassium fertilizer and temperature, age of the tuber and storage conditions have been found to influence bruising susceptibility of tubers (Howard et al., 1961, and Reeve, 1968a). Therefore, prevention of any form of bruising could improve the processing potential of harvested or stored potato tubers.

Storage of potato tubers at high temperature leads to a high metabolic rate and loss of moisture (Cayley et al., 1982) and, sprouting of tubers. Although low temperature prevents sprouting, sweetening of tubers becomes a major problem in tubers intended for processing. Therefore, use of sprout inhibitors would alleviate the sprouting problem at intermediate storage temperatures. The major sprout inhibitor used in Manitoba, Canada, is isopropyl-N-(3-chlorophenyl)-carbamate (CIPC) and this chemical is volatilized at high pressure into tightly sealed bins. This sprout inhibitor treatment could injure the tubers and also stimulate their respiratory activity. The product of the

respiratory process may thus accumulate in storage bins and contribute to changes in tuber quality. Of particular concern is the ambient bin $CO_2$ build up associated with the sprout inhibitor treatment. A 0.1-0.2% level of $CO_2$ is considered safe for storage of potato tubers (Schaper and Varns, 1978). Howard et al., (1961) found that concentrations of $CO_2$ between 0.5 and 5.0% surrounding the tubers in the soil caused black spot susceptibility to remain high after harvest. Therefore, application of sprout inhibitors and ventilation of storage bins should receive great attention so as to reduce the $CO_2$ levels in the immediate environment of the tubers.

The objectives of this study were to attempt to relate potato tuber respiration rates to maturity, bruising effects under short and long term storage and various quality parameters such as reducing sugars, sucrose content and, dry matter content and chip colour. Also to determine the influence of sprout inhibitor (CIPC) treatment and the associated $CO_2$ build-up on tuber processing quality.

# Chapter II

# LITERATURE REVIEW

## 2.1 MATURITY AND RESPIRATION OF POTATO TUBERS

### 2.1.1 Respiration process

In respiration of potato tubers, the carbohydrates are used up to provide energy. The main carbohydrate, starch is composed of simple sugars in form of polymers of glucose units. These simple sugars are biologically oxidised in the respiratory process by the living cells. The respiratory process mainly involves the uptake of oxygen, disappearance of sugars and the production of carbon dioxide, water and energy. This reaction can be represented as follows:

$$\text{Starch} \xrightarrow{\quad\quad} n \times \text{glucose}$$

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \xrightarrow{\quad\quad} \underset{\substack{\text{carbon}\\\text{dioxide}}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{(\text{heat})}{\text{Energy}}$$

Respiration of potato tubers is affected by many growth and environmental factors. Schippers (1977a) reviewed literature on the rate of respiration of potato tubers during storage. He reported a) rapid respiration occurred immediately after harvest, especially in immature tubers; b) sudden temperature change or injury increased respiration; c) potassium influenced the respiratory process because of its effect on damage susceptibility; d) chemical sprout stimulators increased respiration and sprout suppressants decreased respiration, and e) the rate of respiration was characteristic of the cultivar.

### 2.1.2 The effect of maturity on respiration

The respiration rate of freshly harvested, immature tubers is much higher than that of mature tubers. Singh and Mathur (1937 and 1938a) found that the respiration intensity of tubers was highest in the earlier harvested, immature tubers and gradually decreased as maturity advanced. Kimbrough (1925) found that a period of high respiration rate occurred immediately after digging potatoes, then the rate became constant after about a month in storage. Peterson et al. (1981) observed a high respiration rate immediately after harvest, then a decline to equilibrium in about 160 hours.

Although respiratory activity was greatest in the earlier harvested, and less mature tubers, it gradually decreased as maturity advanced. The decline in initial respiration rate was very rapid in successive harvests of very immature tubers but became less as tubers approached maturity (Burton, 1974). Burton (1964) related the difference in rate of respiration to the size of the developing tubers, since he found a reasonably close inverse relationship between size and respiration over the period of active growth. This is a logical argument based on the relationship between surface area and resistance to gaseous diffusion. Similarly, Michaels (1932) found that the amount of $CO_2$ respired per kg of tubers increased from large to small tubers. He attributed the high respiration of small sized tubers to the greater surface area in proportion to volume, and the associated increase in lenticel number.

However, Peterson et al. (1981) found no correlation between tuber size and respiration rate. They concluded that physiological and not physical changes were responsible for the decline in respiration

rate. Burton (1964) added that the rapid respiration rate of earlier harvested tubers was due to the susceptibility of immature tubers to bruising and skinning.

### 2.1.3 The effect of temperature on respiration

The respiration rate of potato tubers is influenced by temperature. Burton, (1964) observed that changes in storage temperature resulted in changes in respiration and sugar metabolism. Appleman and Smith (1936) found that transfer of potato tubers from low storage temperature to high temperature led to a high initial respiration rate. In general, the lower the storage temperature, the higher the initial rise in respiration upon removal of tubers to higher temperatures. Magness (1920) found that the $\%CO_2$ in the gas within the potato tuber tissue increased markedly at the higher temperature. He found an average $CO_2$ of 19.6% and 34.4% at 11 and 22$^0$C, respectively. Craft (1963) observed a large burst of respiration from tubers transferred from 0 to 25$^0$C relative to those transferred from 12.5 to 25$^0$C .

Low temperature also increases respiration rate. Boe et al. (1974) and, Dwelle and Stallknecht (1978) found that storage of tubers at 7.2$^0$C gave the lowest respiration rates, but increase or decrease in temperature from 7.2$^0$C increased the rate of respiration. Schippers (1977b) found that the rate of respiration at 7.5$^0$C was minimal as compared to that at 5$^0$C . He attributed the high respiration at 5$^0$C mainly to the after-effect of change in temperature from 15-20$^0$C during curing to 5$^0$C storage temperature.

### 2.1.4 Sugars and respiration of tubers

A marked increase in respiration rate concomitant with sugar accumulation is a frequent result of low temperature storage. Hopkins (1924) suggested that the initial increased respiration of tubers after removal from cold storage was caused by previous accumulation of sugars. Craft (1963) found an association between higher sugar content of tubers and higher respiratory rates. Although Peterson et al. (1981) found a correlation between reducing sugars and respiration, Dwelle and Stallknecht (1978) found no correlation between respiration rate and total or reducing sugars. Therefore, respiration of tubers may be independent of sugar concentration. Appleman and Smith (1936) found that the rate of respiration of tubers was not related to sugar concentration. Workman et al. (1979) found increased respiration of tubers within 24 hours at $0^{0}$C and since it preceeded the increase in sugars and ion leakage, other factors were attributed to the low temperature induced respiratory rise. Amir et al. (1977) found in their preliminary experiments that aged potato tubers did not exhibit the typical respiratory burst at $4^{0}$C, although they did accumulate sugars. They concluded that the respiratory rise was not always the trigger for sugar accumulation.

### 2.1.5 The effect of storage environment on respiration

In post-harvest physiology of potato tubers, an important criterion of physiological activity is respiration which results in production of $CO_2$. Although $CO_2$ is used extensively in modified storage atmospheres to inhibit respiratory metabolism of fruits and vegetables in order to

extend their post-harvest life, it may affect the respiration rate, weight loss and quality of potato tubers. Wills and Wimalasiri (1979) reported that respiration of carrots, potatoes and zucchini could be reduced by exposure to either high $CO_2$ or low $O_2$ for 2-4 days at $20^0C$ . However, they found that very high $CO_2$ concentration of 25% resulted in potatoes which when cooked were of poor flavor and hard texture. Perez-Trejo et al. (1981) found that application of a high concentration of $CO_2$ to whole potato tubers stimulated a rapid and pronounced respiratory gas exchange which persisted for a long time. Workman and Twomey (1970) reported that increasing storage $CO_2$ levels resulted in either complete tuber breakdown or if tubers were used for seed, an increased decay by an unidentified Fusarium spp or a yield reduction was observed in the field. They also noted that increased $CO_2$ significantly increased reducing sugars at $5^0C$ . Wills and Wimalasiri (1979) studying carrots, observed that a storage atmosphere containing 15% $CO_2$ did not affect their respiration rate, but it induced an injury response with the appearance of soft brown areas on the surface.

Carbon dioxide produced by the stored tubers may accumulate in the storage environment and affect the tubers in one way or another. Schaper and Varns (1978) found that during the one-week suberization period in the absence of ventilation, a maximum accumulation of 2-4% $CO_2$ occurred in potato storage bins. Singh and Mathur (1938b) reported that concentration of $CO_2$ was high in the atmosphere surrounding the adolescent tubers due to the high rate of respiration of the immature tubers. Howard et al., (1961) reported that $CO_2$ concentrations of 0.5-5.0% surrounding the tubers in the soil caused black spot

susceptibility to remain high after harvest. Therefore, it may be necessary to restrict the accumulation of $CO_2$ in the potato storage environment. Schaper and Varns (1978) and Sherman and Ewing (1983) considered 0.10-0.20% $CO_2$ as being safe for storage of potatoes. Thus, ventilation of bins should be adequate to prevent $CO_2$ build-up in all locations within potato storages in order to maintain seed vigor and resistance by breakdown of pathogenic fungi (Workman and Twomey, 1969) and, also to maintain the quality of processing for potatoes. Consideration of different locations within the storage bins is important, since Singh and Mathur (1938b) found that the bottom of the bin had higher $\%CO_2$ than the middle and top. They attributed the higher $\%CO_2$ in the bottom to the following factors: a) greater tuber respiratory activity; b) inability of gases to escape and; c) accumulation from layers above due to the density of the $CO_2$ gas.

## 2.2 BRUISING OF POTATO TUBERS

### 2.2.1 Bruising

Injury to potato tubers has been receiving great attention in recent years. Injury to the tubers occurs during the harvesting operation as well as during storage. Larsen (1962) reported that on average, growers injured 38% of the tubers during the harvesting operation and 54% during grading.

Bruising of tubers is a serious problem since it cannot be detected during the normal grading operation. In bruising, the skin is unbroken and the affected area is not visible until the bruised area is cut. The bruised area is normally characterised by black (melanin) discoloration.

This internal discoloration of the tissues of tubers which results from any form of bruising has previously been referred to as black spot, blue spot, internal and deep bruising (Maas, 1966, Reeve, 1968a,b, Schippers, 1971 and Smittle et al.,1974).

### 2.2.2 Discoloration of tubers due to bruising

The black spot or discolored area due to bruising develops a few mm under the skin and is normally identifiable within 24 hours (Maas, 1966 and Schippers, 1971). This black melanin results from the oxidation of tyrosine, chlorogenic acid and other phenolic compounds by phenolase when the cell membranes are damaged (Hughes, 1980). Reeve (1968a,b) in his histological studies on internal black spot in potato tubers observed that many of the cells within the black areas appeared to have more granular and slightly darker protoplasmic contents, and also showed more intense colour reaction for chlorogenic acid and other phenolic compounds than did cells of healthy tissues. The granular appearance was attributed to melanin effect. McIlroy (1980) found that cells from bruised potato tuber cortex tissue contained amorphous bodies 0.5-1.5μm in diameter which were absent from undamaged tissues. These were found to be melanin granules which appeared to be derived from the 'peroxisome' bodies which contained single large protein crystals. He proposed that during physical shock or damage, disruption of the membrane about the peroxisome occurs allowing access of tyrosine to the ortho-diphenol oxidase located in the peroxisome where melanin is formed. It therefore becomes clear that physiological disorders due to bruising involve phenolic changes.

### 2.2.3 Factors influencing bruising

Bruising of tubers is influenced by a number of factors. Consideration of some of these factors could reduce the effects of bruising. Tuber size and shape as well as composition influence the susceptibility of tubers to damage. Large tubers because of their increased mass are more susceptible to damage than small tubers (Hughes, 1980). Murfitt and Obobi (1980) reported that large tubers generally suffer more internal damage than small ones due to the fact that large tubers are less cushioned by the soil than small ones. Wilcockson et al. (1980) reported that susceptibility to tuber damage increases with tuber size, presumably because of the effect of kinetic energy of impact of the tubers during harvesting and handling. Thus, on the basis of size, tubers become increasingly susceptible to damage as they approach full maturity.

Turgidity and cellular structure of potato tubers determine their firmness and influences damage to tubers. Hughes (1980) reported that increased turgidity and cell wall tension in the tuber increases susceptibility to structural cell wall failure during impact. He found that freshly dug tubers were more turgid than stored tubers and thus more susceptible to cracking and splitting. Dry matter content is another important factor associated with turgor pressure of the tubers. Since internal bruising is often associated with high dry matter, increase in dry matter content with maturity would result in increased susceptibility to bruising (Wilcockson et al., 1980). Also, the loss in water due to the thin skin of immature tubers which are prone to abrasion damage or 'skinning' can lead to an indirect change in tuber

dry matter content, a direct change in turgor pressure of cortex cells and a general softening which would influence susceptibility to damage during subsequent handling (Wilcockson et al., 1980 and Hughes, 1980). However, Smittle et al. (1974) found that damage susceptibility was minimal with turgid tubers. Although black spot susceptibility was low in hydrated (turgid) tubers, it increased to peak susceptibility with dehydration while shatter bruising decreased with tuber dehydration. Hughes (1980) concluded that there may be a fine balance in the water relationship of potatoes when tubers are most resistant to damage - too turgid, they crack and split while too flaccid, they suffer from black spot.

Low temperature at harvest and during storage increases internal injury as well. Murfitt and Obobi (1980) reported survey results that indicated a positive, inverse relationship between temperature and internal damage and recommended that all handling operations be carried out above 7.2°C. Rogers-Lewis (1980) also found that tubers were more susceptible to bruising when harvested or handled during cold temperature than warm temperature. He suggested that bruising could be reduced by warming tubers before handling, harvesting tubers early in the season when temperatures are high or harvesting late in the day after the soil has warmed. Howard et al., (1961), Reeve, (1968a) and Smittle et al. (1974) found that environmental temperature, tuber condition, harvester operation and storage conditions influenced potato tuber damage. They observed increased total damage as the temperature decreased and, more damage of immature than mature tubers at harvest. The low temperature effect was attributed to the fact that the tubers were cold and the tissues quite 'brittle'.

Certain field conditions have also been associated with high incidence of black spot, rendering the tubers more or less susceptible to bruise discoloration. Hughes (1980) reported that tubers grown under low levels of potassium (which produces tubers with a high starch and tyrosine content) are generally more prone to black spot. Rogers-Lewis (1980) found that high rates of potassium reduced bruising susceptibilty. Reeve (1968a) also reported that black spot was reduced by application of high potassium fertilizer. Black spot reduction by potassium appears to result from increased water content of the tubers.

### 2.2.4 The effect of bruising on respiration

Bruising of tubers results in a high respiration rate. Wyse (1978) found that the respiration rate of severely injured machine-harvested sugar beet roots were higher than that of the control. Pisarczyk (1982) found that the respiration of artificially bruised potato tubers increased 150% over unbruised control, but that it declined 25-60% over the one week period of measurement. Although the respiration of damaged tubers was higher initially, it decreased faster than that of control tubers.

The increase in respiration due to bruising may be due to the removal or damage of the epidermis which would greatly facilitate the entrance of $O_2$ to the tissues and also the escape of accumulated $CO_2$ in the tuber tissues. Magness (1920) reported that the increased respiration rate due to wounding could be due to both mechanical injury facilitating gaseous exchange and also actual metabolic changes in the wounded tissues. But Johnstone (1925) emphasized that increased respiration was largely due

to mechanical injury facilitating the exchange of gases rather than the direct stimulation of metabolic changes or respiration.

The increased respiration rate due to bruising may be affected by such factors as temperature and maturity. Burton (1964) reported that immature tubers were highly permeable, susceptible to skinning, wounding and bruising. Therefore, damage to the skin could lead to high diffusion of $CO_2$ from the cell sap to the outside. Singh and Mathur (1938a) found a greater loss in weight of immature tubers in comparison to mature tubers. They concluded that in immature tubers, the periderm layer is incompletely formed and the tubers are more susceptible to injuries during harvesting. Evidently, a greater loss of moisture and $CO_2$ was found to occur from heavily wounded immature tubers.

Other than increased respiration rate of bruised tubers, Wyse (1978) found increases in reducing sugars and increased losses of sucrose in injured sugar beet roots. However, Pisarczyk (1982) found that damage to potato tubers had no effect on total sugar content but decreased the sucrose content.

## 2.3 PROCESSING QUALITIES OF POTATO TUBERS

### 2.3.1 Colour of processed products

The production of desirable chip or fry colour is of utmost importance in the potato processing industry. The colour of processed products depends on the chemical composition of the tuber. Undesirable dark brown colour in processed products is caused by sugars. The major sugars that are found in potatoes are the reducing sugars glucose and

fructose and, the nonreducing dissacharide, sucrose. These sugars play an important role before and during processing of potatoes. The formation of colour of processed potato products such as chips and french fries depends upon the formation of brown pigments during the frying of potato slices in oil. This pigmentation results from the interaction of reducing sugars and amino acids in a process known as the Maillard reaction (Talburt and Smith, 1975).

### 2.3.2 Sucrose content of potatoes and chip colour

The sucrose does not directly participate in the browning reaction. But it acts as an intermediate product in the formation of reducing sugars from starch. Therefore, it is the reducing sugar content which is important when tubers are processed into fried products. However, sucrose can impart a sweet taste and produce off-flavors of processed potato products (Iritani and Weller, 1977).

Sucrose content of tubers has been used as an indicator of harvest index for maturity of potatoes and also as a predictor of how well tubers process after long-term storage. Nelson and Sowokinos (1983) found that potato cultivars which had the inherent ability to reduce their sucrose content to about 0.25% (2.5 mg sucrose/g tuber) before harvest had the necessary biochemical potential to maintain tubers in a state acceptable for satisfactory chip colour after long-term storage. Sowokinos (1978) suggested that potatoes should be harvested with a sucrose rating of less than 2.8 mg/g tuber since they chip longer than those with higher sucrose content from intermediate storage temperature of 11.7$^{0}$C. Huber and Gould (1979) also found that sucrose level below

2.8 mg/g tuber was good for processing potatoes. Their results indicated that low sucrose levels in potato tubers stored at intermediate temperature (10-12°C ) produce acceptable chips with storage periods up to six months. Although, Hair and Gould (1979) found sucrose to be a very useful indicator of potato tuber and processing maturity, they proved reconditioning time as a much more successful and consistent predictor of post-storage colour than sucrose concentration at harvest.

### 2.3.3 The effect of reducing sugars on processed products

Reducing sugars play the final role in contributing to processing quality of potato tubers. As indicated earlier, the brown colour of potato products produced during the frying process was as a result of the interaction between the reducing sugars and the free amino acids of the tubers, the limiting factor being the reducing sugars. Rastovski and van Es (1981) in their review reported that reducing sugars because of their nonenzymatic browning reaction during frying have the most effect on the colour of chips. They concluded that 2.5 to 3.0 mg per gram of fresh weight must be regarded as the maximum permissible level of reducing sugars for chipping. Sowokinos (1973) reported that potato cultivars which maintained an equilibrium level of reducing sugars of 0.15% or less in storage were in the necessary condition to produce chips of satisfactory colour after long-term storage. Therefore, the amount of reducing sugars in the tuber determines the colour of the product. Habib and Brown (1956) showed that chip colour as measured by Hunter Color and Color Difference meter was significantly correlated with reducing sugar of raw tubers.

### 2.3.4 Factors influencing tuber sugar content and chip colour

The sugar content of tubers and the resultant chip colour is affected by a number of factors. Pressey (1969) noted that high sucrose levels in tubers could result from such factors as maturity and physiological stress of tubers during the growing or storage period. Shekhar and Iritani (1978) indicated mechanical damage as being one of the major stress conditions causing increased sucrose content of tubers. Burton (1969) stated that, all factors disturbing the metabolic equilibrium in the plant (stress factors) give rise to an increase in the sugar content.

The amount of sugars the tubers accumulate varies during growing and storage season and, this is an inherited characteristic. Sowokinos (1973) found that the sugar content of potatoes during tuberization and at the time of lifting was largely dependent on cultivar even under virtually identical growing conditions from year to year. He also found that the response of potatoes to storage at low temperature was a typical cultivar characteristic and was associated with sugar content at the beginning of storage. Agle and Woodbury (1968) reported that the amount of sugars in a tuber depends on growing environment, maturity of tubers at harvest, cultural practises (irrigation, fertilizer etc) and, time of storage or reconditioning. Burton (1969) attributed the variation of sugar content during storage at high temperature on cultivar, location, environmental factors during growth, age of tubers, maturity and the storage conditions proceeding actual storage. Singh and Mathur (1937), Sowokinos, (1978), Iritani and Weller, (1977) and Mazza et al. (1983) followed the sugar contents during the growing

season. They found that sucrose content and reducing sugars were much higher in the earlier harvested tubers than in the mature tubers.

All these factors will in turn influence the processed products. Since the sugars change with maturity, the quality of the processed products will change as well. Mazza et al. (1983) found that the chip colour improved with maturity as the sugars declined, reaching a maximum at the final harvest time and then darkening during the initial storage period. Hope et al. (1960) concluded that mature tubers gave chips of lighter colour than immature potatoes, and that the effect of maturity on chip colour appeared to be due to the higher reducing sugar levels in immature tubers. Fertilizers also influence chip colour. Mondy and Koch (1978) found increasing nitrogen fertilizer resulted in discolored tubers. This could be related to the lipid content which was found to decrease as the discoloration increased with increased nitrogen fertilization. Since the lipid content of potatoes is associated with biophysical properties of cellular membranes, their maintenance of cellular integrity is important. Therefore, a reduction in lipid could render the tubers more susceptible to enzymatic darkening since interaction between phenolic substrate and phenolase enzymes would be facilitated. Hope et al. (1960) also found that potato fields receiving less nitrogen matured earlier and produced whiter chips.

### 2.3.5 The effect of temperature on sugars and chip colour

In general, a temperature of 7-10$^{0}$C is the most satisfactory for long term storage since at this temperature sprouting may not begin before 6-8 months (Habib and Brown, 1956). Burton (1969) reported that low

temperature of 2-4°C had the advantage of inhibiting sprout growth, storage rots and reducing evaporative loss at high humidity. But he pointed out the concern in regard to the increased refrigeration cost and sweetening of tubers at low storage temperature.

The storage temperature, especially low temperature for potatoes has pronounced effect on the reducing sugar content. Zaehringer et al. (1966) found that tubers stored at lower temperature of 3.3°C (38°F) had significantly higher reducing sugars than those stored at 7.2°C (45°F) or 11.1°C (52°F ). Hyde and Morrison (1964) found that there was an increase in reducing sugars in tubers stored at 4.4°C (40°F) and as a result, darkening of chips occurred. Habib and Brown (1956) found that all the cultivars they were working on accumulated high amounts of reducing sugars during cold storage but that the sugars decreased with reconditioning. Burton (1969) also noted that sucrose content and reducing sugars accumulated during low temperature storage, and that if the reducing sugars exceeded 0.25% fresh weight, fried products prepared from the potatoes were unacceptablely dark. Isherwood (1973) reported that both sucrose and reducing sugars accumulate during low temperature storage and in the case of potatoes held at +2°C the increase in sugars could rise to over 2% of the fresh weight.

The changes in sugar content due to low temperature storage and aging of tubers may be the result of changes in the membranes of the tubers. Isherwood (1976) found that the tubers that had started senescence had delicate membranes which showed evidence of disintegration, with the layers of double membrane separating and breaking away. This could have meant that the membranes had been damaged irreversibly and no longer

functioned to control the flow of metabolites. Ohad et al. (1971) also found that storage of tubers in the cold induced disintegration of the membrane surrounding the starch granule. They suggested that the cold-induced changes in the starch and sugar content during storage of the potato tubers might be correlated with damage to the membranes surrounding the starch granules and changes in their permeability to degradative enzymes and substrates. Secondly, the changes in sugars during low temperature storage may be related to enzyme activity. Hyde and Morrison (1964) found that the phosphorylase activity was higher in tubers stored at 4.4°C (40°F) and since this enzyme catalyzes the breakdown of starch, it could be a factor in influencing sugar accumulation and chip quality. Pressey (1969) also found that total invertase activity which hydrolyses sucrose increased sharply when potatoes were placed in cold storage.

Although low temperature results in increased reducing sugars, high temperature has the opposite effect. Paez and Hultin (1970) found that when tubers were removed from low temperature storage and placed at high temperature, the amount of sugars decreased. Timm et al. (1968) found that exposure of tubers to short-term non-lethal high temperature induced a marked stimulation of sugar accumulation but that prolonged exposure at high temperature diminished the sugars. Lighter coloured chips resulted from this reduction in the total sugar concentration due to high temperature.

Therefore, in cases where the sugar content has increased excessively due to low temperature storage, reduction of these sugars prior to frying becomes important. This is achieved by holding the tubers at

elevated temperature of approximately 20°C for 2-3 weeks prior to processing i.e. reconditioning. Hyde and Morrison (1964) found that reconditioning of tubers at 21.1°C (70°F) lowered the reducing sugars and improved the chip colour. Iritani and Weller (1977) found a decrease in sucrose content with reconditioning at 15°C (60°F) for 3 weeks. Habib and Brown (1956) found that, even though potatoes taken from low storage temperature (7-10°C) could not be used for chips, suitable cultivars could be reconditioned in 2-3 weeks. But the rate at which the reducing sugars disappear during conditioning depends upon the cultivar, the length and temperature of previous storage and, the temperature of reconditioning. Burton (1969) and Isherwood (1973) found reconditioning reduced sugars and Isherwood (1973) presumed the reduction of sugars to be due to recondensation to starch and increased respiration. All these changes contribute to quality of processed potatoes in one way or another.

### 2.3.6 Tuber dry matter content and processed potato products

The dry matter content is an important factor in processed potato products such as chips and french fries. The dry matter content can easily be calculated from the specific gravity which is the 'ratio of the mass of a body to the mass of an equal volume of water at 4°C or other specified temperature' (Porter et al., 1964). Smith (1975) reported that the dry matter content is important in determination of mealiness of potatoes before they are cooked, canned or dehydrated and is also the property used to predict mealiness of french fries, yield of dehydrated potatoes and potato chips. This is because the dry matter

content determines the weight of processed products which can be obtained from a given weight of raw potatoes.

Potatoes of high dry matter content are important in the processing of potato tubers into chips, french fries and dehydrated products. For instance, french fry quality has been shown to be related to whole tuber specific gravity and solid contents. Because of its importance, specific gravity of potatoes is now widely accepted by the processing industry as a measure of the total solids, starch content and other qualities (Fitzpatrick et al., 1969). Sayre et al., (1975) working with individual strips of potato tubers concluded that yield of par-fries (fried for 1 minute) and to a lesser extent of finish fries (fried for 3 minutes) increased as solids content increased. Habib and Brown (1956) also found that higher specific gravity was associated with higher yields of potato chips. Lulai and Orr (1979) emphasized the need to breed, produce and utilize potatoes of very high specific gravity and showed that high specific gravity potatoes had increased chip yield and decreased oil consumption. Lyman and Mackay (1961) observed that tubers with high specific gravity consistently produced chips of lighter colour than did tubers of low specific gravity.

### 2.3.7 Factors affecting tuber dry matter content and quality

A number of factors affect the specific gravity or the dry matter content of tubers. Rastovski and van Es (1981) reported in their review that the dry matter content is influenced by a large number of factors such as cultivar, maturity, nitrogen and potassium fertilizers, and climate. Agle and Woodbury (1968) found that the specific gravity-dry

matter relationship was affected by production area, potato cultivar and storage length. Wilson and Lindsay (1969) reported that the specific gravity of potato tubers varies according to cultivars, different soil conditions, cultural practices and environmental conditions. Fitzpatrick et al., (1969) found that tubers with a specific gravity of 1.080 ranged in total solids from 18-20%. They concluded that the variation in specific gravity-total solids relationship may be due to such factors as cultivar, internal composition of tubers, area of growth and analytical techniques.

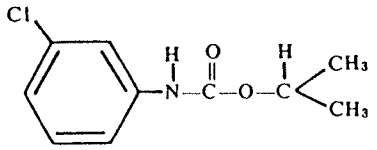
Many workers have attributed the influence of the above discussed factors to variations in air volumes in the tubers. Kushman and Haynes Jr. (1971), Isherwood (1973) and Hudson (1975) reported that differences in specific gravity were due to intercellular space in the tubers. On the other hand, Basker (1975) indicated that temperature of potatoes and water in which the tubers are weighed is relevant in determining specific gravity, while Singh and Mathur (1937) attributed the low starch content during the early developmental stages to high respiration of the immature tubers.

## 2.4 CHEMICAL TREATMENT OF POTATO TUBERS

### 2.4.1 Chemical treatment

Potato tubers are commonly stored at low temperature for long periods. Unfortunately, the low temperature results in increased reducing sugars which lower the processing potential of tubers. Higher temperatures can be used for storage, but sprouting becomes a serious problem. Therefore, use of chemicals as sprout inhibitors has become important.

The chemical isopropyl-N-(3-chlorophenyl)-carbamate (CIPC) is a highly volatile compound which has found a major use as a potato sprout inhibitor. CIPC belongs to a family of herbicides called carbamates and its common name is chlorpropham (structure below).



## 2.4.2 The effect of CIPC and related compounds

Some knowledge of the physiological effects of carbamates, especially CIPC is important. CIPC is primarily used as pre- and post-emergence herbicide on a variety of fruit and vegetable crops. It has several modes of action in plants such as the inhibition of root and shoot growth, particularly of the primary roots; inhibition of photolytic activity of the chloroplast; inhibition of protein synthesis and mitosis (Wilson et al., 1981). It seems CIPC has a selective action on dividing cells and accomplishes its physiological effects both as a toxicant and a narcotic. Ivens and Blackman (1949) studying the effect of a related compound, ethyl phenylcarbamate on mitosis in roots, proposed that carbamate esters combine with the lipid component of the spindle protein causing an intramolecular precipitation, collapse and disintegration of the spindle. Therefore, the herbicidal effects of CIPC are thought to be due to its anti-mitotic effects.

Although low dosages of CIPC have been reported to depress respiration in cotton roots (Swanson et al., 1953), grass seedlings (Al-Aish and Brown, 1958) and bracken (Kirkwood, 1976) and, to cause a significant increase in reducing and total sugars in soybean plants (Meade et al., 1958), other workers have reported increased respiration with CIPC treatment. Schippers (1977a) reported as a general trend, an increase in respiration after CIPC application, followed by a decline. The chemical most likely exerted an indirect influence through damage to the tuber tissue rather than a direct influence on the reactions involved in the respiration process. Craft and Audia (1959) only found significant increase in respiration rate of potato tuber discs that were injured and appeared discolored after CIPC treatment. Hanes and Baker (1931) and Dilley et al. (1970) studied the influence of hydrogen cyanide and potassium azide on potato tuber and sugar beet respiration, respectively. Although both chemicals were thought to be potent respiratory inhibitors, they increased the respiration rate of potatoes and sugar beets. Hanes and Baker (1931) attributed the increase in respiration to injury of tubers which occured in the form of brown patches and sunken areas, while Dilley et al. (1970) suggested that the chemical perhaps had an indirect effect on the permeablity characteristics of the sugar beet roots.

Other than increased respiration due to injury by the chemicals, excessive leakage of ions and metabolites from the potato may indicate damage to tissues. Craft and Audia (1959) found that CIPC caused a significant increase in ion leakages. They also found that potato discs infiltrated with $10^{-3}$ or $10^{-4}$ M CIPC accumulated slightly higher amounts

of sugars than the control. Isherwood and Burton (1975) found increased sugars in chemically treated potatoes as well as damaged tubers. They found an increase of 3% and 2.1% in the hand-desprouted and the CIPC-treated tubers respectively. Athough other workers have indicated and found increased sugars with chemical application, Perlasca (1956) reported that isopropyl-N-phenyl-carbamate (IPPC) and CIPC had no effect on reducing sugar content and breakdown of treated tubers in storage. Zaehringer et al., (1966) also found that tubers stored and treated with either maleic hydrazide or CIPC maintained the same level of reducing sugars.

### 2.4.3 Effectiveness of chemical treatments

Chemical treatments can be applied to the tubers during the growing season or in storage. During the growing season, timing of application is important, while during storage, specialized systems and proper ventilation are important as well as the timing of application. Marth and Schultz (1952) found that CIPC was extremely effective in preventing sprouting when compared to other sprout inhibiting chemicals. Tubers treated with CIPC remained dormant and relatively firm for four months in a room where air temperature was 21.1-23.9°C (70-75°F). But Reeve et al. (1963) and Leach (1978) found that when CIPC was applied to freshly dug potatoes or bruised tubers, it prevented wound healing. Sawyer (1961) reported that application of CIPC to freshly cured potatoes in storage resulted in increased dry rot. This was due to poor wound healing as a result of the inhibitor. Craft and Audia (1959) attributed the effect of CIPC in interfering with periderm development in wounded

tubers to insufficient suberin and periderm development. However, the potent effect of CIPC in preventing wound healing could be prevented by combination with other chemicals such as chlorine which enhances wound healing of tubers. Leach (1978) found that, although CIPC together with thiobendazole caused wounds with more tissue degradation, the combination of CIPC ,thiabendazole and chlorine reduced the detrimental effect of CIPC on freshly dug tubers.

### 2.4.4 Losses of CIPC during storage

Knowledge of CIPC concentration in stored potatoes is of importance because sprouting could occur if the concentration falls below a certain minimum level. At 7.2$^{0}$C (45$^{0}$F) which is good enough to maintain suitable internal quality, 'Russet Burbank' tubers may complete their normal rest period within 4-5 months before beginning to sprout. Most of the aerosol-applied CIPC residues in white potatoes is within the peel layer which includes the periderm and cortical region (Corsini et al., 1979). Wilson et al., (1981) found that CIPC does not wash off easily after prolonged storage and this tended to indicate that the CIPC may be bound to the plant surface.

Since carbamates, in particular CIPC, are so volatile, high losses during storage may be expected. Loss of most sprout inhibitors is through volatilization. Dalziel et al., (1980) found that a sprout inhibitor tecnazene (1,2,4,5-tetrachloro-3-nitrobenzene) was lost mainly through volatilization and also biotransformation by the potato tissue or surface micro-organism. Marth and Schultz (1952) found that CIPC rapidily evaporated when exposed to room temperature, with little

chemical being left on the treated surface. Therefore, the losses of the sprout inhibitors led to lower concentrations of the chemical in the tuber. Corsini et al. (1979) estimated the minimum concentration of CIPC in the peel layer for complete inhibition of sprouting as 20 ppm. They thus defined a threshold value for sprout-inhibiting levels of CIPC in the peel layer as approximately 20 ppm.

Although 20 ppm CIPC was defined as the threshold value, the location of the tubers in the bins will influence the amount of chemical that will coat the tuber. Corsini et al., (1979) found that most of the CIPC was located near the surface and bottom of the potato pile in the bin. Apparently, the high levels at the top of the pile were as a result of fall-out from the aerosol mist circulation above the pile. On the other hand, the bottom of the pile functions to some extent as a filtering surface since the aerosol is introduced via the ventilation system, which circulates from the bottom to the top of the pile.

## Chapter III

## MATERIALS AND METHODS

Potato tubers of the cultivars 'Norchip' and 'Russet Burbank' employed in this study were commercially grown at two locations in Southern Manitoba under standard production practices in 1983 by Southern Manitoba Co. Ltd. and Kroker Farms Ltd. Harvesting at bi-weekly interval began on the 6 and 7th of August through 4 and 10th of October for 'Norchip' and 'Russet Burbank', respectively. By the final harvest, five different harvest dates had been made for each cultivar. Tubers were harvested at random from a quarter of the field that was selected for the study. Approximately, 30 kg of potatoes from 20-30 plants were harvested at each site. To minimize disturbance of the tubers, a fork was used to lift the tubers from the ground. The harvested tubers were placed in small jute bags and transported immediately to Agriculture Canada Research Station, Morden for analyses. All harvests were made in the morning between 7.00 and 8.00 am.

Following washing, the tubers were analyzed for specific gravity/dry matter content, sucrose content, glucose and fructose as reducing sugars, chip colour and respiration rate.

## 3.1 SPECIFIC GRAVITY/DRY MATTER CONTENT

Determination of specific gravity was by weighing the tubers in air and water. The specific gravity was calculated from the formula:-

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

From the specific gravity, the dry matter content was calculated using the following equation proposed by Simmonds (1977):-

$$\% \text{ Dry matter content} = 2.2 + 49.1U$$

where

$$U = \frac{5G - 5}{G}$$

G = specific gravity.

## 3.2 SUCROSE CONTENT ANALYSIS

The sucrose content was determined by the anthrone colorimetric method developed by Van Handel (1968) and adopted for potatoes by Sowokinos (1978). Six to ten tubers were selected for each analysis. The tubers were washed, peeled by an abrasive peeler and cut lengthwise into pieces. Random pieces were selected from 1/2 of each tuber to obtain three 200g samples.

Juice was extracted from the 200 g sample using an Acme Juicerator and collected in a 600 ml chilled beaker. Three 100 ml cold distilled water washings were passed through the juicerator using a 100 ml chilled graduated cylinder, allowing 2-3 minutes between washings. The extract volume was brought to 430 ml with cold distilled water, mixed and

transferred to a chilled erlenmeyer flask. The flask was covered with stretch and seal plastic film, and placed in a refrigerator at about 4.4$^{0}$C for one hour to settle. All sucrose analyses were carried out on the same day of extraction.

### 3.2.1 Anthrone reagent

The anthrone reagent was prepared by mixing 0.15 g of anthrone with diluted sulfuric acid ($H_2SO_4$ ). The diluted sulfuric acid was prepared by adding 76 ml of sulfuric acid to 30 ml distilled water while stirring. The diluted sulfuric acid solution was added to the 0.15 g of anthrone and mixed for two hours to dissolve all the anthrone. The reagent was stored in a dispensing flask covered with aluminium foil to prevent decomposition under light and stored in a refrigerator at 4$^{0}$C until used.

### 3.2.2 Sucrose determination

A sample of the juice extracted was removed from refrigerator after one hour and analysed as outlined above. In the case of new potatoes (during growing season), a sample of 10 ml was diluted with distilled water and brought up to volume in 50 ml volumetric flask (1:5 dilution). During storage, 25 ml of juice was diluted with water and brought to volume in a 50 ml volumetric flask (1:1 dilution).

From the 1:5 dilution or 1:1 dilution made, 0.2 ml of the juice was transferred to a test tube. For each set of determinations, two reagent blanks (0.2 ml distilled water) were used to standardize the

spectrophotometer and, 0.1 mg of sucrose as a standard were included. To each tube, 0.2 ml of 30% KOH was added and the solutions were mixed by shaking. Marbles were used to cover tubes which were placed in a heating block at 100°C for 15 minutes to destroy the reducing sugars (Sowokinos, 1978). The samples were allowed to cool and 6 ml of anthrone reagent added to each tube. The solutions were again mixed, covered with marbles and incubated in a water bath at 40°C for 40 minutes after which they were allowed to cool at room temperature. The samples were then transferred to cuvets and the absorbance measured spectrophotometrically at 620 nm. The samples were run in triplicate.

The sucrose content or rating was calculated from the following equation:-

$$\frac{\text{OD extract} \times 0.1 \text{ mg sucrose}}{\text{OD standard}} = \text{mg Sucrose(0.2 ml extract)} = S$$

$$S \times \text{Dilution Factor(DF)} = \text{Tuber Sucrose(SR)} = \text{mg Sucrose/g Tuber}$$

where
OD = optical density or absorbance reading
SR = sucrose rating

A sample dilution factor (DF) was derived as follows:-

$$DF = \frac{430 \text{ ml(total extract)}}{0.2 \text{ ml(assay volume)}} \times \frac{5(\text{dilution extract})}{200\text{g tuber}}$$

The dilution factor during growing season was 53.75 and during storage it was 21.50.

## 3.3 REDUCING SUGAR ANALYSIS

For the determination of reducing sugars, 6-10 tubers were washed, peeled and diced into 0.5 cm cubes by chopping with a kitchen knife. A portion of 25 g of the chopped potato was weighed and placed in a Waring blender with 100 ml distilled water. The sample was blended for exactly one minute at low speed and the homogenate was filtered into a 50 ml erlenmeyer flask. After thorough mixing, 2 ml of the extract was pipeted and transferred to a test tube and mixed with 3,5-dinitro salicylate reagent (Ross, 1975). After mixing, the mixture was then heated at 100$^{0}$C in boiling distilled water bath for 5 minutes. It was then rapidly cooled in an ice bath and diluted to 25 ml by adding 21 ml of distilled water. After mixing well, the absorbance was read at 560 nm.

A calibration curve was prepared using standards prepared from glucose solutions (dextrose). Five grams of anhydrous dextrose was dissolved in 500 mls of distilled water and, 1 ml of this solution was equivalent to 10.0 g of glucose.

To a series of clean 100 ml volumetric flasks, 10, 20, 30, 40, and 50 mls of the standard glucose solution was added. The contents of each flask was diluted to 100 mls with distilled water and mixed well. Two mls of solution was pipeted from each flask into a series of clean dry test tubes. Each tube then contained 2, 4, 6, 8 and 10 mg of glucose. To a sixth tube, 2 mls of distilled water was added as a blank. To each of the tubes, 2 mls of 3,5-dinitro salicylate reagent was added, mixed well and treated as the above procedure was repeated and the absorbance at 560 nm outlined above. The calibration curve of mg glucose vs

absorbances obtained was used to calculate the concetration of reducing sugars in the potato samples.

### 3.3.1 3,5-dinitro salicylate

The reagent was prepared by suspending 20.0 g of 3,5-dinitro salicylic acid in 400 mls distilled water, then slowly adding 32 g sodium hydroxide which had been dissolved in 320 mls distilled water. Then 600 g potassium sodium tartrate was gradually added while stirring until dissolved. The solution was diluted to 2000 mls with distilled water.

### 3.3.2 Calculation of % reducing sugars

The calibration curve of mg glucose vs absorbance was used to find the glucose content from the absorbance of the sample. The % reducing sugars was calculated as follows:-

25 g of raw potato in 100 ml extract (2 ml extract used) was equivalent to 500 mg.

$$\% \text{ Reducing sugar} = \frac{\text{mg dextrose in extract} \times 100}{500}$$

$$= \frac{\text{mg of dextrose}}{5}$$

## 3.4 CHIP COLOUR MEASUREMENT

Six to ten tubers were selected for chip colour determination. The potato tubers were washed, and peeled in an abrasive potato peeler to remove the skin. Potato chips were obtained by slicing the peeled tubers into 1 mm thick slices using a rotary Hobart slicer.

The slices were rinsed in cool water for a short time to remove the starch, and the excess water was removed by shaking the slices in an automatic shaking machine. The dried slices were fried in hydrogenated vegetable oil at 180-185$^{0}$C for 2-3 minutes. The end point of frying was determined by ceasation of bubbling. The fried chips were drained and allowed to cool and placed in polyethylene bags until Agtron measurements were taken.

The chip colour was evaluated objectively using the Agtron Reflectance colour meter, model M-30-A. The instrument was standardized using the red mode at 0 with the black reflectance disc (00) and at 90 with the white disc (90). The chips were placed in a 16 cm diameter sample cap and crushed to provide even distribution of the sample. Samples were read in duplicate and the mean of the measurement calculated. Values of 40 or more Agtron units represented acceptable chip colours. Higher values indicate visually lighter colour and lower values a darker brown colour.

## 3.5 RESPIRATION MEASUREMENT

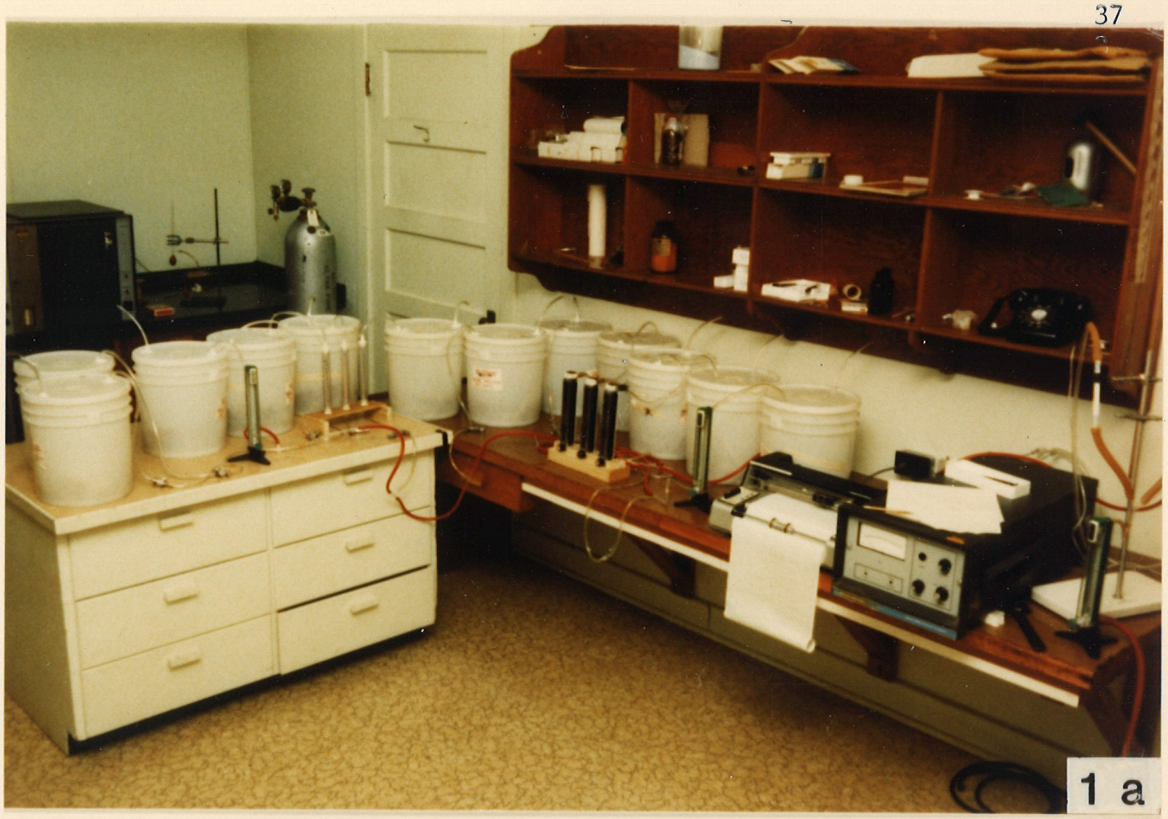
Respiration rate was measured by monitoring the carbon dioxide evolved from the tubers. The instrument used was a Beckman infrared (IR) gas analyzer, general-purpose model 865. In this instrument, infrared radiation is produced from two separate energy sources. The infrared beams pass through two cells; one a reference cell containing a non-absorbing background gas, the other a sample cell containing a continuously flowing carrier gas with the sample.

During operation, a portion of the infrared radiation is absorbed by the component of interest in the sample, with the percentage of infrared radiation absorbed being proportional to the component concentration. The detector converts the difference in transmitted radiant energy between sample and reference cells to a capacitance change. This capacitance change, equivalent to component concentration, is amplified and indicated on a meter and used to drive a chart recorder (Beckman Instruments, 1976).

The set-up of the IR gas analyzer for the respiration measurement was that described by Clegg et al. (1978). The whole system consisted of the IR gas analyzer, chart recorder, flow meter and drying columns with anhydrous magnesium chloride (plate # 1a). Tygon tubing was used to connect the system. The tubing lengths from the tee connector to the IR gas analyzer were the same to balance line resistance. The flow rate of the carrier gas, nitrogen, was adjusted to approximately 0.6 l/minute. At this flow rate, a narrow based peak was recorded on the strip chart recorder when gas samples containing $CO_2$ were injected in the line and,

PLATE 1a. The set-up for the measurement of the respiration rate experiment.

PLATE 1b. The bruising device used for bruising potato tubers.



1 a

1 b

only measurements of peak heights were necessary to obtain $CO_2$ concentrations.

### 3.5.1 Sample measurements

Carbon dioxide evolution was determined from potato tubers enclosed in 16 l plastic pails. Each pail had an inlet and outlet tubing and contained 2.5-3.0 kg potato tubers. Commercial tank air or ambient air was pumped through the pails at 8 l/hr and the outcoming air from each pail was sampled in duplicate at each sampling time.

A 5 ml or less air sample was collected from the outlet tubing with a 5 ml glass syringe and injected through a short section of tubing in the sample line (Fig. 1). It passed through the drying column for removal of water and then through the IR gas analyzer where the $CO_2$ concentration was determined with the instrument response being traced by the chart recorder.

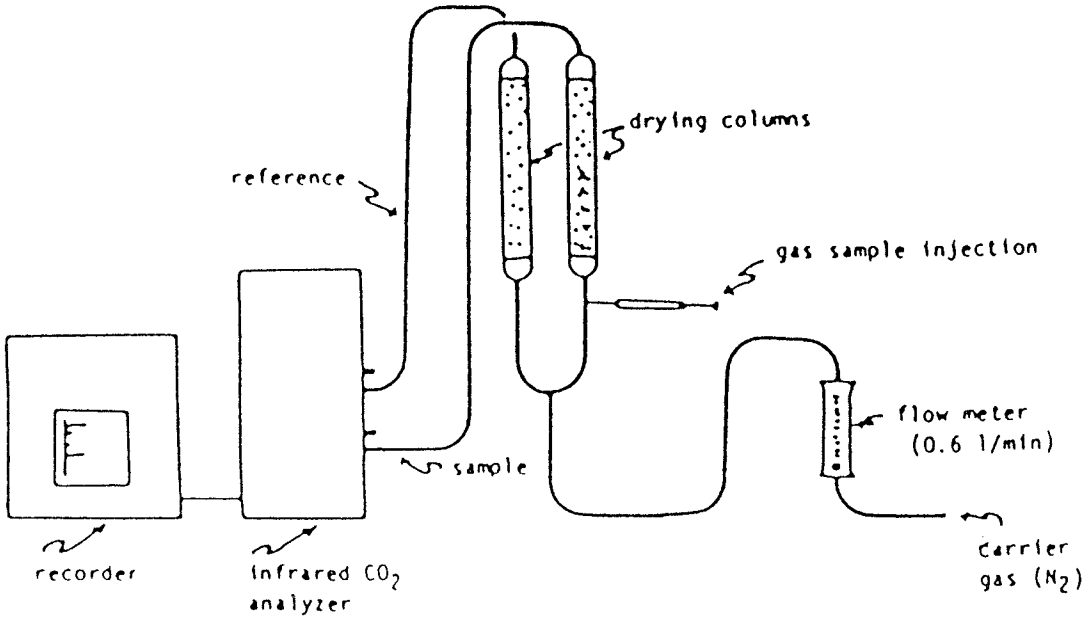
All the respiration measurements were started two hours after harvest. The measurements were made at the following time intervals: 3, 5, 8, 11, 14, 24, 27, 30, 32 and 50 hours after harvest.

### 3.5.2 Calibration curve and calculation of respiration

The calibration curve was prepared from two commercial standard gases of 740 ppm and 1150 ppm $CO_2$ . The calculations were in mg $CO_2$ and were derived as follows:-

$$\text{mg } CO_2 = \frac{\text{moles } CO_2 \times T \times MW\ CO_2 \times \text{mls STD } CO_2 \text{ gas}}{T^0}$$

Figure 1. Schematic of the system for measurement of $CO_2$ concentration in a gas sample.


drying columns
reference
gas sample injection
flow meter
(0.6 l/min)
sample
recorder
infrared $CO_2$
analyzer
carrier
gas ($N_2$)

where

moles of $CO_2$ = moles of $CO_2$ occupying 1 ml of volume at standard temperature and pressure (STP)
T = standard temperature in degree Kelvin
$T^0$ = room or study temperature
MW $CO_2$ = molecular weight of $CO_2$
mls STD $CO_2$ = mls of standard $CO_2$ gas per ml of gas

Sample calculation of mg $CO_2$ at $20^0C$:-

$$\text{mg } CO_2 = \frac{4.46\times10^{-5} \times 273 \times 44\times10^{3} \times 7.4\times10^{-4}}{293}$$

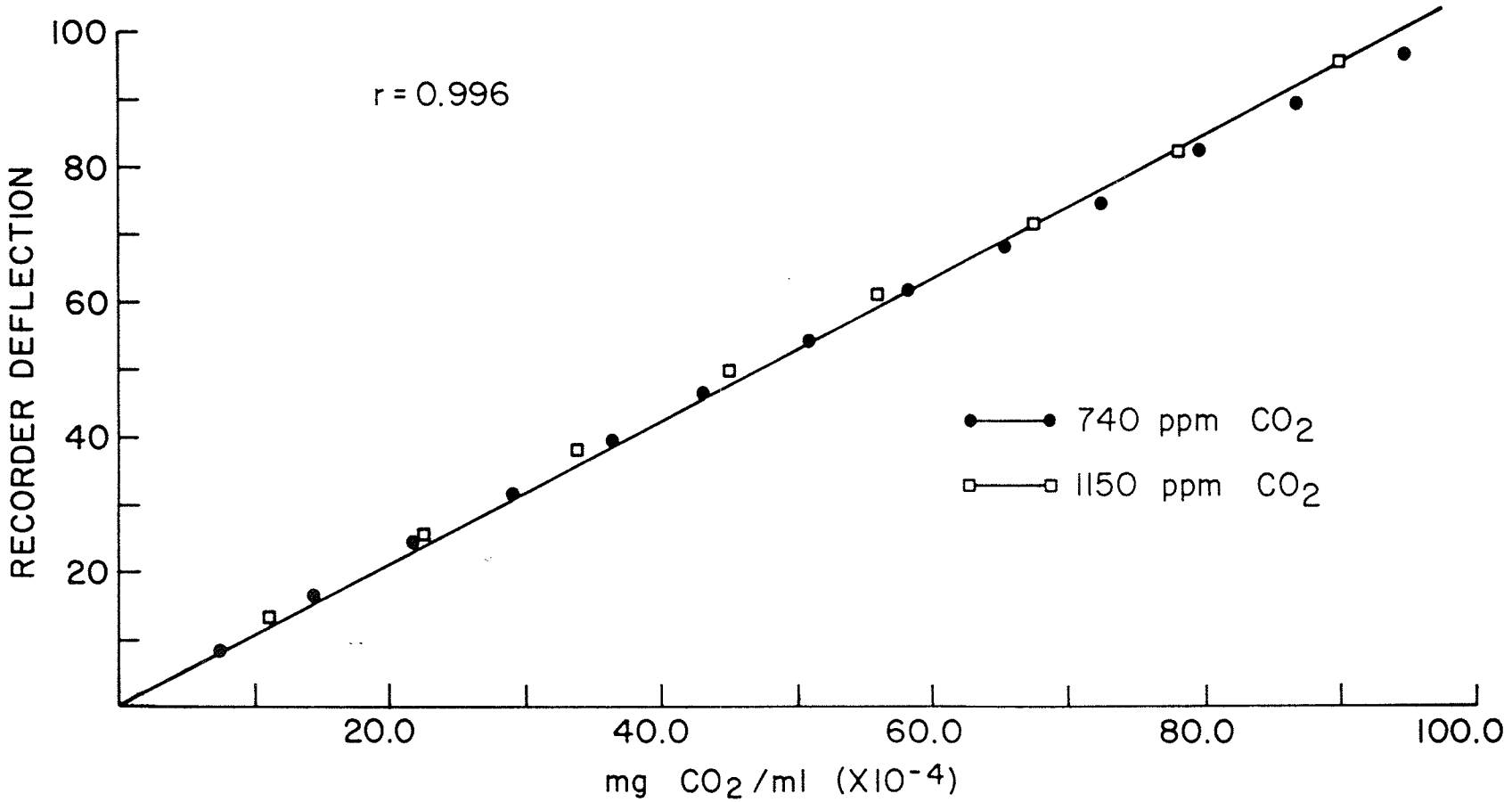
$$= 13.53\times10^{-4} \text{ mg } CO_2/\text{ml gas.}$$

A number of standard gas samples between 0.5 to 6.5 mls of $CO_2$ were injected into the IR analyzer. Recorder deflections were recorded and a calibration curve of mg $CO_2$ against recorder deflection plotted (Fig. 2).

Using the mg $CO_2$ obtained from the calibration curve, including the airflow and weight of the tubers in each pail, the respiration data were calculated as milligrams $CO_2$/kilogram of fresh weight/hour (mg $CO_2$/kg fw/hr). The following equation was used:-

$$\text{mg } CO_2/\text{kg fw/hr} = \frac{\text{mg } CO_2/\text{ml} \times \text{airflow(mls/hr)}}{\text{kg of fresh potatoes}}$$

Figure 2. Calibration curve for the measurement of respiration rate.


r = 0.996
RECORDER DEFLECTION
100
80
60
40
20
20.0
40.0
60.0
80.0
100.0
mg CO2 /ml (X10-4)
740 ppm CO2
1150 ppm CO2

## 3.6 BRUISING OF POTATO TUBERS

### 3.6.1 The bruising device

The bruising device and technique was similar to that designed and used by Maas (1966). It was simply a hollow tube through which a 100 g metal plug could be dropped on a potato tuber held in position at the end of the tube (plate # 1b).

The device consisted of a 30 cm long of 5 mm diameter copper pipe clamped to a ring stand. The metal bolt or plug was 10 cm long with a round-headed carriage bolt with a washer welded 1/2 mm from the threaded end. The total weight of the bolt was 100 g. A dropping distance of 30 cm was obtained by lowering the bolt into the tube until the washer was level with the top. The head of the bolt with a 3.5 mm diameter and 1/2 mm radius of curviture provided a convex striking surface and caused adequate bruising with a minimum of shattering.

### 3.6.2 Bruising technique

At each harvest date, the tubers were divided into four replicates of approximately 2.5-3.0 kg and placed in the 16 l plastic pails at 20°C to determine the respiration rate. Three degrees of bruising plus the control were used. The tubers were bruised by holding each potato tuber firmly against the bottom of the tube to avoid movement on impact with the bolt head. Bruises were made on both ends of the tuber plus other areas on the tuber depending on the bruising treatment. According to Maas (1966), the basal end of tuber shows the greatest susceptibility to bruising. The degrees of bruising were 1) intact tubers; 2) slightly

bruised tuber - the weight was dropped twice, once on each end of the tuber; 3) moderately bruised tubers - the weight was dropped ten times, once on each end of the tuber and at random spots around the tuber; and 4) severely bruised tubers - the tubers were dropped into a potato abrasive peeler for 10 seconds. Duplicate gas samples were removed from the tuber samples periodically over a period of 48-50 hrs of incubation.

## 3.7 STORAGE

Potato tubers of the cultivars 'Norchip' and 'Russet Burbank' employed in this study were stored in two commercial storage bins in Southern Manitoba. The study started after suberization when the temperature was lowered to $10^{0}$C at the end of October, 1983. Tuber sprouting was prevented by treating the tubers in December with the sprout inhibitor CIPC. During storage, analyses were performed at predetermined intervals for sucrose content, reducing sugars, chip colour and dry matter content. At each sampling time, the $CO_2$ level in the bins was monitored.

At the beginning of the storage study, four lots each of 20 kg from 'Norchip' and 'Russet Burbank' were randomly sampled. Three levels of bruising and the control were inflicted on the tubers as described earlier. The tubers were bagged and left in the commercial storage bins. Samples from these bags were taken at predetermined intervals and analyzed for specific gravity, sugars and chip colour.

### 3.7.1 Sprout inhibitor application (CIPC)

The storage bins were tightly sealed five days before the sprout inhibitor application. This is not the usual practice, but because the machines had broken down, the delay was unavoidable. The sprout inhibitor is usually applied within 24 hours after the storage bins have been sealed.

The machinery for the sprout inhibitor application was set up externally in a vehicle. It mainly consisted of a motor with an air combustion chamber. In the chamber, the air was heated to a very high temperature and moved through a pipe to the expansion nozzle chamber where the temperature was set at 288$^{0}$C . In the expansion chamber, the CIPC solution was broken down into very fine droplets and moved along a pipe attached to the storage bin. The fine droplets were forced into the bin and circulated with the fans running to ensure uniform application.

The whole operation lasted two-and-half hours for each bin. The inhibitor was applied at a rate of 38 ppm (inhibitor per wet weight of tubers), of which 12 ppm envetually is expected to coat the tubers. A maximum of 15 ppm on the tubers is allowed according to the applicator (StanChem Ltd., 1983). A 3-4$^{0}$C increase in temperature is expected during the application due to heat of combustion from the machine, heat from the inhibitor and also the activity of the potato tubers.

After the sprout inhibitor was applied, the bins remained closed for a period of 24 hours after which the bins were ventilated for 2 hours and closed again. After another 24 hour period, the bins were opened and ventilated for 2 hours and closed again. On the 6th day, the bins were

opened and normal ventilation resumed. According to the storage operator (Kohl, 1983), ventilation of the bins 24 hours after the inhibitor application was necessary to prevent $CO_2$ accumulation, increase in temperature and tuber quality deterioration. The short periods of ventilation for 2 hours were used to prevent losses of the inhibitor.

### 3.7.2 Air sampling during storage

Air samples were collected from commercial storage bins during the early part of storage after suberization and through the sprout inhibitor application period. Small bottles of 130 mls volume, closed with rubber septa were evacuated and used to collect air samples in the bins. The evacuated bottles were opened in the bins so that air in the bins could rush in the bottles. Air was sampled inside the bins at different points. The air sample in the bottles was removed with a gas syringe and injected into the infrared gas analyzer to determine the $CO_2$ concentration as described earlier. The amount of $CO_2$ was reported in percentage.

# Chapter IV

# RESULTS AND DISCUSSION

## 4.1 MATURITY AND RESPIRATION OF POTATO TUBERS

The $CO_2$ evolution of harvested tubers was followed during the active growth of the tubers until the final harvest time. In general, the mean respiration rate of tubers of both cultivars declined as tuber maturity increased (Table 1). The $CO_2$ evolution was significantly higher in the earlier harvested, immature tubers, but gradually decreased as maturity advanced. This decline was from 57 to 24 and, 71 to 24 mg $CO_2$/kg fw/hr in immature to mature tubers of 'Norchip' and 'Russet Burbank', respectively (Table 1). At the last harvest date in October, rates of respiration were 41% and 35% of observed maximum during the growing season for 'Norchip' and 'Russet Burbank', respectively. This seasonal decline in $CO_2$ evolution was observed in both 'Norchip' and 'Russet Burbank' cultivars. These results agree with those reported by Peterson et al. (1981) who attributed this phenomenon to maturation of the tubers and other physiological changes occurring in response to season-dependent environmental changes.

The $CO_2$ evolution shortly after each harvest date increased to a maximum value and then declined to an equilibrium level (Fig. 3 and Fig. 4). The highest $CO_2$ evolution was attained within 8-14 hours while the equilibrium level was attained within 48-50 hours after each harvest.

TABLE 1. Overall mean $CO_2$ evolution at different harvest dates of Norchip and Russet Burbank potatoes.

| Harvest date | | Mean $CO_2$ evolution (mg $CO_2$/kg fw/hr) | | $CO_2$ evolution (% of highest rate) | |
|---|---|---|---|---|---|
| N | RB | N | RB | N | RB |
| 15/8/83 | 24/8/83 | 53 b* | 71 a | 92 | 100 |
| 30/8/83 | 08/9/83 | 57 a | 49 b | 100 | 69 |
| 18/9/83 | 24/9/83 | 49 c | 44 c | 85 | 62 |
| 30/9/83 | 06/10/83 | 46 d | 24 d | 80 | 34 |
| 04/10/83 | 11/10/83 | 24 e | 25 d | 41 | 35 |

N = Norchip
RB = Russet Burbank
* Values within columns followed by the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

Figure 3. $CO_2$ evolution of intact tubers of Norchip soon after each harvest.

Date 1 = 15/8/83
Date 2 = 30/8/83
Date 3 = 18/9/83
Date 4 = 30/9/83
Date 5 = 04/10/83

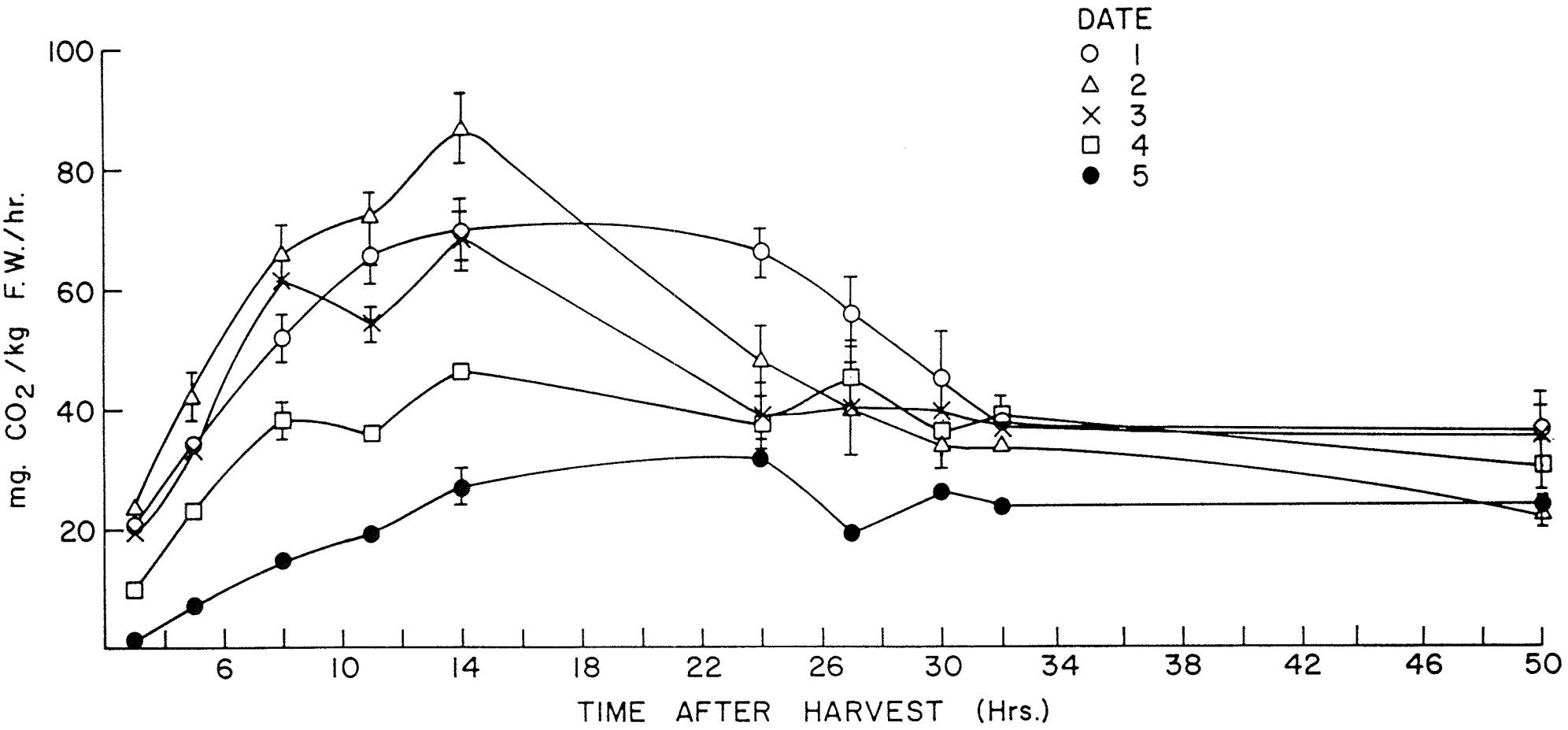
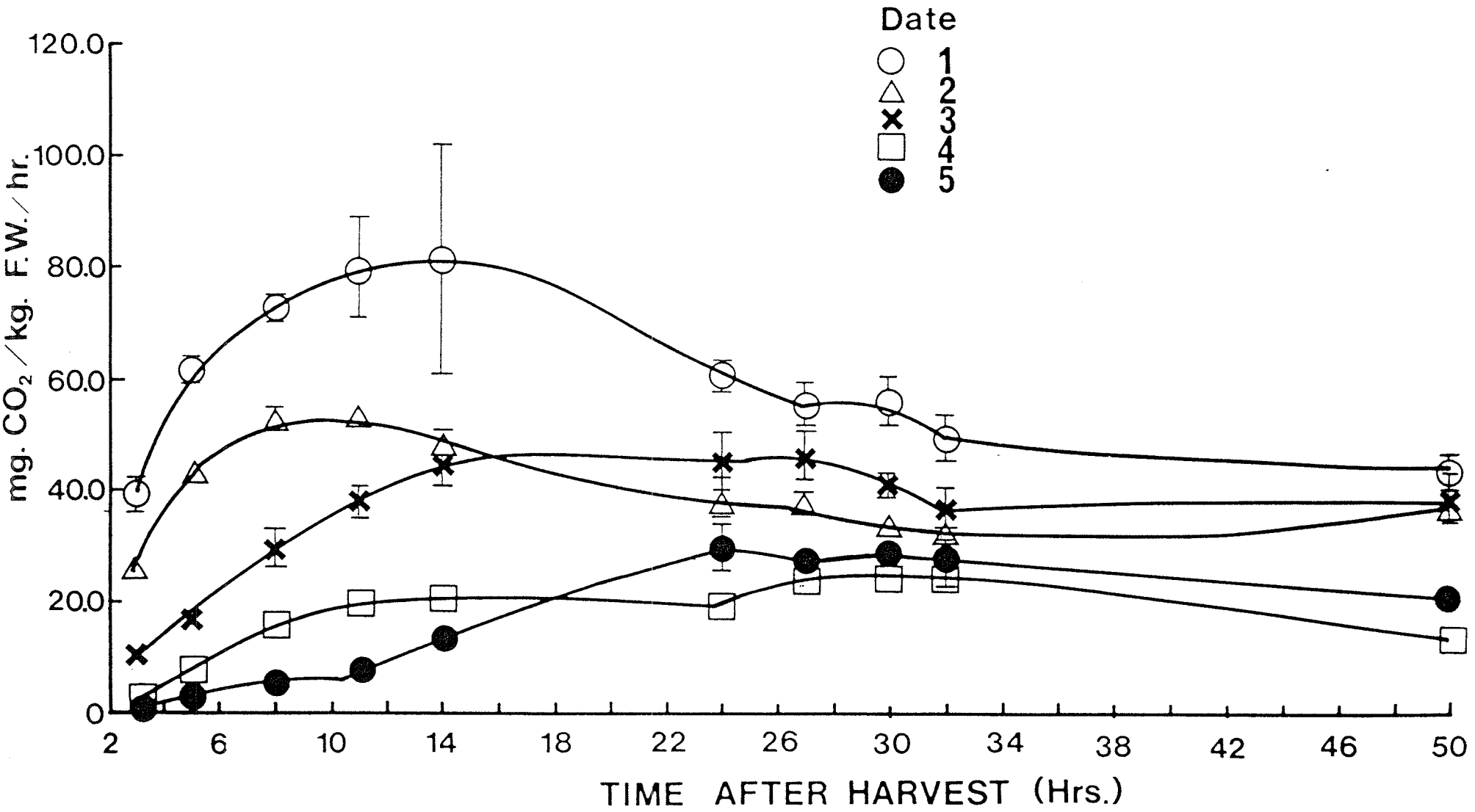

DATE
1
2
3
4
5
100
80
60
40
20
mg. $CO_2$ /kg F.W./hr.
6
10
14
18
22
26
30
34
38
42
46
50
TIME AFTER HARVEST (Hrs.)

Figure 4. $CO_2$ evolution of intact tubers of Russet Burbank soon after each harvest.

Date 1 = 24/8/83
Date 2 = 08/9/83
Date 3 = 24/9/83
Date 4 = 06/10/83
Date 5 = 11/10/83


Date
1
2
3
4
5
120.0
100.0
80.0
60.0
40.0
20.0
0
mg. $CO_2$ / kg. F.W. / hr.
2
6
10
14
18
22
26
30
34
38
42
46
50
TIME AFTER HARVEST (Hrs.)

This post harvest respiratory burst was observed for three and two early harvest dates of 'Norchip' and 'Russet Burbank', respectively. In the early harvested immature tubers, the increase in $CO_2$ evolution was rapid and the decline steep while in mature tubers, it was gradual with a plateau respiratory level (lower than for early harvested tubers) reached in about 26 hours. The changes in respiration rate or $CO_2$ evolution were thus characteristic for different states of tuber maturity.

From the data obtained, the rapid increase in $CO_2$ evolution after harvest of immature tubers indicated that these tubers were more susceptible to harvest shock than mature tubers which showed a gradual increase in $CO_2$ evolution. Kimbrough (1925), Singh and Mathur (1937 and 1938a,b) and Peterson et al. (1981) reported similar results. Since the skin of immature tubers is highly permeable and, susceptible to bruising and skinning at harvest (Singh and Mathur, 1938a and Burton, 1964), it may not be surprising that the immature tubers evolved more $CO_2$ than mature tubers. Secondly, there was a high content of sugars in immature tubers (Tables 6 and 7) and, since sugars play a major role in respiration of potato tubers (Craft, 1963 and Peterson et al., 1981), they may have contributed to the increased $CO_2$ evolution observed.

## 4.2 EFFECT OF BRUISING AND MATURITY ON RESPIRATION

Bruising of potato tubers by dropping the 100 g weight on the tubers induced a drastic increase in $CO_2$ evolution compared to intact tubers (Table 2). The mean total $CO_2$ elvolved by the tubers varied depending on the degree of bruising and, that released by bruised tubers was significantly higher than that released by intact tubers. The $CO_2$ evolution increased with the severity of bruising. The total $CO_2$ evolution by intact tubers of 40 and 36 increased to 54 and 51 mg $CO_2$/kg fw/hr in the severely bruised tubers of 'Norchip' and 'Russet Burbank', respectively. This represents an increase of 34-42% in $CO_2$ evolution by the severely bruised tubers over intact tubers in both cultivars.

In all treatments, the $CO_2$ evolution declined with maturity but the level of decline depended on the bruising treatment (Tables 3 and 4). Differences in $CO_2$ evolution as a result of different bruising treatment were observed throughout the growing season. Tubers that were bruised had significantly higher $CO_2$ evolution than intact tubers at each and every harvest date. The highest $CO_2$ evolution of 66 (30/08/83) and 92 (24/08/83) mg $CO_2$/kg fw/hr was observed with immature and severely bruised tubers of 'Norchip' and 'Russet Burbank', respectively. And the lowest $CO_2$ evolution of 20 (04/10/83) and 18 (11/10/83) mg $CO_2$/kg fw/hr was observed in intact, mature tubers of 'Norchip' and 'Russet Burbank', respectively. Therefore, other than maturity of the tubers, the differences in $CO_2$ evolution could mainly be attributed to the different levels of bruising.

TABLE 2. Overall means of $CO_2$ evolved by different bruising treatments of Norchip and Russet Burbank potatoes during growing season.

| Bruising level | Mean $CO_2$ evolved (mg $CO_2$/kg fw/hr) | | % Increase in $CO_2$ evolved with bruising | |
|---|---|---|---|---|
| | Norchip | Russet Burbank | Norchip | Russet Burbank |
| Intact tubers | 40 c* | 36 d | 0 | 0 |
| Bruised 2X | 44 b | 41 c | 10 | 14 |
| Bruised 10X | 54 a | 48 b | 34 | 32 |
| Bruised S | 54 a | 51 a | 34 | 42 |

* values within columns followed by the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).
2X = twice
10X= ten times
S = severely

In general, the increase in $CO_2$ released was proportional to the degree of bruising, regardless of the stage of maturity. Although the immature tubers released more $CO_2$ than the mature tubers, the effects of bruising were more pronounced as the tubers matured (Tables 3 and 4). For intance, the immature bruised tubers of 'Russet Burbank' harvested on 24/08/83 released 15-53% more $CO_2$ than intact tubers while the mature bruised tubers harvested on 11/10/83 released 22-78% more $CO_2$ than intact tubers. One would expect the mature tubers to produce less $CO_2$ when bruised, since in mature tubers the skin is set and the sugars are low (Burton, 1969). There are two explanations for this somewhat surprising observation. Firstly, the basal respiration was very much higher for intact tubers at the first harvest (49 and 60 mg $CO_2$/kg fw/hr) as compared to 20 and 18 mg $CO_2$/kg fw/hr at the final harvest date for 'Norchip' and 'Russet Burbank', respectively. Consequently small increase in $CO_2$ release due to bruising became more significant on on percentage basis for mature tubers. Secondly, the rapidly metabolizing immature tuber may more readily recover from imposed injury. This is clear from figures 5 and 6 which show the different respiration rates of intact and bruised tubers at each harvest date of immature and mature tubers of 'Russet Burbank' potatoes. Although the bruised immature and mature tubers respired at a higher rate than intact tubers, 48-50 hours after each harvest , all treatments of immature tubers (Fig. 5) were nonsignificant while the respiration rates of mature tubers (Fig. 6) differed significantly. Relations between injury and tuber respiration have also been noted by Wyse (1978), Wyse et al. (1979), Peterson et al. (1981), Pisarczyk (1982) and Shamaila et al. (1984 and 1985b).

TABLE 3. Effect of bruising on mean total respiration after each harvest of Norchip potatoes.

| Harvest date | $CO_2$ evolution (mg $CO_2$/kg fw/hr) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 15/8/83 | 49(100)#b* | 50(102) b | 58(118) a | - |
| 30/8/83 | 43(100) c | 57(133) b | 63(147) a | 66(153) a |
| 18/9/83 | 43(100) c | 42 (98) c | 53(123) b | 58(135) a |
| 30/9/83 | 34(100) c | 43(126) b | 53(156) a | 52(153) a |
| 04/10/83 | 20(100) c | 19 (95) c | 26(130) b | 33(165) a |

# Values in brackets are percentages of those of intact tubers.
* Values in rows followed by the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 4. Effect of bruising on mean total respiration after each harvest of Russet Burbank potatoes.

| Harvest date | $CO_2$ evolution (mg $CO_2$/kg fw/hr) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 24/8/83 | 60(100)#c* | 69(115) b | 72(120) b | 92(153) a |
| 08/9/83 | 41(100) d | 44(107) c | 52(127) b | 58(141) a |
| 24/9/83 | 35(100) d | 42(120) c | 52(149) a | 47(134) b |
| 06/10/83 | 17(100) c | 19(112) c | 25(147) b | 37(218) a |
| 11/10/83 | 18(100) d | 22(122) c | 27(150) b | 32(178) a |

# Values in brackets are percentages of those of intact tubers.
* Values in rows followed by the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).
2X =twice
10X=ten times
S =severely

Figure 5. $CO_2$ evolution soon after harvest of intact and bruised immature tubers of Russet Burbank potatoes.

2X = twice
10X = ten times
S = severely

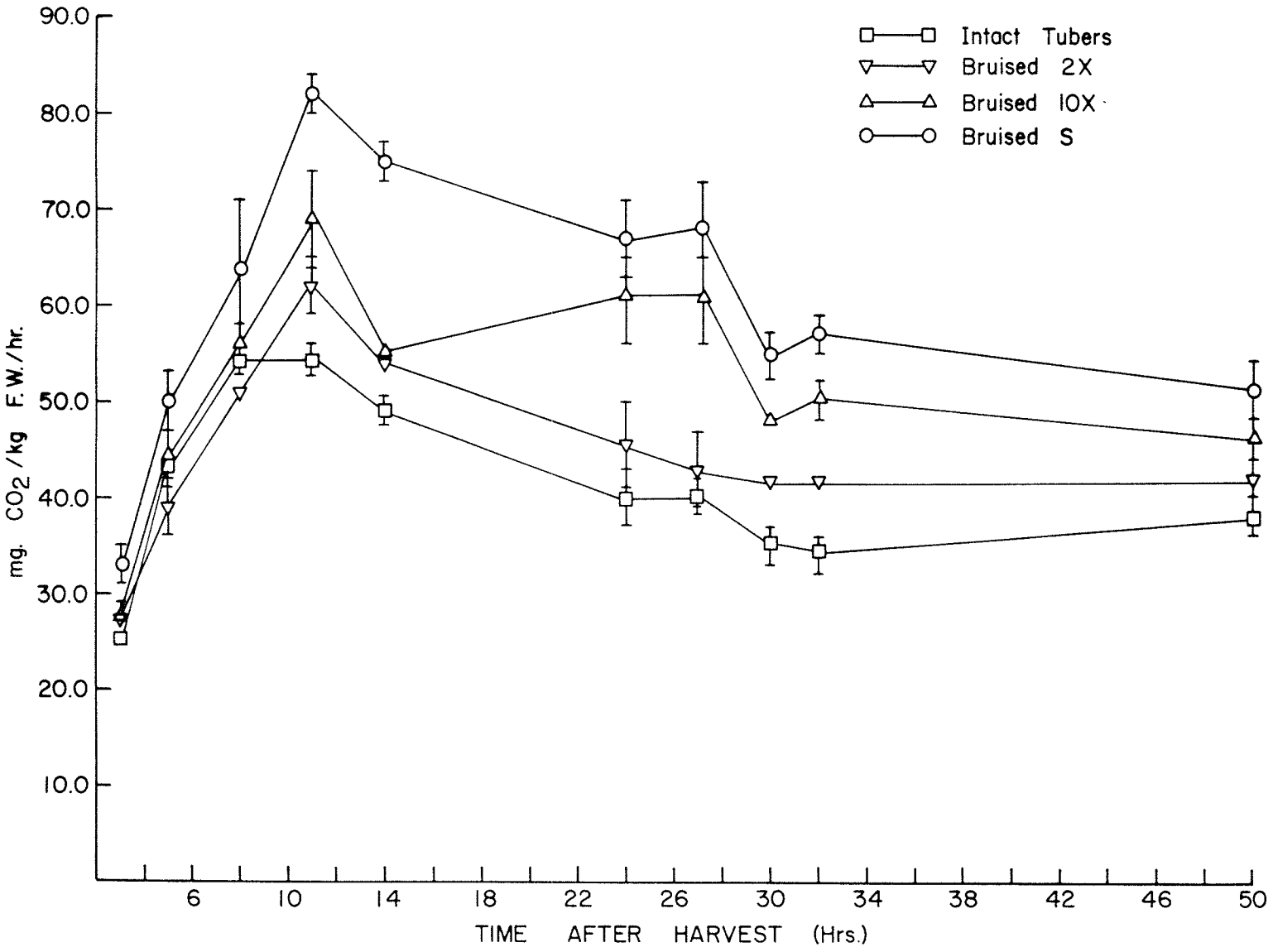
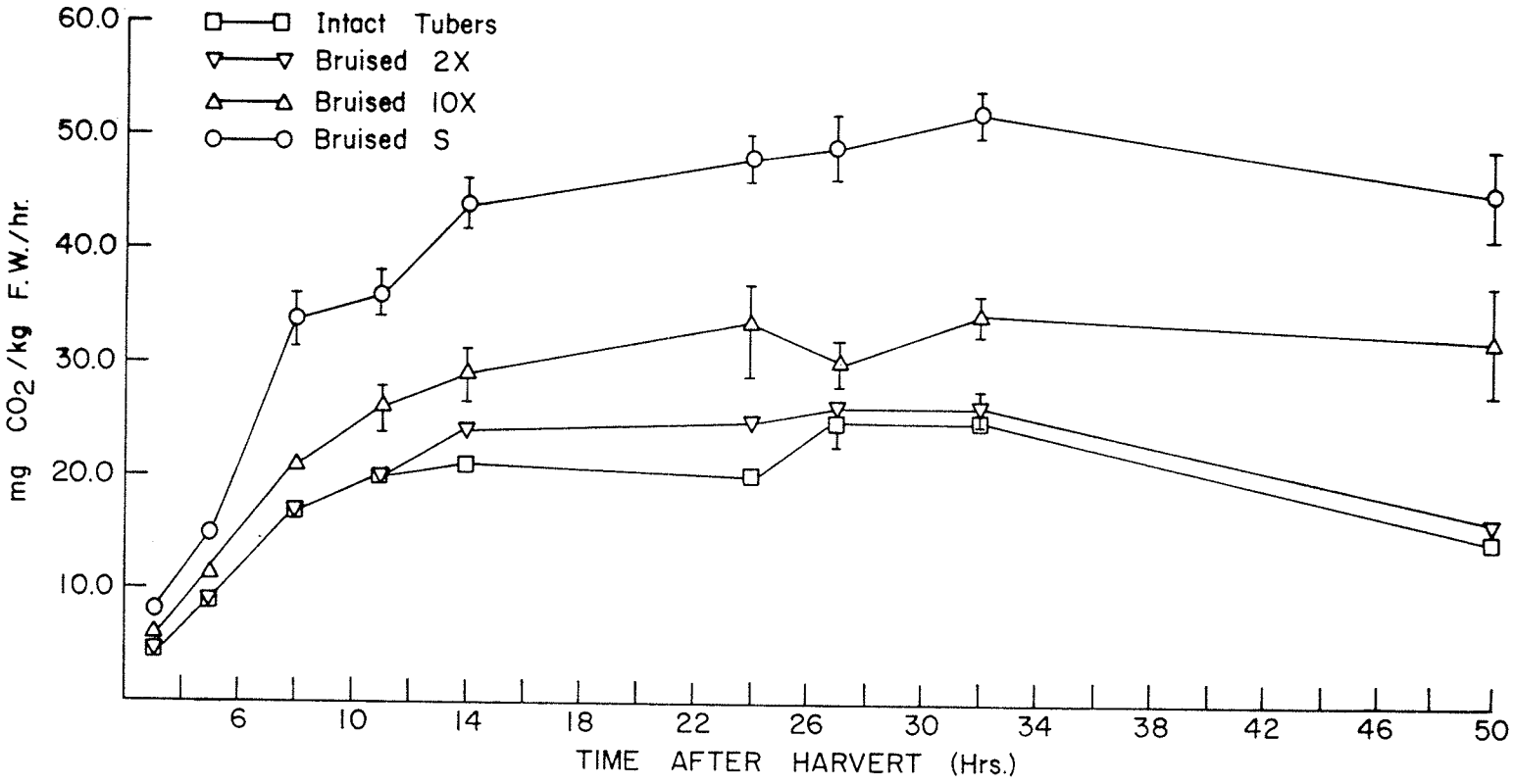

Intact Tubers
Bruised 2X
Bruised 10X
Bruised S
mg. $CO_2$ / kg F.W./hr.
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
6
10
14
18
22
26
30
34
38
42
46
50
TIME AFTER HARVEST (Hrs.)

Figure 6. $CO_2$ evolution soon after harvest of intact and bruised mature tubers of Russet Burbank potatoes.

2X = twice
10X = ten times
S = severely


Intact Tubers
Bruised 2X
Bruised 10X
Bruised S
60.0
50.0
40.0
30.0
20.0
10.0
mg $CO_2$/kg F.W./hr.
6
10
14
18
22
26
30
34
38
42
46
50
TIME AFTER HARVERT (Hrs.)

Since bruising of tubers damaged the skin and in the case of severely bruised tubers, most of the skin was removed, escape of $CO_2$ may have been greatly facilitated. Also, damage to the tissue may have induced metabolic activity as a result of a wounding response at the cellular level (Magness, 1920, Johnstone 1925 and Dilley et al., 1970). Therefore, both direct stimulation of metabolic changes and facilitation of gaseous exchange may have contributed to the increased $CO_2$ evolution that was observed for the bruised tubers in this studies.

## 4.3 CIPC TREATMENT AND $CO_2$ LEVELS IN COMMERCIAL STORAGE BINS

During the early part of storage just after the suberization period and, prior to closure of bins and application of CIPC sprout inhibitor, the $CO_2$ levels in the storage bins were about 0.2% (Table 5) and thus safe for storage of potato tubers (Schaper and Varns, 1978). With closure of bins and application of CIPC, the $CO_2$ level in the bins increased to as high as 0.384, 0.453 and 1.956% in 'Norchip' (bin 1) and 'Russet Burbank' (bins 2 and 3), respectively. Twenty-four hours after CIPC application, the bins were ventilated for approximately 2 hours and closed again for a period of 24 hours. Ventilation of bins for only 2 hours after the first and second day of sprout inhibitor application did not decrease the $CO_2$ to safe levels during the subsequent days. However, 6 days after CIPC application, the bins were opened and regular ventilation resumed and, the $CO_2$ levels in the bins began to decrease. Even then, the $CO_2$ levels did not return to the original level which existed prior to CIPC application.

The temperature was monitored and it did not increase during sprout inhibitor application. It may seem that, both bin closure and CIPC application caused some stress in stored tubers and this resulted in increased $CO_2$ release.

One would assume that the respiratory rate which contributed to bin $CO_2$ level would be lower after fumigation since CIPC is a respiratory inhibitor. However, the CIPC stimulated tuber respiratory rate with the peak bin $CO_2$ accumulation on the second day following treatment after which the bin $CO_2$ concentration began to decline to reach near safe

TABLE 5. $CO_2$ levels in storage bins containing Norchip and Russet Burbank potatoes prior to and after CIPC treatment.

| Sampling date | | | $CO_2$ Content (%) | | |
|---|---|---|---|---|---|
| BIN 1 & 2 | BIN 3 | | N BIN 1 | RB BIN 2 | RB BIN 3 |
| NOV 8 | - | | 0.095 e* | 0.088 g | - |
| NOV 14 | - | | 0.121 d | 0.188 e | - |
| NOV 17 | - | | 0.121 d | 0.154 f | - |
| NOV 21 | DEC 5 | | 0.131 d | 0.124 f | 0.224 d |
| NOV 25 | DEC 6 | BINS CLOSED | | | |
| NOV 30 | DEC 6 | CIPC APPLIED | | | |
| DEC 1 | - | | 0.204 c | 0.304 c | - |
| | | BINS VENTILATED 2hrs | | | |
| DEC 2 | DEC 8 | | 0.384 a | 0.453 a | 1.956 a |
| | | BINS VENTILATED 2hrs | | | |
| DEC 6 | DEC 12 | | 0.370 a | 0.381 b | 0.463 b |
| | | BINS OPENED | | | |
| DEC 12 | DEC 15 | | 0.204 c | 0.225 d | 0.387 c |
| DEC 15 | - | | 0.241 b | 0.244 d | - |

N = Norchip
RB = Russet Burbank
* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

levels as the bins remained open. The CIPC most likely exerted an indirect influence through damage to the tuber tissues rather than a direct influence on the reactions involved in the respiration process (Schippers, 1977a). Secondly, since the CIPC does not penetrate far beyond the surface cells (Corsini et al., 1979 and Wilson et al., 1981), it may have affected the permeabilty characteristics of the skin of potato tubers (Dilley et al., 1970).

## 4.4 QUALITY CHANGES OF POTATO TUBERS WITH MATURITY

The sucrose content and reducing sugars were significantly higher in the earlier harvested immature tubers of both cultivars (Tables 6 and 7). But these sugars tended to decline with the later harvest dates. There was a sharp decline in sucrose content of 'Russet Burbank' from 4.0 to 2.0 mg sucrose/g tuber. The reducing sugars of 'Russet Burbank' were very variable during the growing season and did not show a definite trend as shown by the 'Norchip' cultivar i.e. a decline with maturity. Of the two cultivars studied, 'Russet Burbank' seemed to have an inherently high content of sucrose and reducing sugars. This would suggest a distinct cultivar difference with regards to accumulation of sucrose during the growing season (Mazza et al., 1983). But it may also suggest an influence of environmental conditions and cultural practices (Agle and Woodbury, 1968 and Burton 1969). Although differences in sucrose content existed throughout the growing season between these two cultivars, the sucrose content declined to 1.6 and 2.3 mg sucrose/g tuber at the final harvest of 'Norchip' and 'Russet Burbank' respectively. This was well below 2.8 mg sucrose/g tuber proposed by

TABLE 6. Effect of maturity on some processing quality of intact tubers of Norchip potatoes.

| Harvest date | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| 15/8/83 | 1.8 ab* | 0.113 a | 61.2 a | 17.6 b |
| 30/8/83 | 2.1 a | 0.084 b | 61.8 a | 20.6 a |
| 18/9/83 | 1.5 b | 0.076 b | 62.5 a | 20.2 a |
| 30/9/83 | 1.4 b | 0.088 b | 55.0 b | 20.3 a |
| 04/10/83 | 1.6 b | 0.074 b | 61.7 a | 20.1 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 7. Effect of maturity on some processing quality of intact tubers of Russet Burbank potatoes.

| Harvest date | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| 24/8/83 | 4.0 a* | 0.230 a | 54.5 bc | 16.7 a |
| 08/9/83 | 2.6 b | 0.112 d | 59.2 a | 19.5 a |
| 24/9/83 | 2.6 b | 0.172 bc | 55.7 b | 18.1 a |
| 06/10/83 | 2.0 c | 0.209 ab | 52.8 c | 18.1 a |
| 11/10/83 | 2.3 c | 0.147 cd | 55.7 b | 17.7 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

Sowokinos (1978) as the maximum acceptable level for potatoes intended for long storage.

The chip colour of both cultivars remained relatively light and acceptable (above 40 Agtron units) through the growing season (Tables 6 and 7). One would expect the chip colour to improve with maturity, but in our experiment, the chips were light and acceptable at any harvest date. The 1983 growing season was very hot and dry and, this may have contributed to lighter coloured chips. Of the two cultivars, 'Norchip' had much lighter chip colour than 'Russet Burbank'. This can be attributed to the fact that 'Russet Burbank' had higher sugar contents throughout the growing season than 'Norchip'. Habib and Brown (1956), Sowokinos (1978) and Mazza et al., (1983) have all shown that sugars play a major role in colour of processed products.

The dry matter content was significantly lower in the earlier harvested tubers of 'Norchip', but increased with maturity and remained relatively high throughout the growing season without much change (Table 6). However, the increase in dry matter content of 'Russet Burbank' was nonsignificant (Table 7), and this may be attributed to variations between plants, environmental conditions and cultural practises. Rastovski and van Es (1981) reported increases in dry matter content with maturity. Tubers of the 'Norchip' cultivar had higher dry matter content than 'Russet Burbank' throughout the growing season. The high dry matter content coupled with low sugars may have contributed to the lighter chip colour observed in the 'Norchip' cultivar. Sayre et al. (1975), Lulai and Orr (1979) and, Lyman and MacKay (1961) observed that tubers with high dry matter content consistently produced chips of

lighter colour, high chip yield and decreased oil consumption than did tubers of low dry matter content.

## 4.5 EFFECT OF BRUISING AT HARVEST ON PROCESSING QUALITY OF TUBERS

Bruising of potato tubers tended to reduce the processing quality of potato tubers of both 'Norchip' and 'Russet Burbank' cultivars. Tables 8 and 9 show the mean total changes in processing quality of intact and bruised tubers during the growing season. Significant increases in sucrose levels occurred with bruised tubers of both cultivars. However, the two levels of bruising 2X and 10X which involved impact injury, may have resulted in greater damage than the abrasive action caused by the potato peeler.

By the final harvest date, the sucrose content of bruised tubers (2X, 10X and severely bruised) of 'Norchip' and 'Russet Burbank' had increased from 1.5 to 2.0 and 2.3 to 3.1 mg sucrose/g tuber respectively (Tables 18 and 22). Therefore, in 'Russet Burbank' the sucrose content had actually increased above the maximum acceptable level (2.8 mg sucrose/g tuber) for potatoes intended for long term storage (Sowokinos, 1978). The increased sucrose content due to bruising can have serious implications relative to the quality of stored potato tubers. Its generally recognized that the sucrose content of stored tubers is important in determining the ability of the tubers to process well after prolonged storage. The increase in sucrose of bruised tubers would lower the potential of the stored tubers to process well.

TABLE 8. Effect of bruising on quality of Norchip potatoes over all dates of harvest.

| Bruising level | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| Intact tubers | 1.7 c* | 0.089 a | 60.3 a | 19.7 a |
| Bruised 2x | 1.8 bc | 0.079 b | 58.4 b | 19.7 a |
| Bruised 10x | 2.0 a | 0.086 ab | 56.6 c | 19.3 ab |
| Bruised S | 1.9 ab | 0.079 b | 56.0 c | 18.9 b |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 9. Effect of bruising on quality of Russet Burbank potatoes over all dates of harvest.

| Bruising level | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| Intact tubers | 2.7 b* | 0.177 ab | 55.5 a | 18.0 a |
| Bruised 2X | 3.0 a | 0.171 b | 53.7 b | 18.0 a |
| Bruised 10X | 3.1 a | 0.196 a | 51.9 c | 17.5 a |
| Bruised S | 3.0 a | 0.184 ab | 52.5 c | 17.6 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).
2X =twice
10X=ten times
S =severely

The reducing sugar levels of all bruised tubers were very variable and showed no definite trend among the different bruising treatments (Tables 8,9,19 and 23). One would expect increased reducing sugars with bruised tubers. Pisarczyk (1982) also found extreme variability in sugars of bruised potato tubers and could not obtain any meaningful data from his bruising and respiration experiment.

Although chip colour values for all treatments were acceptable, significantly darker chips were obtained from the bruised tubers of both cultivars (Tables 8 and 9). At each and every harvest date, the 10X and severely bruised tubers of both cultivars produced chips that were significantly darker than those of intact tubers (Tables 20 and 24). This indicates that bruising of tubers adversely affected the chipping potential of potato tubers regardless of harvest date.

Since the reducing sugars did not significantly increase with bruising tubers (Tables 19 and 23), they may not have been the major cause of dark chips in bruised tubers. The major cause could have been the blemishes and dark wounds at areas of impact (plate # 2). These areas were very dark and this may be due to enzymatic browning as a result of high phenolic content of potato tubers (Reeve, 1968a, Hughes, 1980 and McIlroy, 1980).

Although there was variation in dry matter content loss between intact and bruised tubers of both 'Norchip' and 'Russet Burbank' potatoes at each harvest (Tables 21 and 25), the mean total dry matter content of 10X and severely bruised tubers significantly decreased in 'Norchip' cultivar (Table 8). This loss in dry matter content of bruised

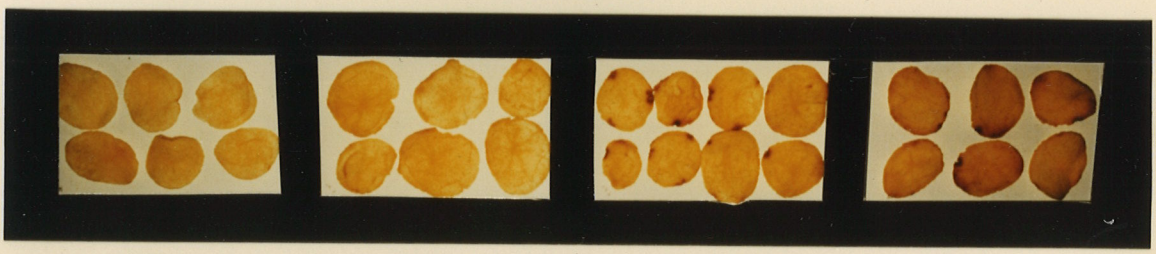
PLATE 2. The effect of bruising on chip colour of Norchip and Russet Burbank potatoes.

C = Intact tubers
B2 = Bruised twice
B10 = Bruised ten times
S = Bruised severely

RUSSET BURBANK

C B10 BS

NORCHIP



C B2 B10 BS

RUSSET BURBANK

C B2 B10 BS

tubers could be due to the high respiration rate of bruised tubers as observed in Tables 2,3 and 4 (Singh and Mathur, 1938a). This loss in dry matter content would also partly explain the poor chipping ability of the bruised tubers, since high dry matter content is associated with better processed potatoes (Lulai and Orr, 1979 and Lyman and MacKay, 1961).

## 4.6 EFFECT OF CIPC TREATMENT AND $CO_2$ ACCUMULATION ON QUALITY

Prior to CIPC application, the reducing sugars were low in both 'Norchip' and 'Russet Burbank' cultivars. With CIPC application, there was a sudden increase in reducing sugars especially in bin 2 of 'Russet Burbank' potatoes (Tables 10, 11 and 12). The increased reducing sugars after CIPC treatment coincided with increased $CO_2$ levels that were observed in the storage bins (Table 5). The reducing sugars increased from 0.077 to 0.107, 0.309 to 0.572 and 0.529 to 0.665% in 'Norchip' (bin 1) and 'Russet Burbank' (bins 2 and 3), respectively. Although the reducing sugars began to decline with time, three months after CIPC treatment (14/02/84), the sugars of 'Russet Burbank' (bin 2) had not reached initial concentrations prior to CIPC treatment. Craft and Audia (1959), Isherwood and Burton (1975) and Shamaila et al. (1985a) also reported increased sugars with CIPC treatment of potato tubers. They suggested that the increased sugars were an indication of damage to the tissues due to the chemical. The increase in sugars may also be a response to physiological stress caused by the CIPC treatment and increased $CO_2$ in the environment (Pressey, 1969, Shekhar and Iritani, 1978 and Mazza et al., 1983). However, there did not seem to be much

TABLE 10. Effect of CIPC treatment and $CO_2$ levels in storage bins on quality of Norchip potatoes (Bin 1).

| Sampling date | | Sucrose (mg/g fw) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|---|
| 08/11/83 | | 1.4 a* | 0.077 d | 62.0 ab | 20.6 e |
| 21/11/83 | | 1.4 a | 0.079 d | 59.3 c | 22.1 b |
| 30/11/83 | CIPC APPLIED | | | | |
| 01/12/83 | | 1.3 b | 0.107 a | 62.4 a | 21.4 c |
| 02/12/83 | | 1.4 a | 0.101 b | 62.0 ab | 22.4 a |
| 06/12/83 | | 1.3 b | 0.103 b | 52.5 d | 19.2 g |
| 12/12/83 | | 1.2 c | 0.087 c | 61.0 b | 20.7 d |
| 15/12/83 | | 1.2 c | 0.094 bc | 58.2 c | 20.3 c |
| 14/02/84 | | 1.0 d | 0.078 d | 62.0 ab | 20.4 f |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 11. Effect of CIPC treatment and $CO_2$ levels in storage bins on quality of Russet Burbank potatoes (Bin 2).

| Sampling date | | Sucrose (mg/g fw) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|---|
| 08/11/83 | | 1.7 a* | 0.313 d | 42.8 b | 18.7 f |
| 21/11/83 | | 1.7 a | 0.309 d | 46.5 a | 19.0 e |
| 30/11/83 | CIPC APPLIED | | | | |
| 01/12/83 | | 1.2 c | 0.572 a | 35.4 d | 19.7 b |
| 02/12/83 | | 1.5 b | 0.482 b | 37.4 c | 19.3 c |
| 06/12/83 | | 1.0 d | 0.418 c | 38.3 c | 20.1 a |
| 12/12/83 | | 0.9 d | 0.419 c | 38.3 c | 19.2 d |
| 15/12/83 | | 1.3 c | 0.417 c | 46.8 a | 18.1 f |
| 14/02/84 | | 1.0 d | 0.380 c | 39.8 c | 18.5 f |
| 01/05/84 | | 0.7 e | 0.240 e | 39.5 c | 18.2 f |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 12. Effect of CIPC treatment and $CO_2$ levels in storage bins on quality of Russet Burbank potatoes (Bin 3).

| Sampling date | Sucrose (mg/g fw) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| 05/12/83 | 1.5 b* | 0.529 d | 33.3 a | 19.5 d |
| 06/12/83 CIPC APPLIED | | | | |
| 08/12/83 | 0.9 d | 0.578 c | 33.1 a | 19.7 c |
| 12/12/83 | 1.3 c | 0.613 b | 26.5 b | 19.9 b |
| 15/12/83 | 1.9 a | 0.665 a | 23.2 c | 20.1 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

change in sucrose content of the tubers, although there was a general decline. Sucrose content of potato tubers has been found to decrease in storage until the end of dormancy (Burton, 1977).

The chip colour from tubers of both cultivars was light, acceptable and above 40 Agtron units prior to CIPC treatment in 'Norchip' (bin 1) and 'Russet Burbank' (bin 2). With CIPC treatment, the chips of 'Norchip' cultivar still remained light, acceptable chip colour. However, in 'Russet Burbank', the chips darkened and reached levels below 40 Agtron units which were unacceptable and in bin 3, tubers produced chips having a colour as low as 23.3 Agtron units. Six months after CIPC treatment (01/05/84), the chip colour from 'Russet Burbank' tubers (bin 2) could barely make the acceptable chip colour level (40 Agtron units). The dark colour observed in chips of 'Russet Burbank' could be attributed to the high reducing sugars accumulated in tubers after CIPC treatment. The CIPC chemical and increased bin $CO_2$ level may have injured the tubers or disturbed the metabolic equilibrium of the tubers and thus caused the increased sugar content observed (Craft and Audia, 1959, Burton, 1969, Isherwood and Burton, 1975 and Mazza et al., 1983).

There was a wide variation in dry matter contents of both cultivars after CIPC treatment. Therefore, no conclusive information could be obtained in regards to possible effects of CIPC on tuber dry matter.

Table 13 shows correlation coefficients between chip colour and other quality factors prior to and after CIPC treatment. Although there are variations among the cultivars studied in each bin regarding significant

TABLE 13. Correlation coefficients between chip colour and other quality parameters, prior to and after CIPC treatment of Norchip and Russet Burbank potatoes taken from storage bins.

| Quality parameters | Norchip (Bin 1) | Russet Burbank (Bin 2) | Russet Burbank (Bin 3) | Combined cultivars |
|---|---|---|---|---|
| Sucrose | 0.240 | 0.236 | -0.525 *** | 0.022 |
| Red. sugars | -0.231 | -0.771 *** | -0.754 ** | -0.966 *** |
| $CO_2$ | -0.447 * | -0.715 *** | 0.331 | -0.407 *** |

*,**,***,indicates significance at the 0.05,0.01 and 0.001 levels of probability, respectively.
Red. sugars = Reducing sugars.

correlation coefficients, its clear from the combined data from these cultivars that increased $CO_2$ levels in the bins and increased reducing sugars of the tubers prior to and after CIPC treatment corresponded to dark chips. Therefore, special attention should be paid to CIPC treatment and ventilation of bins during this critical period.

## 4.7 EFFECT OF BRUISING AT HARVEST AND STORAGE TIME ON QUALITY

In storage, sucrose content of both cultivars declined (Tables 14 and 15) while the reducing sugars of 'Russet Burbank' showed an increase after the CIPC sprout inhibitor was applied (12/12/83). The chip colour continued to darken in both cultivars and in 'Russet Burbank', the chip colours reached unacceptable levels of less than 40 Agtron units (Tables 14 and 15). The dry matter content did not appear to change much.

Bruising of tubers at harvest reduced the processing quality of stored tubers in the same way as during growing season. Tables 16 and 17 show the mean total change in processing quality of intact and bruised tubers during the whole storage period. Bruised tubers in both cultivars showed significantly higher sucrose content, dark chip colours and lower dry matter content. At each and every storage sampling date, the sucrose content tended to be significantly higher in bruised tubers while the reducing sugars showed wide variation (Tables 26,27,30 and 31). The chip colour was significantly darker in all bruised tubers at all storage sampling dates (Tables 28 and 32) and, by the final sampling date, the chip colour of severely bruised 'Russet Burbank' tubers was 25.3 Agtron units (Table 32). The dry matter content of bruised tubers in both cultivars was significantly lower at all sampling dates (Tables 29 and 33). The loss in dry matter content of bruised tubers may be attributed mainly to their high respiration rate. The loss in dry matter may have contributed to the poor chipping of bruised tubers observed in our studies.

TABLE 14. Effect of storage time on processing quality of intact tubers of Norchip potatoes.

| Sampling date | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| 08/11/83 | 1.4 a* | 0.077 a | 60.1 a | 20.7 a |
| 21/11/83 | 1.4 a | 0.079 a | 58.0 b | 20.7 a |
| 12/12/83 | 1.3 a | 0.087 a | 55.8 b | 20.7 a |
| 14/02/84 | 0.9 b | 0.073 a | 49.1 c | 20.4 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 15. Effect of storage time on processing quality of intact tubers of Russet Burbank potatoes.

| Sampling date | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| 08/11/83 | 1.7 a* | 0.311 c | 42.7 a | 18.7 a |
| 21/11/83 | 1.7 a | 0.309 c | 46.5 a | 19.0 a |
| 12/12/83 | 0.9 b | 0.419 a | 38.3 b | 18.1 a |
| 14/02/84 | 1.0 b | 0.374 b | 39.8 b | 18.3 a |
| 01/05/84 | 0.7 c | 0.245 d | 39.5 b | 18.0 a |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 16. Effect of bruising at harvest on processing quality of stored Norchip potatoes overall storage period.

| Bruising level | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| Intact tubers | 1.2 c* | 0.079 b | 60.9 a | 20.6 a |
| Bruised 2x | 1.4 b | 0.098 a | 55.7 b | 20.0 b |
| Bruised 10x | 1.5 b | 0.093 a | 54.8 c | 19.8 c |
| Bruised S | 1.7 a | 0.093 a | 53.0 c | 18.0 d |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 17. Effect of bruising at harvest on processing quality of stored Russet Burbank potatoes overall storage period.

| Bruising level | Sucrose (mg/g FW) | Reducing sugars (%) | Chip colour (Agtron units) | Dry matter (%) |
|---|---|---|---|---|
| Intact tubers | 1.2 b* | 0.332 b | 42.9 a | 18.7 a |
| Bruised 2X | 1.2 b | 0.373 a | 40.8 a | 17.7 b |
| Bruised 10X | 1.2 b | 0.329 bc | 37.4 b | 17.7 b |
| Bruised S | 1.4 a | 0.319 c | 35.6 b | 16.6 c |

* Values within columns with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).
2X =twice
10X=ten times
S =severely

The results of this study show that bruising of tubers at harvest will limit their potential to process well after storage. The combination of increased sucrose content, low dry matter content and discolored areas due to bruising would make it impossible to have good processed potatoes after storage.

## Chapter V

## SUMMARY AND CONCLUSIONS

From the results presented on respiration studies, readily discernible decreases in respiration rate of tubers of 'Norchip' and 'Russet Burbank' were observed as tuber maturity progressed. Immature tubers produced more $CO_2$ than mature tubers. This may be because of the greater permeability of the skin and high sugar content of immature tubers. The pattern of respiration after each harvest was distinct for immature tubers, in that a respiratory upsurge was observed for both cultivars. Respiration rates gradually increased to a plateau level for more mature tubers than earlier harvested, immature tubers which tended to have a higher plateau level. The tuber respiratory rate may be indicative of overall metabolism in the tuber and one would expect sucrose and reducing sugar levels to be relatively high with higher metabolic rates associated with tuber maturity. These trends of decreased respiratory rate and sugars with maturity were apparent in our data, but significant correlations were not consistently observed. However, by the final harvest, the respiratory rate had declined to low levels of 18-20 mg $CO_2$/kg fw/hr and the sucrose content had reached levels far below the maximum recommended (2.8 mg/g) for long term storage.

Although the $CO_2$ repiratory rate was high and declined with maturity, the chip colour was light and acceptable throughout the growing season

and the dry matter content noteably increased with maturity. In storage, the sucrose of both cultivars continued to decline, while the reducing sugars of 'Russet Burbank' drastically increased after CIPC treatment and the chips darkened without much change in dry matter content.

Physical damage (bruising) to potato tubers resulted in a significant increase in respiratory rate. The percentage increase in respiration for both 'Norchip' and 'Russet Burbank' as a result of bruising was greater as maturity progressed, although the absolute values decreased. The results of this study also indicate that the respiration measurements were an effective method for determining differences among various tuber maturity and injury treatments of tubers, since these differences were detected at any harvest time. Therefore, respiration may be a good index of potato maturity and also an indicator of the amount of injury that has been inflicted onto the tuber.

Considering quality, bruising of tubers resulted in significant increases in sucrose level in those tubers bruised at harvest and stored for short or long time. This may indicate increases in over all metabolism of bruised tubers. In 'Russet Burbank', the severely bruised tubers increased their sucrose content well above the acceptable maximum for long term storage. The bruised tubers also produced significantly dark chip colour at any time during the short or long storage period, and also the dry matter content of bruised tubers was significantly lower than intact tubers.

CIPC treatment of potato tubers was found to result in increased $CO_2$ levels in the storage bins. Although regular ventilation was resumed

after CIPC treatment, the $CO_2$ level in the bins remained at a higher level than before the treatment. This may be attributed to the sugars that increased in the tubers after CIPC treatment. A new higher respiratory level may therefore have been established. Secondly, CIPC may actually be a respiratory stimulant or may cause injury to the tubers and this could result in high activity of tubers and thus high $CO_2$ release as observed in this study. The high $CO_2$ levels in the storage bins corresponded to increases in reducing sugars of the tubers and the total effect led to dark processed potato chips which were unacceptable.

In conclusion, the results of this study reemphasize the importance of selecting proper harvesting dates and the extreme care that should be exercised in harvesting and handling to prevent bruising of tubers. Proper harvesting dates would allow harvesting of tubers with low sucrose content, tubers that would respire at lower rates and tubers that would be less susceptible to bruising. In addition, there is an important need to carry out research to modify the methods used to achieve sprout inhibition, since the increased $CO_2$ found after CIPC treatment resulted in poor processed chips. Shorter periods of bin closure and longer ventilation times could probably prevent the detrimental effects observed in this study.

## LITERATURE CITED


AGLE, W. M., and WOODBURY, G. W. 1968. Specific gravity-dry matter relationship and sugar changes affected by potato variety, production area and storage. Am. Potato J. 45:119-131.

AL-AISH, M. and BROWN, W. V. 1958. Grass germination responses to isopropylphenol carbamate and classification. Am. Jour. Bot. 45:16-23.

AMIR, J., KAHN, V and UNTERMAN, M. 1977. Respiration, ATP level, and sugar accumulation in potato tubers during storage at 4. Phytochemistry 16:1495-1498.

APPLEMAN, C. O., and SMITH, C. L. 1936. Effect of previous cold storage on the respiration of vegetables at higher temperatures. Jour. of Agric. Res. 53:557-580.

BASKER, D. 1975. Centigrade scale temperature corrections to the specific gravity of potatoes. Potato Res. 18:123-125.

BECKMAN. 1976. In, Addendum to Beckman Instructions (015-082438-A). Beckman Instruments, Inc., Fullerton. p. 14.

BOE, A. A., WOODBURY G. W. and LEE T. S. 1974. Respiration studies on Russet Burbank potato tubers: Effects of storage temperature and chemical treatments. Am. Potato J. 51:355-360.

BURTON, W. G. 1964. The respiration of developing potato tubers. Eur. Potato J. 7:90-99.

BURTON, W. G. 1969. The sugar balance in some British potato varieties during storage. II. The effects of tuber age, previous storage temperature, and intermittent refrigeration upon low-temperature sweetening. Eur. Potato J. 12:81-95.

BURTON, W. G. 1974. The oxygen uptake, in air and in 5% $O_2$ , and the carbon dioxide output, of stored potato tubers. Potato Res. 17:113-137.

BURTON, W. G. 1977. Senescence in stored potato tubers. Ann. Appl. Biol. 85:433-436.

CAYLEY, G. R., DENT, T., DUNNE, Y., LORD, K. A. and VOJVODIC, P. J. 1982. Uniformity of distribution and prevention of loss of potatoes in store by tecnazene. Potato Res. 25:285-291.

CLEGG, M. D., SULLIVAN, C. Y. and EASTIN, J. D. 1978. A sensitive technique for the rapid measurement of carbon dioxide concentration. Plant Physiol. 62:924-926.

CORSINI, D., STALLKNECHT, G. and SPARKS, W. 1979. Changes in chlorpropham residues in stored potatoes. Am. Potato J. 56:43-50.

CRAFT, C. C. and AUDIA, W. A. 1959. Some effects of isopropyl N-(3-chlorophenyl) carbamate on respiration, water uptake and ion leakage of potato tissue. Am. Potato J. 36:386-393.

CRAFT, C. C. 1963. Respiration of potatoes as influenced by previous storage temperature. Am. Potato J. 40:289-298.

CRAFT, C. C. 1967. Respiration of potato tissue as influenced by previous storage temperature of the tubers. Am. Potato J. 44:174-181.

DALZIEL, J., AITCHISON, T. C. and DUNCAN, H. J. 1980. Studies on potato sprout suppressants. 3. Effect of storage conditions on tecnazene residue levels in treated tubers. Potato Res. 23:335-344.

DILLEY, D. R., WOOD, R. R. and BRIMHALL, P. 1970. Respiration of sugarbeets following harvest in relation to temperature, mechanical injury and selected chemical treatment. Amer. Soc. of Sugarbeet Techn. Jour. 15:671-683.

DWELLE, R. B. and STALLKNECHT G. F. 1978. Respiration and sugar content of potato tubers as influenced by storage temperature. Am. Potato J. 55:561-571.

FITZPATRICK, T. J., PORTER, W. L. and HOUGHLAND, G. V. C. 1969. Continued studies of the relationship of specific gravity to total solids of potatoes. Am. Potato J. 46:120-127.

HABIB, A. T. and BROWN, H. D. 1956. Factors influencing the color of potato chips. Food Techn. 10:332-336.

HAIR, B. L. and GOULD, W. A. 1979. Recondition of cold-stored potato tubers as influenced by maturity. In, Food Processing and Technology 1979: A summary of research. Ohio Agric. Res. Dev. Center. 250:35-37.

HANES, C. S. and BARKER, J. 1931. The physiological action of cyanide. I. The effects of cyanide on the respiration and sugar content of the potato at 15$^0$ C. Proc. Roy. Soc. Lond. B. 108:95-118.

HOPE, G. W., MacKAY, D. C. and TOWNSEND, L. R. 1960. The effect of harvest date and rate of nitrogen fertilization on the maturity, yield and chipping quality of potatoes. Am. Potato J. 37:28-33.

HOPKINS, E. F. 1924. Relation of low temperature to respiration and carbohydrate changes in potato tubers. Bot. Gaz. 78:311-325.

HOWARD, F. D., LARBORDE, J. F., YAMAGUCHI, M. and KNOT, J. E. 1961. Studies of internal black spot of California-grown White Rose potato tubers. Proc. Am. Soc. Hort. Sc. 78:406-412.

HUBER, F. V. and GOULD, W. A. 1979. Relationship of sucrose content in raw potatoes to color of chips from stored potatoes. In Food Processing and Technology 1979: A summary of research. Ohio Agric. Res. Dev. Center. 250:32-34.

HUDSON, D. E. 1975. The relationship of cell size, intercellular space, and specific gravity to bruise depth in potatoes. Amer. Potato J. 52:9-14.

HUGHES, J. C. 1980. Role of tuber properties in determining susceptibility of potatoes to damage. Annal. Appl. Biol. 96:341-387.

HYDE, R. B. and MORRISON J. W. 1964. The effect of storage temperature on reducing sugars, pH, and phosphorylase enzyme activity in potato tubers. Am. Potato J. 41:163-168.

IRITANI, W. M. and WELLER, L. D. 1977. Changes in sucrose and reducing sugar contents of Russet Burbank tubers during growth and post harvest holding temperatures. Am. Potato J. 54:395-404.

ISHERWOOD, F. A. 1973. Starch-sugar interconvrsion in SOLANUM TUBEROSUM. Phytochemistry 12:2579-2591.

ISHERWOOD, F. A. 1976. Mechanism of starch interconversion in SOLANUM TUBEROSUM. Phytochemistry 15:33-41.

ISHERWOOD, F. A. and BURTON, W. G. 1975. The effect of senescence, handling, sprouting and chemical sprout suppression upon the respiratory quotient of stored potato tubers. Potato Res. 18:98-104.

IVENS, G. W. and BLACKMAN, G. F. 1949. The effects of phenylcarbamates on the growth of higher plants. In, Selective toxicity and antibiotics. Symposia of the Soc. for Exper. Biol. Academic Press. pp. 266-282.

JOHNSTONE R. G. 1925. Effect of wounding on respiration and exchange of gases. Bot. Gaz. 79:339-340.

KIMBROUGH, D. W. 1925. A study of respiration in potatoes with special reference to storage and transportation. Univ. Maryland Agric. Exper. Stat. Bulletin No. 276.

KIRKWOOD, R. C. 1976. Action on respiration and intermediary metabolism. In, Herbicides. Physiology, Biochemical, Ecology. Second Edition. Volume 1. Ed.(AUDUS, L. J.). Academic Press Inc. London. p. 462.

KOHL, R. 1983. Personal communication.

KUSHMAN, L. J. and HAYNES, Jr.,F. L. 1971. Influence of intercellular differences due to variety and storage upon tuber specific gravity-dry matter relationship. Am. Potato J. 48:173-181.

LARSEN, F. E. 1962. External and internal (blackspot) mechanical injury of Washington Russet Burbank potatoes from field to terminal market. Am. Potato J. 39:249-259.

LEACH, S. S. 1978. Quuality of stored potatoes improved by chemical treatment. Am. Potato J. 55:155-159.

LULAI, E. C. and ORR, P. H. 1979. Influence of potato specific gravity on yield and oil content of chips. Am. Potato J. 56:379-390.

LYMAN, S. and MacKAY, A. 1961. Effect of specific gravity, storage and conditioning on potato chip colour. Am. Potato J. 41:329-336.

MAAS, E. F. 1966. A simplified potato bruising device. Am. Potato J. 43:424-426.

MAGNESS, J. R. 1920. Composition of gases in intercellular spaces of apples and potatoes. Bot. Gaz. 70:308-316.

MARTH, P. C. and SCHULTZ, E. S. 1952. A sprout inhibitor for potato tubers. Am. Potato J. 29:268-272.

MAZZA, G., HUNG, J. and DENCH, M. J. 1983. Processing/Nutritional quality changes in potato tubers during growth and long term storage. Can. Inst. Food Sci. Technol. 16:39-44.

McILROY, D. C. 1980. Electron microscope studies of bruised and unbruised potato tuber tissue. Annal. Appl. Biol. 96:384.

MEADE, J. A. 1958. The effect of isopropyl N-(3-chlorophenyl) carbamate on the carbohydrate content of soybean plants. Weeds 6:66-67.

MICHAELS, W. H. 1932. Relation of lenticels and surface area to respiration in the potato tuber. Bot. Gaz. 94:416-418.

MONDY, N. I. and KOCH, R. C. 1978. Influence of nitrogen fertilizer on potato discoloration in relation to chemical composition. I. Lipid, potassium and dry matter content. J. Agric. Food Chem. 26:666-669.

MURFITT, R. F. A. and OBOBI, A. A. 1980. Delayed bruise development in potato tubers. Annal. Appl. Biol. 96:354.

NELSON, D. C. and SOWOKINOS, J. R. 1983. Yield and relationships among tuber size, sucrose and chip colour in six cultivars on various harvest dates. Am. Potato J. 60:949-958.

OHAD, I., FRIEDBERG, I., NE'EMAN, Z. and SCHRAMM, M. 1971. Biogenesis and degradation of starch. 1. The fate of the amyloplast membranes during maturation and storage of potato tubers. Plant Physiol. 47:465-477.

PAEZ, L. E. and HULTIN, H. O. 1970. Respiration of potato mitochondria and whole tubers and relation to sugar accumulation. J. Food Sc. 35:46-51.

PEREZ-TREJO, M. S., JANES, H. W. and FRENKEL, C. 1981. Mobilization of respiratory metabolism in potato tubers by carbon dioxide. Plant Physiol. 67:514-517.

PETERSON C. L., WYSE, R. and NEUBER H. 1981. Evaluation of respiration as a tool in predicting internal quality and storabilty of potatoes. Am. Potato J. 58:245-256.

PERLASCA, G. 1956. Chemical control of sprouting in white potatoes. Am. Potato J. 33:113-133.

PISARCZYK, M. J. 1982. Field harvest damage affects potato tuber respiration and sugar content. Am. Potato J. 59:205-211.

PORTER, W. L., FITZPATRICK, T. J. and TALLEY, E. A. 1964. Studies of the relationship of specific gravity to total solids of potatoes. Am. Potato J. 41:329-336.

PRESSEY, R. 1969. Role of invertase in the accumulation of sugars in cold-stored potatoes. Am. Potato J. 46:291-297.

RASTOVSKI, A. and van ES, A. 1981. In, Storage of potatoes. Post-harvest behaviour, storage design, storage practice, handling. Wageningen Centre for Agricultural Publishing and Documentation,1981. p. 37,82.

REEVE, R. M.,FORRESTER, J. L. and HENDEL, E. C. 1963. Histological analysis of wound healing in potatoes treated to inhibit sprouting I. CIPC (Isopropyl-N-3-Chlorophenyl Carbamate) treatments. J. Food Sc. 28:649-654.

REEVE, R. M. 1968a. Preliminary histological observation on internal blackspot in potatoes. 45:157-167.

REEVE, R. M. 1968b. Further histological comparisons of black spot, physiological internal necrosis, black heart, and hollow heart in potatoes. Am. Potato J. 45:391-400.

ROGERS-LEWIS, D. S. 1980. Methods of reducing damage in maincrop potatoes. Annal. Appl. Biol. 96:345-349.

ROSS, A. G. 1975. Dinitrophenol method for reducing sugars. In Potato Processing, Third edition, W.F. Talburt and O. Smith(Eds.) AVI Publishing Company, Inc., Westport, CT., p. 696-697.

SAYRE, R. N., NONAKA, M. and WEAVER, M. L. 1975. French fry quality related to specific gravity and solids content variation among potato strips within the same tuber. Am. Potato J. 52:73-82.

SAWYER, R. L. 1961. Relation of CIPC for potato sprout inhibition to internal sprouting of potatoes. Am. Potato J. 38:203-207.

SCHAPER, L. A. and VARNS, J. L. 1978. Carbon dioxide accumulation and flushing in potato storage bins. Am. Potato J. 55:1-14.

SCHIPPERS, P. A. 1971. Measurement of black spot susceptibilty of potatoes. Am. Potato J. 48:71-81.

SCHIPPERS, P. A. 1977a. The rate of respiration of potato tubers during storage I. Review of literature. Potato Res. 20:173-188.

SCHIPPERS, P. A. 1977b. The rate of respiration of potato tubers during storage. 3. Relationships between rate of respiration, weight loss and other variables. Potato Res. 20:321-329.

SHAMAILA, M. M., MAZZA, G. and La CROIX, L. J. 1984. Effects of maturity and bruising on $CO_2$ evolution, sugars and chip colour of potatoes. Can. Inst. Food Sci. J. 17:34(abs).

SHAMAILA, M. M., MAZZA, G. and La CROIX, L. J. 1985a. Effects of maturity, bruising and $CO_2$ levels in storages on quality of potato tubers. To be published in the Proceedings of 41st Annual meeting for Western Canadian Society for Horticulture.

SHAMAILA, M. M., MAZZA, G. and La CROIX, L. J. 1985b. Potato tuber respiration and quality as influenced by maturity and bruising. Submitted for Publication in American Potato Journal.

SHEKHAR, V. C. and IRITANI, W. M. 1978. Starch and sugar interconversion in SOLANUM TUBEROSUM L. I. Influence of inorganic ions. Am. Potato J. 55:345-350.

SHERMAN, M. and EWING, E. E. 1983. Effects of temperature and low oxygen atmospheres on respiration, chip color ,sugars, and malate of stored potatoes. J. Amer. Soc. Hort. Sci. 108:129-133.

SIMMONDS, N. W. 1977. Relations between specific gravity, dry matter content and starch content of potatoes. Potato Res. 20:137-140.

SINGH, B. N. and MATHUR, P. B. 1937. Studies in potato storage. I. Investigation of physiological and chemical changes during the development and ripening of potato tubers. Annal. Appl. Biol. 24:469-474.

SINGH, N. B. and MATHUR, P. B. 1938a. Studies in potato storage. II. Influence of (1) the stage of maturity of the tubers and (2) the storage temperature for a brief duration immediately after digging, on physiological losses in weight of potatoes during storage. Ann. Appl. Biol. 25:68-78.

SINGH, N. B. and MATHUR, B. P. 1938b. Studies in potato storage. III. Respiration of potato tubers during storage. Ann. Appl. Biol. 25:79-87.

SMITH, O. 1975. Potato Processing. Third Edition, W.F. AVI Publishing Company, Inc., Westport, CT., p. 310.

SMITTLE, A. D., THORNTON, E. R., PETERSON, L. C. and DEAN, B. B. 1974. Harvesting potatoes with minimum damage. Am. Potato J. 51:152-164.

SOWOKINOS, J. R. 1973. Maturation of SOLANUM TUBEROSUM L. I. Comparative sucrose synthetase levels between several good and poor processing varieties. Am. Potato J. 50:234-247.

SOWOKINOS, J. R. 1978. Relationship of harvest sucrose content to processing maturity and storage life of potatoes. Am. Potato J. 50:333-344.

STANCHEM Ltd. 1983. Winnipeg. Manitoba. Canada.

SWANSON, C. R., SHAW, W. C. and HUGHS, J. H. 1953. Some effects of isopropyl -(3-chlorophenyl) carbamate and an alkanolamine salt of dinitro ortho secondary butyl phenol on germinating cotton seeds. Weeds 2:178-189.

TALBURT, W. F. and SMITH, O. 1975. Potato Processing. Third Edition AVI Publishing Company, Inc., Westport, CT. p. 313-318.

TIMM, H., YAMAGUCHI, M., CLEGG, D. M. and BISHOP, C. J. 1968. Influence of high-temperature exposure on sugar content and chipping quality of potatoes. Am. Potato J. 45:359-365.

VAN HANDEL, E. 1968. Direct microdetermination of sucrose. Anal. Biochem. 22:280-283.

WILCOCKSON, S. J., GRIFFITH, R. L. and ALLEN, E. J. 1980. Effects of maturity on susceptibilty to damage. Annal. Appl. Biol. 96:349-353.

WILLS, R. B. H. and WIMALASIRI, P. 1979. Short pre-storage exposures to high carbon dioxide or low oxygen atmospheres for the storage of some vegetables. HortScience 14:528-530.

WILSON, H. J. and LINDSAY, M. A. 1969. The relation between specific gravity and dry matter content of potato tuber. Am. Potato J. 46:323-328.

WILSON, A. M., BUSHWAY, A. A. and BUSHWAY, R. J. 1981. Residue analysis of isopropyl N-(3-chlorophenyl)carbamate in fruits and vegetables using high-performance liquid chromatography. J. Agric. Food Chem. 29:746-749.

WORKMAN, M. and TWOMEY, J. 1967. The influence of oxygen concentration during storage on seed potato respiratory metabolism and on field performance. Proc. Amer. Soc. Hort. Sci. 90:268-274.

WORKMAN, M. and TWOMEY, J. 1969. The influence of storage atmosphere and temperature on the physiology and performance of 'Russet Burbank' seed potatoes. J. Amer. Soc. Hort. Sci. 94:260-263.

WORKMAN, M. and TWOMEY, J. 1970. The influence of storage on the physiology and production of Kennebec seed potatoes. Am. Potato J. 47:372-378.

WORKMAN, M., CAMERON, A. and TWOMEY, J. 1979. Influence of chilling on potato tuber respiration, sugar, o-dihydroxyphenolic content and membrane permeability. Am. Potato J. 56:277-288.

WYSE, R. E. 1978. Effect of injury on respiration and sucrose loss in sugarbeet roots during storage. J. Am. Soc. Sugar Beet Technol. 20:193,202.

WYSE, R. E. and PETERSON, L. C. 1979. Effect of injury on respiration rates of sugarbeet roots. J. Am. Soc. Sugar Beet Technol. 20:269-280.

ZAEHRINGER, V. M., CUNNINGHAM, H. H. and SPARKS, C. W. 1966. Sugar content and color of Russet Burbank potatoes as related to storage temperature and sprout inhibitors. Am. Potato J. 43:305-314.

# APPENDIX TABLES

## Chapter VI

## APPENDIX TABLES

TABLE 18. Mean sucrose content of intact and bruised tubers during growing season of Norchip potatoes.

| Harvest date | Sucrose content(mg/g) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 15/8/83 | 1.8 a* | 2.1 a | 2.2 a | - |
| 30/8/83 | 2.1 a | 2.2 a | 2.3 a | 2.2 a |
| 18/9/83 | 1.5 c | 1.6 bc | 2.1 a | 1.8 b |
| 30/9/83 | 1.4 b | 1.4 b | 1.7 a | 1.7 a |
| 4/10/83 | 1.6 a | 1.5 b | 1.7 a | 2.0 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 19. Mean reducing sugars of intact and bruised tubers during groqwing season of Norchip potatoes.

| Harvest date | %Reducing sugars | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 15/8/83 | 0.113 a* | 0.111 a | 0.090 b | - |
| 30/8/83 | 0.084 ab | 0.067 b | 0.095 a | 0.088 a |
| 18/9/83 | 0.076 a | 0.082 a | 0.076 a | 0.072 b |
| 30/9/83 | 0.088 a | 0.083 a | 0.076 a | 0.083 a |
| 04/10/83 | 0.074 a | 0.071 a | 0.060 b | 0.067 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 20. Mean chip colour of intact and bruised tubers during growing season of Norchip potatoes.

| Harvest date | Chip colour(Agtron units) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 15/8/83 | 61.2 a* | 58.2 a | 54.7 b | - |
| 30/8/83 | 61.8 a | 59.2 ab | 57.7 b | 58.3 b |
| 18/9/83 | 62.5 a | 61.3 a | 60.2 ab | 58.7 b |
| 30/9/83 | 55.0 a | 54.2 a | 52.5 c | 50.3 c |
| 4/10/83 | 61.7 a | 60.3 ab | 59.0 bc | 57.0 c |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 21. Mean dry matter content of intact and bruised tubers during growing season of Norchip potatoes.

| Harvest date | Dry matter content(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 15/8/83 | 17.6 a* | 17.5 a | 17.5 b | 16.4 b |
| 30/8/83 | 20.6 a | 20.7 a | 20.2 a | 20.1 a |
| 18/9/83 | 20.2 a | 20.1 a | 19.4 a | 19.5 a |
| 30/9/83 | 20.3 a | 20.4 a | 20.2 c | 19.6 b |
| 4/10/83 | 20.1 a | 19.9 b | 19.2 c | 19.2 c |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 22. Mean sucrose content of intact and bruised tubers during growing season of Russet Burbank potatoes.

| Harvest date | Sucrose content(mg/g) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 24/8/83 | 4.0 a* | 4.7 a | 4.7 a | 4.5 a |
| 08/9/83 | 2.6 a | 2.3 a | 2.7 a | 2.3 a |
| 24/9/83 | 2.6 b | 2.9 ab | 2.7 ab | 3.2 a |
| 06/10/83 | 2.0 c | 2.2 bc | 2.3 b | 2.6 a |
| 11/10/83 | 2.3 c | 3.1 a | 2.8 ab | 2.5 b |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 23. Mean reducing sugars of intact and bruised tubers during growing season of Russet Burbank potatoes.

| Harvest date | Reducing sugars(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 24/8/83 | 0.230 a* | 0.214 a | 0.228 a | 0.162 a |
| 08/9/83 | 0.123 b | 0.129 ab | 0.146 a | 0.125 ab |
| 24/9/83 | 0.172 a | 0.174 a | 0.178 a | 0.180 a |
| 06/10/83 | 0.209 a | 0.153 b | 0.219 a | 0.225 a |
| 11/10/83 | 0.147 b | 0.266 a | 0.235 a | 0.250 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 24. Mean chip colour of intact and bruised tubers during growing season of Russet Burbank potatoes.

| Harvest date | Chip colour(Agtron units) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 24/8/83 | 54.5 a* | 54.7 a | 50.8 b | 49.7 b |
| 08/9/83 | 59.2 a | 56.0 b | 53.2 b | 53.8 b |
| 24/9/83 | 55.7 a | 53.7 b | 52.8 b | 53.0 b |
| 06/10/83 | 52.7 a | 51.8 ab | 50.5 b | 51.2 ab |
| 11/10/83 | 55.7 a | 50.7 b | 52.0 ab | 54.0 ab |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 25. Mean dry matter content of intact and bruised tubers during growing season of Russet Burbank potatoes.

| Harvest date | Dry matter content(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 24/8/83 | 16.7 a* | 16.9 a | 16.1 a | 16.5 a |
| 08/9/83 | 19.5 a | 18.8 a | 18.6 a | 18.5 a |
| 24/9/83 | 18.1 a | 17.9 a | 17.6 a | 17.6 a |
| 06/10/83 | 18.6 a | 18.1 a | 18.1 a | 18.1 a |
| 11/10/83 | 17.7 b | 17.8 a | 16.7 d | 17.2 c |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 26. Mean sucrose content of intact and bruised tubers during storage of Norchip potatoes.

| Sampling date | Sucrose content(mg/g) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 12/10/83 | 1.4 a* | 1.6 a | 1.7 a | 1.6 a |
| 08/11/83 | 1.4 d | 1.8 c | 2.0 b | 2.3 a |
| 21/11/83 | 1.3 b | 1.5 ab | 1.5 ab | 1.7 a |
| 12/12/83 | 0.9 b | 0.9 b | 0.9 b | 1.2 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 27. Mean reducing sugars of intact and bruised tubers during storage of Norchip potatoes.

| Sampling date | %Reducing sugars | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 12/10/83 | 0.077 b* | 0.089 ab | 0.092 a | 0.090 a |
| 08/11/83 | 0.079 b | 0.096 a | 0.089 ab | 0.090 a |
| 21/11/83 | 0.087 b | 0.090 b | 0.120 a | 0.091 b |
| 12/12/83 | 0.073 c | 0.117 a | 0.070 c | 0.091 b |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 28. Mean chip colour of intact and bruised tubers during storage of Norchip potatoes.

| Sampling date | Chip colour(Agtron units) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 12/10/83 | 62.0 a* | 60.1 ab | 59.1 b | 59.7 b |
| 08/11/83 | 59.5 a | 58.0 a | 55.2 b | 55.4 b |
| 21/11/83 | 61.0 a | 55.8 ab | 55.5 ab | 53.0 b |
| 12/12/83 | 61.0 a | 49.1 b | 49.6 b | 43.7 c |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 29. Mean dry matter content of intact and bruised tubers during storage of Norchip potatoes.

| Sampling date | Dry matter content(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 12/10/83 | 20.7 a* | 20.3 b | 20.4 b | 19.4 c |
| 08/11/83 | 20.7 a | 19.4 c | 19.7 b | 18.4 d |
| 21/11/83 | 20.7 a | 20.0 b | 19.9 b | 18.3 c |
| 12/12/83 | 20.4 a | 20.1 b | 19.0 c | 16.0 d |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 30. Mean sucrose content of intact and bruised tubers during storage of Russet Burbank potatoes.

| Sampling date | Sucrose content(mg/g) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 08/11/83 | 1.7 a* | 1.3 b | 1.5 ab | 1.6 ab |
| 21/11/83 | 1.7 ab | 1.8 ab | 1.7 b | 1.9 a |
| 12/12/83 | 0.9 c | 1.0 bb | 1.1 b | 1.5 a |
| 14/02/84 | 1.0 a | 1.0 ac | 1.1 a | 1.1 a |
| 01/05/84 | 0.7 b | 0.8 a | 0.8 a | 0.8 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 31. Mean reducing sugars of intact and bruised tubers during storage of Russet Burbank potatoes.

| Sampling date | Reducing sugars(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 08/11/83 | 0.311 b* | 0.481 a | 0.301 b | 0.265 b |
| 21/11/83 | 0.309 c | 0.352 b | 0.205 d | 0.450 a |
| 12/12/83 | 0.419 a | 0.321 a | 0.420 a | 0.250 c |
| 14/02/84 | 0.374 a | 0.376 a | 0.415 a | 0.294 b |
| 01/05/84 | 0.245 b | 0.333 a | 0.302 ab | 0.338 a |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 32. Mean chip colour of intact and bruised tubers during storage of Russet Burbank potatoes.

| Sampling date | Chip colour(Agtron units) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 08/11/83 | 42.7 b* | 53.0 a | 43.6 b | 42.0 b |
| 21/11/83 | 46.5 a | 44.0 a | 41.6 a | 40.3 a |
| 12/12/83 | 47.2 a | 45.1 a | 35.3 b | 38.3 b |
| 14/02/84 | 39.1 a | 34.8 a | 31.5 b | 32.0 b |
| 01/05/84 | 39.0 a | 27.0 b | 35.0 ab | 25.3 b |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

TABLE 33. Mean dry content matter of intact and bruised tubers during storage of Russet Burbank potatoes.

| Sampling date | Dry matter content(%) | | | |
|---|---|---|---|---|
| | Intact | Bruised 2X | Bruised 10X | Bruised S |
| 08/11/83 | 18.7 a* | 18.0 c | 18.5 b | 17.0 d |
| 21/11/83 | 19.0 a | 17.9 b | 17.6 c | 17.2 d |
| 12/12/83 | 19.6 a | 18.0 b | 18.0 b | 16.9 c |
| 14/02/84 | 18.3 a | 17.4 b | 17.2 c | 16.1 d |
| 01/05/84 | 18.0 a | 17.2 b | 17.0 c | 16.0 d |

* Values within rows with the same letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).