ISBN 0-315-54871-1

MOISTURE, POTASSIUM, AND MATURITY EFFECTS ON BRUISING AND PROCESSING QUALITY OF RUSSET BURBANK POTATOES (*Solanum tuberosum* L.)

BY

LLOYD C. MWANAMWENGE

A Thesis
submitted to the Faculty of Graduate Studies
in partial Fulfillment of the requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

MOISTURE, POTASSIUM AND MATURITY EFFECTS ON BRUISING AND PROCESSING QUALITY OF RUSSET BURBANK POTATOES (*SOLANUM TUBEROSUM* L.)

BY

LLOYD C. MWANAMWENGE

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

The University of Manitoba requires the signatures of all persons using or photocopying this publication. Please sign below, and give address and date.

DEDICATION

This thesis is dedicated to my wonderful parents who introduced me to the fountain of knowledge, my dear wife Martha who has been very supportive, and my darling daughter Chileshe whose smiles have been inspiring and heart warming during the preparation of this thesis.

ACKNOWLEDGEMENTS

My sincere appreciations go to my advisor Dr. M.K. Pritchard for the good guidance and advice he gave me during both the field work and preparation of this thesis.

Special thanks go to Mr. Lorne Adam for always being there when I needed his advice and help, and Drs. L.J. Lacroix and M.G. Britton for serving on my committee and giving me valuable advice.

The assistance given to me by Dr. R.D. Hill of Plant Science in allowing me to use facilities in his laboratory, Mr. J. Rogers and Ms. Donna Ryland of Food Science for assisting me and allowing me to use the facilities in their laboratories, is highly appreciated.

Dr. Shaykewich of the Soil Science department was very helpful during the course of my field work by providing me with advice and equipment without which part of this thesis would not have been completed.

Thanks are due to Mr. I. Brown for supplying me greenhouse facilities and some field equipment for part of my work, and Mr. B. Morgan of Agricultural Engineering for preparing the materials for the structures that were used in the moisture stress experiments.

The financial support provided by the Canadian Commonwealth Fellowship Committee is deeply acknowledged.

Lastly but not the least, I would like to thank all my professors at this University, the administrative staff in Plant Science and the Faculty of Graduate Studies, and friends for contributing in one way or another towards the realization of this thesis.

You are all wonderful people.

ABSTRACT

Mwanamwenge, Lloyd Chileshe, Msc., The University of Manitoba, May 1989. Moisture, Potassium, and Maturity Effects on Bruising and Processing Quality of Russet Burbank Potatoes (*Solanum tuberosum* L.). Advisor: Dr. M.K. Pritchard.

Field experiments were conducted at two locations in southern Manitoba during 1987 and 1988 to investigate the effect of soil moisture, potassium (K), and maturity on bruising susceptibility and processing quality of potato (*Solanum tuberosum* L.) cultivar Russet Burbank. Tubers were bruised in the laboratory by impacting them at two different impact velocities. Quality parameters such as degree of bruise, specific gravity, and sucrose and reducing sugars content were measured. Soil moisture content was also measured in an attempt to define and relate moisture levels to bruising and processing color.

The different levels of K applied did not have any significant effects on sucrose levels. Rather, harvest date greatly determined sucrose levels within the tubers. Sucrose levels were higher at the earliest harvest and dropped drastically at later harvest dates. Harvest sucrose content varied between the seasons depending on the environmental conditions.

Total reducing sugar levels in the tubers were lower when 245 kg K/ha was applied as compared to the lower levels of 95 and 145 kg K/ha. Though not significant, chip color was highest in quality in the 245 kg K/ha treatment at the final harvest, and the 95 kg K/ha treatment consistently showed the lowest chip quality at all harvests. Harvest date affected chip quality in that the earliest harvested tubers produced darker chips upon direct chipping from the field.

K, harvest date, energy of impact, and soil moisture had an effect on bruising. The number of shattered tubers increased with higher impact energy (higher drop height of impact bar). At the low impact energy, the resistance to bruising increased from the first harvest (August 8, 1988) to the second harvest (August 29, 1988) and generally declined by the third harvest (September 21, 1988). At final harvest K at 145 kg/ha resulted in the most resistance to bruising and the 195 kg/ha rate as the least resistant to bruising or which shattered with later harvests. Tubers from plots receiving 195 and 245 kg K/ha had the greatest resistance to bruising at the final harvest (September 21).

Field moisture levels between field capacity (238 mm) and permanent wilting point (76 mm) in the moisture stress trial did not significantly affect chip color and all treatments produced acceptable chip color. Lower soil moisture conditions during harvesting are important as they aid in overriding some effects of high impact energy, resulting in less bruising.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Approximately 18,000 ha of potatoes are grown annually in Manitoba. The crop has a farm value of $40 - 45 million, 80% of which is utilised by the processing industry. Potatoes are by far the most important of the vegetable crops in Manitoba in terms of quantities produced and consumed. Injury to tubers has been a major cause of quality reduction in potatoes and has received great attention in recent years. Changing economic times have forced the industry to reassess its processing operations and to impose more rigid quality standards wherever feasible, in order to minimise the significant monetary losses incurred as a result of bruises.

Mechanical damage or bruising to potato tubers has been identified as a major contributor to economic losses incurred by the industry. Bruising losses of 5 - 20% occur annually in potato tubers and directly affect the processor in two ways; firstly there is loss of finished product through the gradeout operation, and secondly there is increased labor requirements in the gradeout operation. Originally, internal bruising was considered only as a storage problem compared to external bruising which was conspicuously recognised as a harvesting and handling problem. But now this internal injury has been identified as occurring at the producer level and the processing industry is now taking steps through incentive payments to redirect the processing losses back to the producer. External and internal tuber blemishes are scored as grade defects, even though the nutritional value of the tubers is not affected by these disorders, because the poor appearance of these tubers reduce consumer and processor acceptance and lowers the economic value of the crop (Hiller et al., 1985).

Factors such as turgor pressure, temperature, specific gravity, mineral nutrition, cultivar type, and maturity affect bruise susceptibility of tubers (Hiller et al., 1985; Kunkel and Dow, 1961; Kunkel and Gardner, 1959,1965; Sawyer and Collin, 1960). Bruise damage is believed to be a direct result of machinery use during the harvesting process. Machine adjustments skills such as chain speed and travel speed have been shown to compound the extent of bruise damage.

Reducing sugar content in potato tubers is associated with color of the processed product (Hyde and Shewfelt, 1960). Undesirable dark brown color in processed products is caused by large amounts of reducing sugars (glucose and fructose) which react with amino acids during the frying process (Talburt and Smith, 1975).

The objectives of this study were to relate tuber maturity, potassium fertility, and soil moisture levels to bruise susceptibility and processing quality of Russet Burbank potatoes. Quality parameters such as degree of bruise, specific gravity, and sucrose and reducing sugars (glucose and fructose) contents were measured. Soil moisture content was also measured in an attempt to define and relate moisture levels to bruising and processing color.

Chapter II

LITERATURE REVIEW

Bruising and fry or chip color of potatoes are influenced by environmental factors such as soil moisture, fertilizers, and temperature during growth. Tuber maturity and condition of machinery during harvesting also affect bruising and processing quality of potatoes.

2.1 BRUISE DAMAGE

Bruising is defined as damage to plant tissue by external forces causing change in texture and/or eventual chemical alteration of color and flavor (Mohsenin, 1986).

2.1.1 Types of damage

Bruise damage of potatoes can be divided into two categories: firstly external damage or bruising (including skin damage), splits, and crushing injury, and secondly internal damage or bruising. Hiller et al.(1985) classify bruise damage as consisting of blackspot (with internal blackspot, bruise, blue discoloration, blue spotting, internal grayspot, and stem-end blackening as synonyms), shatter bruise (with tissue cracking as a synonym), and pressure bruise (with pressure spot as its synonym). Pressure bruise may have the characteristics of either blackspot or shatter bruise depending on how the tuber responds to the pressure exerted by adjacent tubers in storage. Thus two distinct types of tuber damage result from a bruising force: blackspot and shatter bruise.

In blackspot, the skin is unbroken and the affected area is not visible. After the bruised area is cut a bruised area becomes visible which is normally characterised by a bluish/ black discoloration. Shatter bruise can be recognised as a cracking of the tuber flesh. The cracking may extend to the outer surface presenting the appearance of small multiple fissures or splits in the tuber. Damaged cells around the margins of the fissures may discolor similarly to the damaged cells in blackspot. Pressure bruises are slightly sunken areas that occur in storage at the points of contact between tubers or between tubers and the storage structure. The bruised areas are caused by dehydration of these areas. Severe pressure bruises are extremely susceptible to blackspot if bruised during handling following storage (Gray and Hughes, 1978).

2.1.2 Causes of bruise damage

Injury to tubers occurs during harvesting and subsequent handling operations due to impact with machinery. Distance of fall, size and shape of tubers, area of contact, chain speeds, and soil conditions must all be considered in order to minimise bruise damage (Hesen and Kroesbergen, 1960; Smittle et. al., 1974).

Much work has been done on blackspot (an internal discoloration) but it is not fully understood why certain tubers are more disposed to the disorder than others. Research on the causes of blackspot has produced conflicting results and the causes can not be fully explained. Hiller et al.(1985), in their review article on causal factors of blackspot, give evidence of these differences as partly due to use of different methods for tuber bruising and discoloration evaluation by researchers as well as lack of accounting for some important causal or related factor. The inherent fertility status of the soil, soil moisture level, vine and root condition or tuber flesh temperature at harvest, or specific gravity affect blackspot development. A number of cultural and environmental factors influence the rheological properties of tubers and therefore affect bruise damage. Factors such as turgor pressure, temperature, specific gravity, mineral nutrition, cultivar type, and tuber maturity affect bruise susceptibility of tubers (Hiller et. al., 1985; Kunkel and Dow, 1961; Kunkel and Gardner, 1959, 1965; Sawyer and Collin, 1960).

2.1.3 Bruising studies

In a study by Larsen (1961) in the Columbia basin in 1960, it was discovered that 78% of the potatoes having either external injuries or blackspot were injured during harvest.

Robertson (1970), in trying to explain the underlying causes of blackspot, suggested that blackspot takes place in tubers with strong skin but with a weak underlying tissue. Firmness, turgor pressure, and specific gravity have been consistently shown to be related to blackspot. Blackspot susceptibility is increased when the turgor pressure is reduced by water loss through drying conditions in the field or storage (Kunkel and Gardner, 1959, 1965). Nilsson et al.(1958) attributed the role of turgor in influencing blackspot as due to its effect on the mechanical properties of the tissue. Cells with a low turgor pressure deform to a greater extent under a given force than cells with a high turgor pressure. Visibly flaccid tubers fail to develop blackspot when bruised. Conflicting results were observed by Wright (1957) who found a shortage of soil moisture as being a contributing factor to blackspot.

Hiller et. al. (1985) conclude that many factors that affect these physiological disorders in potatoes are related to tuber hydration. By adjusting cell turgor, tubers can be made either susceptible or resistant to black spot and shatter bruise. 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 turgid tubers were more susceptible to cracking and splitting. Smittle et. al. (1974) found that blackspot damage susceptibility was minimal with turgid tubers. Although blackspot susceptibility was low in hydrated (turgid) tubers, it increased with dehydration while shatter bruising decreased with tuber dehydration. Increase in dry matter content or specific gravity with maturity results in increased susceptibility to bruising (Wilcockson et al., 1980). Hughes (1980) makes the conclusion that there is a fine balance in the water relations of potatoes when the tubers are most resistant to damage (i.e. when too turgid they crack, and when too flaccid they suffer from black spot).

Thornton (1979) reports that the biggest weakness in assessing bruise susceptibility with respect to hydration of tubers is that it is difficult to identify the state of hydration of the tubers except at the extremes i.e. either dehydrated or hydrated. Bruising of tubers can seriously affect the quality of tubers in storage.

The periderm of immature tubers is highly permeable and susceptible to skinning and bruising (Burton, 1964). Pisarczyk (1982) did some studies and found that the respiration rate of injured tubers increased by 50% over unbruised tubers. The increase in respiration due to external damage or bruising may be due to the damage of the epidermis which would greatly facilitate the entrance of oxygen to the tissues and allow the escape of accumulated carbon dioxide in the tuber tissues (Magness, 1920). The increased respiration rate may be affected by such factors as temperature and maturity. Singh and Mathur (1938) found a greater loss in weight due to respiration of immature tubers in comparison to mature tubers.

Mechanical damage during the harvesting operation is a major cause of losses of potatoes during storage. Damaged tubers respire more than undamaged tubers and they easily develop internal black spot which increases under common storage conditions (Pisarczyk, 1982). Tubers that have been harvested before maturity are more prone to bruising during harvesting, packaging, and loading. This favors rapid respiration which may increase the rate and amount of soft rot which develops under conditions of inadequate aeration, especially in compacted loads of tubers packaged for consumer use (Nielson, 1968). Lack of adequate aeration to remove CO_2 can occur in storage bins as well.

External bruising is known to result in infection of tubers by pathogenic organisms resulting in pink rot and bacterial soft rot. Bacterial soft rot is the more serious of the two diseases and damage from soft rot is more serious in wet years. The soft rot organisms in the soil adhere to tubers at harvest and invade tubers through injuries. Infected tubers can spread the disease to healthy ones in storage via the ooze of bacteria produced in infected tubers (Hodgson et. al., 1974).

Pisarczyk (1982) found that damaged tubers had a decreased sucrose content 10 days after harvest. Differences in susceptibility to both internal and external bruising are known to exist between cultivars but the reasons are not understood. Rheological properties of tuber tissue within and between cultivars have not differentiated bruise susceptibility (Sawyer and Collin, 1960; Gray and Hughes, 1978).

2.1.4 The bruising process

Under conditions of stress (sufficient impact), damage to the cortical parenchyma cells occurs. This damage to the cells disorganises the cell contents resulting in chemical reactions between polyphenol oxidase enzymes and phenyl substrates (tyrosine and chlorogenic acid) to form conjugate quinones, which in turn polymerise to produce the bluish/ black pigment melanin (Raper, 1927; Mulder, 1955). Discoloration begins soon after injury, changing from pink to rusty red within 6 to 10 hours. Maximum discoloration occurs about 24 hours later after which color changes are minor (Hiller et al., 1985).

2.2 POTASSIUM EFFECTS ON BRUISING

Potassium (K) affects tuber susceptibility to blackspot. The reduced susceptibility of tubers with adequate K to blackspot is attributed to differences in the properties of cell walls, cell size, and specific gravity which make the tissue resistant to damage even at dynamic deformations which cause cell damage in tubers from low K treatments. It is possible that K itself may have a direct effect on the extensibility of the cell walls as has been shown for other plants (Probine and Preston, 1962).

Hiller et al. (1985) allude to the effect of K on blackspot as being on the chemical composition of the tuber cells and also indirectly through the foliage. As support for their supposition they point to work by Kunkel et al. (1973) and Harris (1978) who have reported that there is no major shift in mineral element content of tubers regardless of the amount of nitrogen, phosphorus, or K applied or the cultivar used. Hiller et al. (1985) therefore state that these findings suggest that the effect of mineral elements is more directly on the vines and only indirectly on the tubers through their influence on vine and root condition and consequently on tuber hydration. They claim high K levels in the vines could also reduce transpiration, and that phosphorus, calcium, magnesium, and several of the minor elements have had little or no effect on blackspot.

In earlier work, Kunkel and Dow (1961) reported that cores cut from tubers grown on K-deficient soils discolor and reach final color sooner than those cut from tubers grown in high K soils. They conclude that K allows a plant to more effectively absorb water from the soil and make the tissue less susceptible to desiccation. They also found that increasing K in the fertilizer from 1 to 450 kg/ha of K_2O decreased blackspot with corresponding decreases in specific gravity. K from muriate of potash and from potassium sulfate gave similar results. Dunn and Nylund (1945) showed that muriate of potash lowers dry matter content of potatoes.

2.3 MOISTURE EFFECTS ON BRUISING

2.3.1 Excess moisture

Kunkel and Gardner (1965) report that resistance of Russet Burbank potatoes to blackspot is associated with turgor. Potatoes grown under high soil moisture content have greater resistance to blackspot. When plant tops were removed, tuber weight increased apparently due to water absorption by the tubers. White-Stevens and Smith (1945) found that irrigation appeared to increase the frequency and severity of blackspot. Hughes (1980) reported that turgid tubers were more susceptible to cracking and splitting.

2.3.2 Reduced moisture

Kunkel and Gardner (1959) reported that withholding water when the vines are still green tends to dehydrate the tubers making them flaccid and spongy at the basal end and turgid toward the apical end. Thus when transpiration exceeds water uptake through either low soil moisture, poor functioning root system, or hot dry days, green vines tend to dehydrate the tubers.

The main concern in moisture stress trials is to calculate the amount of plant available water held in the soil over the experimental period. Available water is the total amount of water in the soil that can be extracted from the profile for plant growth and maturing processes (Jamison, 1956), or water between field capacity (F.C.) and permanent wilting percentage (P.W.P.). Field capacity is defined as the amount of water held in soil after excess water has drained away and the rate of downward movement has stopped, which usually takes place within 2 - 3 days after a rain or irrigation in pervious soils of uniform structure and texture (Veihmeyer and Hendrickson, 1949). Permanent wilting percentage (P.W.P.) is that soil water content at which soil cannot supply water at a sufficient rate to maintain turgor and the plant permanently wilts (Baver, 1956). P.W.P is the lower limit of soil water available for growth, but not the lower limit of water available to plants, i.e. plants continue to absorb water beyond P.W.P.

2.4 FACTORS AFFECTING CHIP COLOR

2.4.1 Sucrose and reducing sugar concentrations

Timm et. al. (1968) report that high concentrations of sucrose enhance darkening of chips during the frying process. Sucrose is non-reducing and therefore does not directly contribute to chip darkening itself. The reducing sugars (glucose and fructose) resulting from hydrolysis of sucrose combine with amino acids during frying to cause darkening of processed products (Maillard reaction). Sucrose content is used to determine processing quality of tubers as it is the intermediate product in the formation of reducing sugars from starch (Sowokinos, 1973).

Translocated to the tubers from the foliage, sucrose is the major free sugar present in all growing potatoes. Thus all potatoes have high sucrose levels during their growth period.

Iritani and Weller (1977) report that reducing sugars were present in relatively small amounts in freshly harvested tubers only during the early sampling dates. Tubers harvested during early sampling dates had high levels of sucrose which decreased at the later sampling dates.

2.4.2 Soil fertility

Mondy and Koch (1978) report that increasing nitrogen fertilizer resulted in discolored chips. Hope et. al. (1960) also found that potato fields receiving less nitrogen matured earlier and produced whiter chips. They also found that K content significantly increased the crude lipid and phospholipid content in both the pith and cortex tissues and K-fertilized fresh tubers discolored less than control tubers. Thus low K will indirectly contribute to chip color through enzymatic darkening of harvested tubers. Enzymatic discoloration can be a source of blemishes in processed potato products (Reeve, 1968).

2.4.3 Specific gravity of tubers

Tuber dry matter content is also an important factor in processed potato products such as chips. Layman and Mackay (1961) state that potatoes with high specific gravity produce chips of lighter color than do potato tubers with low specific gravity. This is confirmed by Schwimmer et al. (1954) who found that as specific gravity of Russet Burbank increased the percentage of reducing sugars decreased. Because of its importance, specific gravity is used as a measure of the total solids and starch content by the processing industry (Fitzpatrick et. al., 1969).

2.4.4 Moisture stress

Iritani (1981) points out that color of processed products can also be detrimentally influenced by stress, such as low moisture. Miller and Martin (1985) evaluated the effect of early season water stress on subsequent growth and internal defects in Russet Burbank potatoes. They found that there were trends to increased internal defects such as brown center early in the season as the amount of irrigation water increased. Hiller et al. (1982,1985) showed that high soil moisture contents during tuber initiation increased brown center when accompanied by low soil temperatures. Such physiological disorders result in tissue discolorations that are sources of blemishes in processed potato products (Reeve, 1968).

Chapter III

MATERIALS AND METHODS

3.1 FIELD STUDIES

The potato cultivar Russet Burbank was grown at two locations in southern Manitoba during 1987 and 1988. The moisture stress trial was located on an Almasippi loamy fine sand soil at Graysville (NW 26 - 6 - 6 in 1987, and SW 35 - 6 - 6 in 1988), whereas the K-trial was located on a Willowcrest loamy fine sand soil at Bagot(NW 30 - 11 - 9 in 1987, and SW 29 - 11 - 9 in 1988). In 1987 seed pieces were planted on May 20 in both experiments while in 1988 plantings were done on June 6 and May 19 for the K and moisture stress trial, respectively. The seed pieces were all planted 45 cm apart in rows 1 m apart for the K-trial and 90 cm apart for the moisture trial.

3.1.1 K-trial

In 1987 the K-trial received an overall broadcast application of 62 kg/ha nitrogen (N) and 89 kg/ha phosphorus (P) before planting. K was broadcast applied at 50, 100, 150, and 200 kg/ha before planting. In 1988, an overall broadcast application of 75 kg/ha N and 55 kg/ha P was done before planting. K was broadcast applied at 95, 145, 195, and 245 kg/ha before planting. The trials were arranged as randomised complete blocks with four replications. The main plots consisted of K and the subplots consisted of three harvest dates (two weeks apart in 1987, and three weeks apart in 1988). Each plot size was 7 m wide and 16 m long and consisted of 9 rows (three harvest rows with guard rows on either side). An extra guard row was added on either side of the experimental unit. Thus each plot had two guard rows on either side.

3.1.2 Moisture trial

In 1987 the original moisture stress trial at Bagot had to be abandoned because one week before beginning the treatments received excessive rainfall which left the area submerged under water. The experiment was moved to Graysville where a site with potatoes already growing was acquired.

The trials were arranged as randomised complete blocks with four replications. Three levels of moisture were achieved using translucent polyethylene tunnels to keep out precipitation on one treatment and provide excessive moisture through runoff onto the treatment at the drip line of the structure. The third treatment was a control which was subjected to the normal moisture conditions. Each structure was tunnel-like in shape with dimensions of about 3.75 m x 3.75 m x 1.8 m. It was made of four arch-shaped metal pipes

90 cm apart and 1.8 m high at the centre. The width of the structure (which was the distance of each arch at its widest base) was about 3.75 m. Three rows were completely covered by the structure. The polyethylene cover was rolled back on all sides up to 1 m above the plant canopy. The rolled part of the polyethylene was stapled on to wooden supports which were attached to all sides of the structures at 1 m above the canopy. The orientation of the structures was east-west.

In 1988 the moisture stress experiment received an application of fertilizer at 50, 70, and 80 kg/ha of N, P, K, respectively, at planting. In the 1988 trial some modifications were made to the moisture trial. The drip line was not used as a treatment and instead a drip irrigation line was laid out beside each structure to provide the excessive moisture treatment. This modification was necessary as a precaution against excessive dry weather which was experienced at this site in 1987. Soil samples were taken at 5 depths (0 - 15 cm, 15 - 30 cm, 30 - 45, 45 - 60, and 60 - 90 cm) to determine moisture content every two weeks beginning the day the structures were installed over the plots. Two sample holes were made per treatment resulting in 30 samples/plot. Thus a total of 120 subsamples were collected on each sampling day.

3.1.3 Harvesting

Harvesting of the moisture stress trial was done one month after imposing the treatments. Tubers from the moisture trial were harvested on Sept. 29 in both 1987 and 1988. The K-trials were harvested on August 18, Sept. 2 and Sept. 16 for the 1987 trial, and August 8, August 29 and September 21 for the 1988 trial.

To avoid damage to the tubers, a fork was used to lift the tubers from the ground, and tubers handled carefully to minimise impact during transportation. After washing, the tubers were analysed for specific gravity. Juice was extracted from the tubers and frozen for sucrose and reducing sugars analysis later. Samples for bruise susceptibility were stored for about two weeks to allow the tuber temperature to equilibrate to about 10° C. Tubers for chip color were left at room temperature overnight and chipped the following day. Moisture content was determined for tubers from the moisture stressed trial on the same day.

3.2 MEASUREMENT OF SPECIFIC GRAVITY

Specific gravity was determined by weighing the tubers in air and water:

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

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

% dry matter content = 2.2 + 49.1U, where,
G = Specific gravity

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

% dry matter was used to convert the sugar concentrations after HPLC from mg/mL of juice to mg/g fresh weight of tuber.

3.3 TUBER MOISTURE DETERMINATION

The method used to determine tuber moisture was according to Ghadge et al. (1987). Three tubers from each treatment were peeled and cut laterally into two parts. Each half was passed through a french fry cutter which produced sticks of square cross-section (10 mm X 10 mm). These were then cut into cubes and two samples of approximately 15 g were drawn from the pool of cubes. The weighed samples were then placed in a single layer in aluminium dishes and dried in a convection oven at 130° C for 12 h. The moisture content was expressed as a percentage on wet basis.

3.4 CALCULATION OF SOIL MOISTURE CONTENT

According to Haussenbuiller (1985) the amount of moisture held in a soil is often expressed gravimetrically as a percent of the oven dry weight of the soil as follows:

$$\%W = \frac{\text{Weight of water in sample (g)}}{\text{Oven dry sample weight (g)}} \times 100$$

where %W = percentage moisture by weight.

The wet soil samples (from various depths) weighing approximately 300 g were weighed, dried in a convection oven at 110^0 C for about 48 h, cooled, and weighed again. The difference in weight is the weight of water in the soil. Percent moisture on a weight basis (W%) of the soil was then converted to a volume measurement and expressed in terms of percent moisture on a volume basis as follows:

$$Q\,\% = \frac{Ww}{Vs + Vv} \times 100 = \frac{Ww}{Ws} \times \frac{Ws}{Vs + Vv} \times 100$$

Q% = percent moisture on a volume basis
Ww = weight of water
Vv = volume of voids
Ws = weight of oven dry soil
Vs = volume of soil solids

$$\text{Bulk density} = \frac{Ws}{Vs + Vv} = \frac{\text{mass of dry soil (g)}}{\text{volume of soil (cm}^3\text{)}}$$

Bulk density was determined by removing a block of soil from the field, using a bucket auger, and the volume of the hole from which the soil sample was removed was measured.

This was done for every depth to be sampled. The soil cores were weighed and sub-samples were taken from each core for soil moisture determination. Thus the soil cores, of which the volume is known, and the dry weight determined from the subsamples, have their bulk densities calculated as above.

3.5 DETERMINATION OF FIELD CAPACITY AND PERMANENT WILTING POINT

Field capacity was determined by preparing samples of air-dried soil according to Shaykewich (Soil Physics laboratory manual, University of Manitoba). The samples for each soil depth were initially passed through a 2 mm sieve. Acrylic cylinders were filled with the soil to within 2 cm of the top. The weight and volume of the soil was computed. Water was then slowly added to each sample until the wetting front had moved one third the way down the sample. Each of the containers was then covered with parafilm to prevent evaporation. After about 48 h, the gravimetric water content of the wetted portion of each sample was determined by drying them at 110° C to constant weight. Using the computed volume, weight of air-dried soil and the air-dry water content, the average bulk density of the soil and then the volumetric field capacity were calculated.

The permanent wilting point for each soil depth was determined by growing tomato plants in the samples again according to Shaykewich (Soil Physics laboratory manual, University of Manitoba). Soil was added to within 2 cm of the top of plastic containers, and tomato seedlings were transplanted through the holes in the lids of the containers. The containers were placed in a pan of water for a while until the water entering through the bottom hole of the containers had brought the entire soil sample to field capacity. The containers were then placed in the greenhouse and watered regularly until the plants were about 30 cm in height. Axillary buds and blossoms that appeared were stripped off during this period of growth. Then the soil was watered to field capacity and left without watering thereafter. Daily measurements of the length and maximum width of the leaves on the top three branches of each plant were made. Plants were removed from the soil when dimensions of the leaves were the same as those on the previous day. All the soil was then placed into previously weighed beakers. The mass of the wet soil was computed and then the soil dried at 110° C for 48 h after which the water content as a percentage by weight of the dry soil was calculated.

3.6 SUCROSE AND REDUCING SUGARS ANALYSIS

The high performance liquid chromatography (HPLC) determination of fructose, glucose, and sucrose in the potatoes was done using a modified method after Wilson et. al. (1981).

3.6.1 High performance liquid chromatography

A Beckman liquid chromatograph, model 322 (Berkeley, CA.), equipped with dual pumps, a refractive index detector, and a microprocessor system control were used. The carbohydrate analysis column consisted of a 300 x 7.8 mm Aminex HPX-87P heavy metal from Bio-Rad Laboratories (Richmond, CA.). A Spectra-physics computing integrator, model SP 4100 was used to record the signal from the detector. A Haake L water bath equipped with a Haake 3 temperature control unit kept the column temperature at 85° C. Operating conditions were as follows:

flow rate - 0.6 mL/min

column temperature - 85° C

mobile phase - filtered degassed double distilled water

operating pressure - 900 to 1000 psi

The flow rate and the pressure limit were automatically controlled by the microprocessor system control. Before running the samples the reference cell of the detector was flushed with the degassed water for at least 30 min.

3.6.2 Standard preparation

A standard containing the three sugars (sucrose,glucose, and fructose) was prepared by adding about 100 mg of each sugar to 25 mL double distilled water to produce a standard solution of approximately 4 mg/mL. A 10 mL aliquot of the standard was mixed with 10 mL of methanol, followed by centrifugation at 15,000 rpm for 15 min. 10 mL of the supernatant was brought to dryness using a rotoevaporator at a temperature of 45^0 C, and then redissolved in 10 mL of distilled water. A Waters Associates C_{18} Sep Pak (Milford, MA), was prepared by passing 5 mL methanol followed by two 5 mL of distilled water through it. 4 mL of the standard was passed through the Sep Pak, and discarded. Then 5 mL of the standard was passed through the same Sep Pak and collected. 50 uL of this standard was used for HPLC analysis of the sugars in the standard.

3.6.3 <u>Sample preparation</u>

A centre cut from each of six uniform sized tubers from each treatment was removed, peeled, and cut into french fry-like sections which were then sliced into smaller pieces. Basal and apical portions were discarded due to the relative differences in sugar content of these parts (Iritani et al., 1973). A 200 g random sample was extracted using an Olympic fruit and vegetable juicer, model # 1000 (San Dimas, CA), and collected in a 500 mL beaker. The juice above the starch deposit was then gently mixed and a 15 - 20 mL aliquot was drawn and immediately frozen at -20^0 C until further analysis.

On the day when the samples were analyzed, the frozen samples were thawed and mixed, and a 10 mL aliquot drawn for preparation. The sample was prepared for HPLC analysis as described for the standards. One sample per replication was analyzed. Since both glucose and fructose contribute to chip color development concentrations of the the two sugars were combined and analysed as 'total reducing sugars'.

3.7 BRUISE TESTING

3.7.1 Bruising device

The device used to bruise the potato samples was developed by Kevin Mason of the Department of Agricultural Engineering, University of Manitoba during the summer of 1986. Modifications were undertaken during the summer of 1987 to correct problems which existed in the original design (Ghadge, 1988). A sketch of the device is given in Figure 1. The bruising device used an impact bar and a catch mechanism. The impact bar (Figure 2) was made out of a picker bar from a harvester so as to make sure the potatoes are impacted in a similar manner to that which would occur in the harvester. Ball bushings were used for a smooth fall of the impact bar. A catch mechanism was used to hold the impact bar after the first impact. The main components of the bruising device are described below.

1. **Main Frame**

   The steel main frame is made of four threaded support rods held between the top and the bottom plates.

The plywood back of the frame had a number of holes to hold the release mechanism at different drop heights. At the centre of the frame two smooth finished shafts guided the fall of the impact bar. Two linear solenoids were fixed in the lower portion of the support rods to catch the impact bar. The frame was supported at the bottom by a heavy tile base to give stability to the frame.

2. **Impact Bar Release Mechanism**

The impact bar release mechanism was fixed horizontally on the plywood back and the impact bar rested on its shaft. The shaft was manually controlled to release the impact bar.

3. **Catch Mechanism**

A catch mechanism was devised to catch the bar after first impact to ensure that the test sample was impacted only once. It consisted of two linear solenoids with catch levers and a magnetic release switch (Figure 1). A transistor mounted on the extension rod and a magnet fixed on the main frame comprised the magnetic release switch. They were positioned in such a way that during the first impact of a sample the transistor would move past the magnet thus closing a switch which activated the solenoids. The activated solenoids lifted the catch levers which, in turn, lifted the two extension rods and the impact bar along with it.

Figure 1: Front view of bruising device

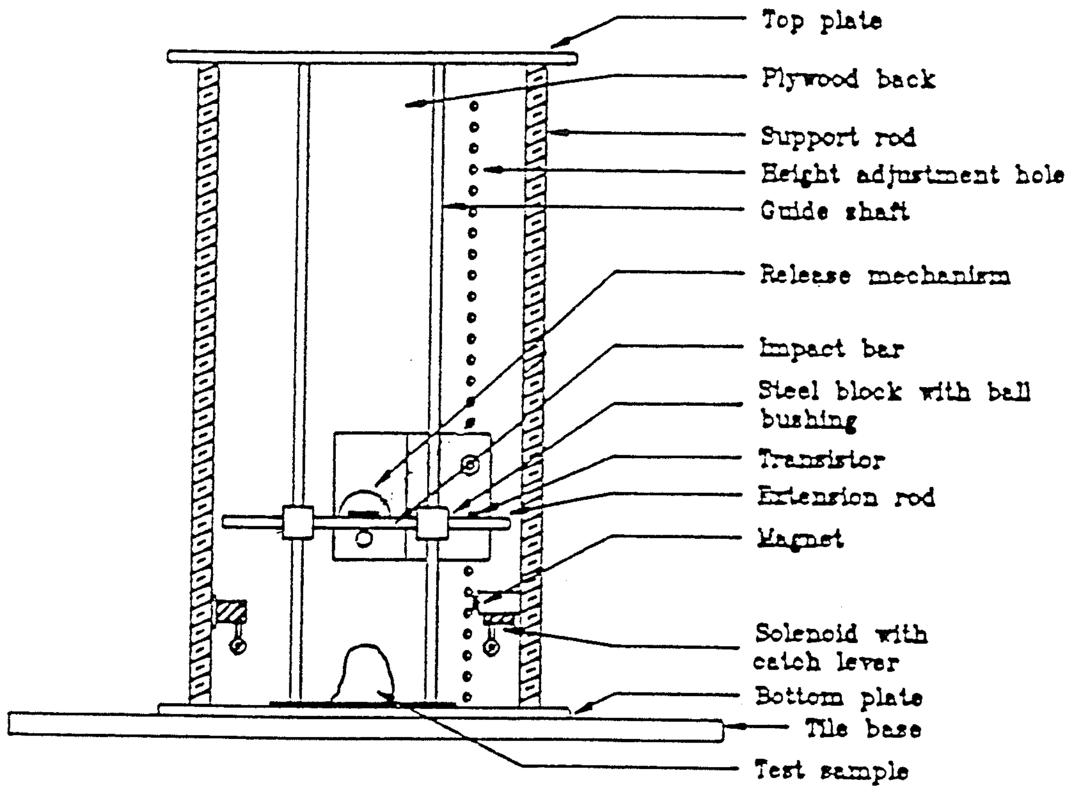
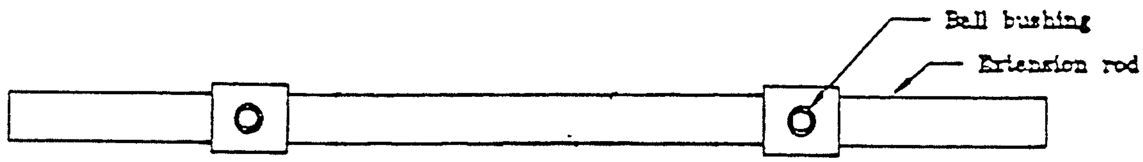

Top plate
Plywood back
Support rod
Height adjustment hole
Guide shaft
Release mechanism
Impact bar
Steel block with ball bushing
Transistor
Extension rod
Magnet
Solenoid with catch lever
Bottom plate
Tile base
Test sample

Figure 2: Impact bar


Ball bushing
Extension rod

3.7.2 Bruising procedure

An impact mass of 389.49 g and drop heights of 195 and 245 mm were used to vary the amount of potential energy going into the tubers. The mass and height combinations were chosen to produce bruising force sufficient to rupture the cells (Ghadge, 1988).

Test tubers were cut laterally and stem end parts of the samples were bruised. The stem end parts of the samples were used as bruise material because according to Kunkel et al. (1978) and Sawyer et al. (1960), they are more susceptible to bruising than the bud ends. Mondy and Mueller (1977) found enzymatic darkening to be greater in the stem region of the tubers. The bruised tubers were put in plastic bags which were stored in styrofoam boxes at room temperature. The plastic bags were left open to allow for air exchange. Air exchange is important as the potential of the tissues to produce colored oxidation products depends partly on the presence of oxygen (Duncan, 1973).

3.7.3 Bruise assessment

Impacted tubers were removed from the styrofoam storage boxes after about 7 days to assess the extent of bruising. A series of 1 mm slices were cut from each tuber using a food slicer.

Slices were cut from the impacted side of the tuber through the bruised area until no bruise could be detected. Then the unbruised slices beyond the bruised area were discarded. Cut slices showed elliptical bruises. The depth and major and minor axes of the bruised areas were measured using a Vernier caliper.

Bruises were assessed on a scale modified from Dwelle and Stallknecht (1976) by Ghadge (1988). Each tested tuber was given a numerical rating based on color, area, and depth of bruise. Area was calculated for each bruise from major and minor axes. An average of areas of all slices was used in the scale. Depth of bruise was calculated by summing the thickness of bruised slices. The key used is given below:

BRUISE SCALE

0 - no discoloration.

1 - vaguely defined spot.

2 - area between 12.56 and 50.26 mm^2, depth less than or equal to 2 mm, color light brown to brown.

3 - area greater than 12.56 mm^2 but less than or equal to 50.26 mm^2, depth 2 to 5 mm, color brown to grey.

4 - area between 50.26 to 113.09 mm^2, depth between 5 to 8 mm, color varying from light to dark grey.

5 - area greater than 113.09 mm^2, depth greater than 8 mm, and color grey to black.

6 - rupture.

The rupture or split (category 6) was included in blackspot assessment as an extreme condition of impact. It produced uneven fissures with edges which were at times discolored as in blackspot. But because of uneven and undefined shape of the fissures, it was difficult to measure the dimensions of the bruises where they occured. Thus no measurements were taken but it was given a bruise rating of 6 indicating that it was an extreme case of impact.

3.8 MEASUREMENT OF CHIPPING QUALITY

Chips were prepared using a modification of the method after Hyde and Shewfelt (1960). Five tubers were washed, peeled, and cut into 1 mm slices. About 20 slices of each test sample were rinsed in cold water to remove the surface starch and then placed between paper towels to absorb the excess moisture. The raw slices were then immersed in hydrogenated canola oil (Canada Packers Ltd., Toronto) previously heated to 190^{0} C and fried for 2.5 min. After draining excess oil for 2 min, the slices were prepared for color determination by manually mashing the slices into smaller pieces. Chip color was determined on a Hunterlab spectrophotometer model 25 by reading the L-values. (The L-values obtained gave an indication of visual lightness of color of the chips). The L-values were then converted to Agtrons using the equation:

$$\text{Agtron} = \text{HL} \times 1.22427 - 17.3943$$

where HL = L-values.

Chips with an Agtron reading of less than 38 were regarded as too dark and thus unacceptable for processing(Zulu, 1983).

3.9 DATA ANALYSIS

All data (except for bruise data) were analysed using the analysis of variance (ANOVA) procedure at 95% and 99% confidence limits. The Least Significant Difference test at 5% and 1% levels was used to test mean differences. As for bruise data, only the percentage of bruise resistant tubers under each treatment was determined due to the subjective nature of the data.

Chapter IV

RESULTS AND DISCUSSION

4.1 K-TRIAL

This experiment, designed to determine the effect of soil K levels on bruise susceptibility and chip quality of potato tubers, showed a lot of variation from year to year with respect to sucrose and reducing sugar contents. The main contributing factor to this variation was soil moisture differences between the two seasons. The 1987 trial had received excess precipitation during the harvest period as compared to the 1988 crop.

4.1.1 Sucrose

The 1987 trial experienced flooding on the weekend of August 13 thus delaying harvesting for three days before the water level would subside substantially to facilitate easier harvesting. All treatments showed a slow decrease in sucrose content of tubers between the first (August 18) and the third harvest (September 16) (Figure 3). This decline in sucrose is slower than would be expected and is probably due to the flooding which could have initiated the increase in sucrose concentration in the tubers as shown for the 50 and 200 kg/ha rate of K. The rates of K applied did not have any significant effect on sucrose content except for the first harvest date (August 18) when the 150 kg K/ha treatment showed significantly higher sucrose levels (Figure 3). Sucrose data were combined by harvest dates for all levels of K. Harvest dates showed significant differences for sucrose (Table 1). Sucrose levels in the tubers decreased from 7.6 mg/g on first harvest to 4.1 mg/g by September 16. This is expected because sucrose drops as tubers mature (Sowokinos and Preston). However, it is worth noting that there was a lot of variability in sucrose levels among the treatments (C.V. = 37). This could have resulted from the effects of excessive moisture during harvest.

TABLE 1

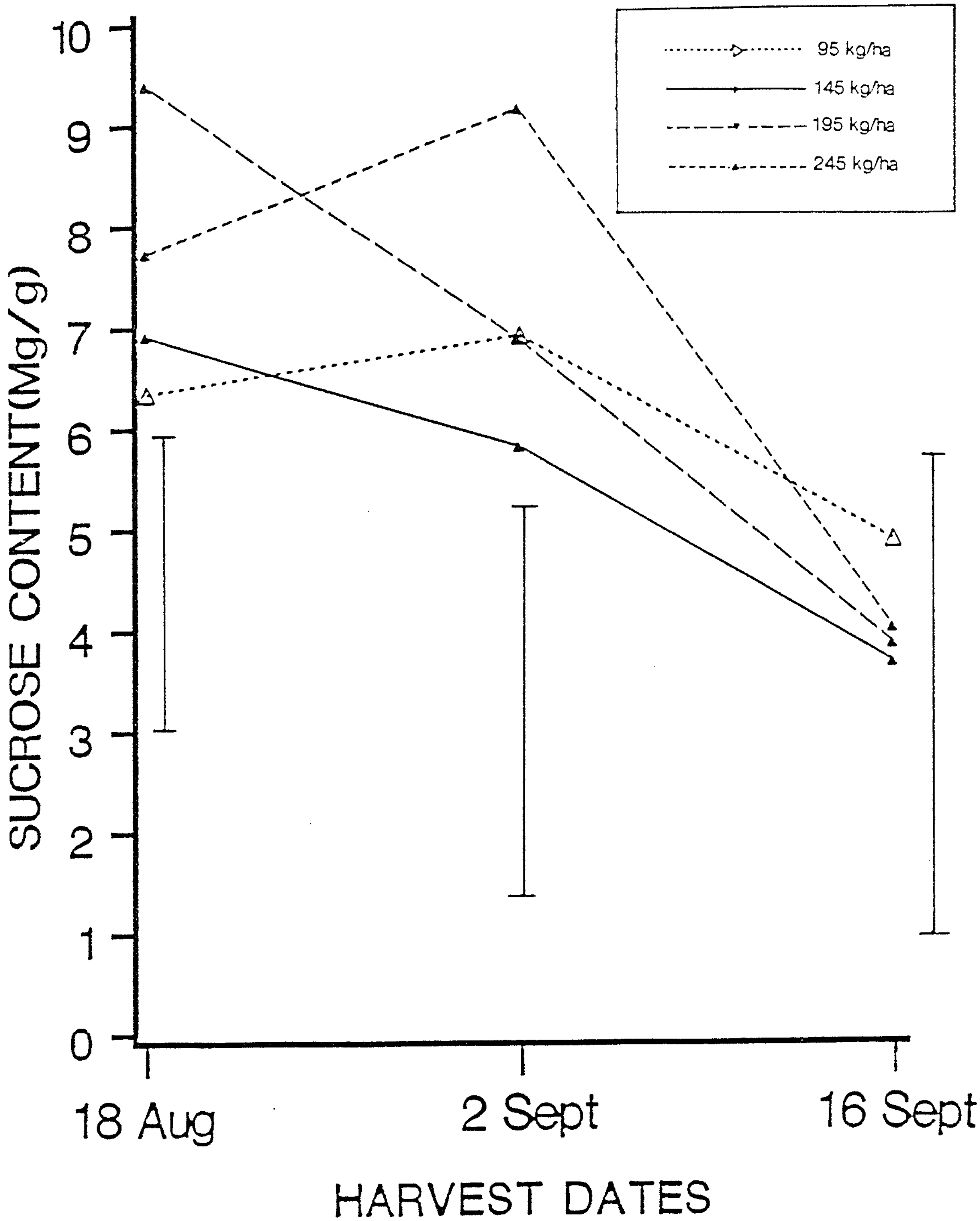
Effect of harvest date on sucrose content of Russet Burbank tubers for combined K levels in 1987

Harvest date	Sucrose content (mg/g)
August 18	7.6 a
September 2	7.2 a
September 16	4.1 b

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference).

Figure 3: Effect of soil K levels on sucrose content of Russet Burbank tubers at three harvest dates in 1987

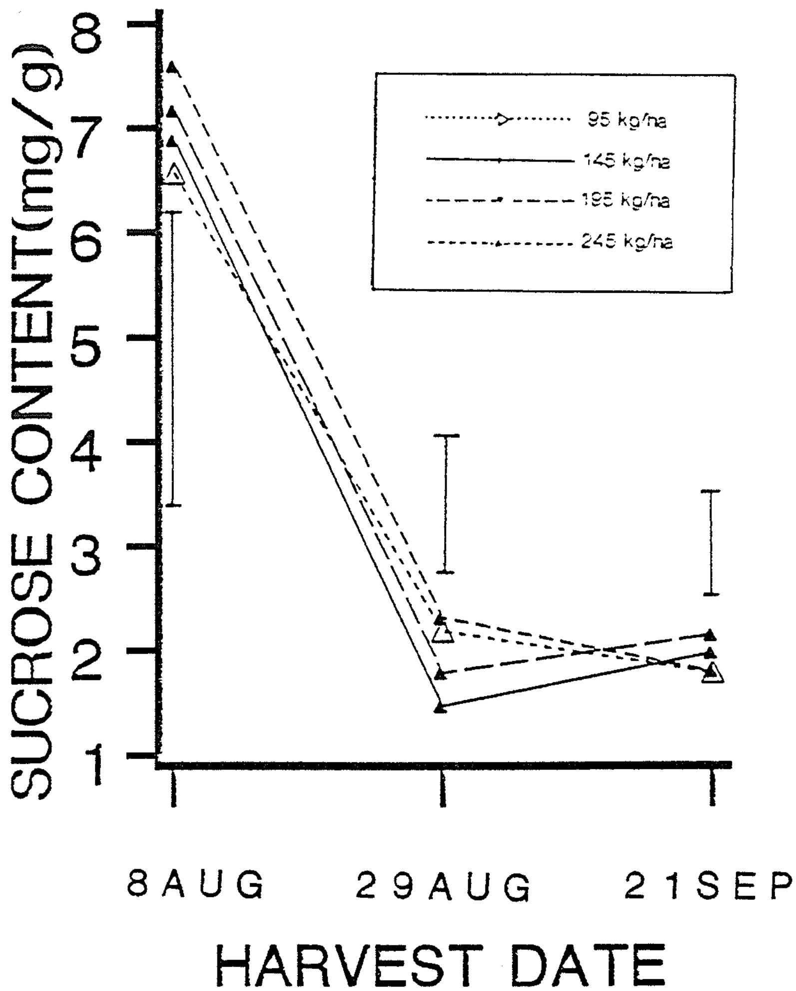
The vertical bars (I) at each harvest date represent the Least Significant Difference at $p=0.05$.


95 kg/ha
145 kg/ha
195 kg/ha
245 kg/ha
SUCROSE CONTENT (Mg/g)
0
1
2
3
4
5
6
7
8
9
10
18 Aug
2 Sept
16 Sept
HARVEST DATES

In 1988 K effects on sucrose levels again did not show any significant differences (Figure 4). The trend in sucrose levels over the harvest period showed a more drastic decrease as compared to the 1987 trial (Figure 4). There was a large decrease from the first to the second harvest and only a slight increase at the third harvest. The coefficient of variation was lower than in 1987 (25), showing an increase in precision, but it was still quite high. Variations could be attributed to many factors. The most obvious observable stress the plants experienced was herbicide injury, which was carried over in the seed from the previous season and which has as yet not been identified.

Figure 4: Effect of soil K levels on sucrose content of Russet Burbank tubers at three harvest dates in 1988

The vertical bars (I) at each harvest date represent the Least Significant Difference at p=0.05.



SUCROSE CONTENT(mg/g)
8
7
6
5
4
3
2
1
95 kg/ha
145 kg/ha
195 kg/ha
245 kg/ha
8AUG
29AUG
21SEP
HARVEST DATE

However the sucrose content for the combined K levels at harvest date one (August 8) was significantly greater than harvest dates two (August 29) and three (September 21) (Table 2).

TABLE 2

Effect of harvest date on sucrose content of Russet Burbank tubers for combined K levels in 1988

Harvest date	Sucrose content (mg/g)
August 8	7.1 a
August 29	1.9 b
September 21	1.9 b

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference).

The decrease in sucrose content of tubers is important because it is the level to which sucrose drops before harvest that determines whether or not the potato will process well from storage. The sucrose level normally drops as the potato reaches physical maturity (Iritani et al., 1977). A correlation has been found by other researchers (Sowokinos, 1978) between the harvest sucrose content of potato tubers and the rate of accumulation of undesirable levels of reducing sugars in storage. Whereas physical maturity is important, potatoes to be used for processing are considered chemically mature when they have reached a sucrose rating

(SR) or harvest sucrose content of less than 2.8 mg/g before harvest and will produce acceptable chip color directly from the field and after long term-storage (Sowokinos and Preston). Thus from these results, the August 29 and September 21 harvests of 1988 would be regarded as acceptable for long-term storage at intermediate temperatures in that they should produce acceptable chip color from such storage. The 1987 results show unacceptable sucrose levels for processing potatoes going into storage as the lowest value was 4.1 mg/g at the last harvest date. The high sucrose levels by the second harvest date in 1987 may be attributed to the excessively wet soil conditions imposing a stress and resulting in an increase in free sugar levels. According to Iritani and Weller (1976) high sucrose content has been reported in stressed potato tubers. The same reason could be attributed to the higher sucrose levels at the third harvest of 1987 as compared to the third harvest of 1988 as soil moisture was less in 1988. The results from these two years show how each growing season is different, and that harvest sucrose content can be used as a method of determining how well a particular field came through its developmental period.

Although sucrose does not directly contribute to chip or fry darkening itself, it is the reducing sugars (glucose and fructose) resulting from hydrolysis of sucrose that interact with amino acids during frying to cause darkening. Thus low sucrose levels (i.e. below 2.8 mg/g) mean that there is less intermediate product available for the formation of reducing sugars (Sowokinos, 1973). Harvest sucrose content is a reflection of the sum total of all stress situations. Thus the 1987 crop went through more stress than the 1988 crop, and this accounts for the differences in sucrose levels combined at each stage of growth. Sowokinos and Preston suggest that pre-harvest sucrose analysis could detect a potential maturity problem prior to harvest. Thus such early detection could lead to adjusted cultural practices, altered storage conditions, or rapid processing, or a combination of the above to assure acceptable processing quality.

4.1.2 Total reducing sugars (glucose and fructose)

In 1987 the total reducing sugars were not statistically reliable as the C.V. was 94. In 1988 K levels and harvest dates both showed significant differences in their effects on total reducing sugars. The reducing sugar content was significantly lower in tubers from plants receiving 245 kg K/ha than those receiving 95,or 145 kg K/ha (Table 3). Increasing K up to 195 kg/ha did not significantly affect the levels of total reducing sugars. However increasing the level of K to 245 kg/ha significantly reduced the levels of reducing sugars compared to 95 and 145 kg/ha. The low level of reducing sugars at 245 kg K/ha are more desirable at harvest time because according to Sowokinos and Preston another criteria for a mature potato for storage is one that has reducing sugar levels less than 2 mg/g. Dark chips result when reducing sugars exceed this value. The C.V. for 1988 was 36.

The reducing sugar contents at the three harvest dates were significantly different from each other (Table 4) with the lowest level occurring at the August 29 harvest. Reducing sugars were highest at the first harvest, lowest at the second harvest and increased slightly by the third harvest. From these results it seems harvest date is not a good predictor of total reducing sugar levels. The last harvest had elevated levels of the sugars as compared to the harvest of August 29.

TABLE 3

Effect of soil K on total reducing sugar content of Russet Burbank tubers for combined harvest dates in 1988

K rate (kg/ha)	Reducing sugar content (mg/g)
95	1.4 a
145	1.3 a
195	1.1 ab
245	1.0 b

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference).

TABLE 4

Effect of harvest date on total reducing sugars of Russet Burbank tubers for combined K levels in 1988

Harvest date	Reducing Sugar content (mg/g)
August 8	1.7 a **
August 29	0.7 b
September 21	1.2 c

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference). Means with two asteriks are significant at p=0.01 (Least Significant Difference).

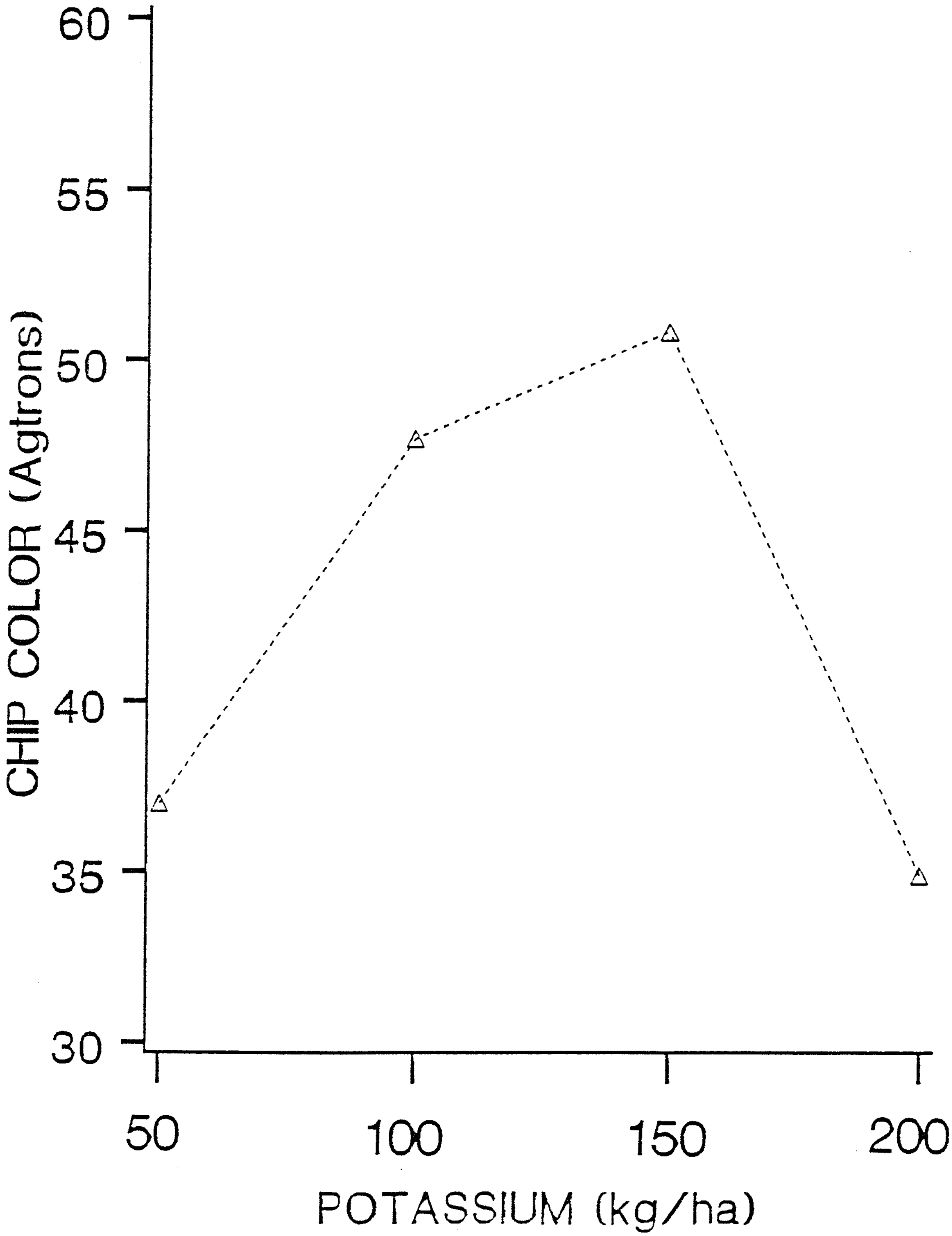
4.1.3 Chip color

It is worth noting that while Russet Burbank potatoes are not commercially used for chipping (they are used for french fries) the chip color obtained also reflects what fry color would be like as the chemical process involved in color development is the same.

Tuber slices were fried to determine the effect of K on processing quality. Due to flooding in the 1987 season, adequate samples were not available for chipping. However, a bulk sample was obtained at the last harvest (September 16) and chip color determined. Statistics could not be run on the data. The 150 kg K/ha rate had the highest value of 51 Agtrons with 200 kg K/ha showing the lowest value of 35 Agtrons (Fig 5). The chips with a higher Agtron value are the lightest and more preferable by the processors. Chips with an Agtron reading of less than 38 are regarded as too dark and thus unacceptable for processing as fries (Zulu, 1983). The 50 and 200 kg K/ha rate resulted in chips of unacceptable quality.

In 1988 harvest dates showed significant differences in their effects on chip color when the data for K levels were combined (Table 5).

Figure 5: Effects of K on chip color of Russet Burbank tubers for the third harvest (September 16) in 1987


60
55
50
45
40
35
30
CHIP COLOR (Agtrons)
50
100
150
200
POTASSIUM (kg/ha)

The chip color on harvest date one (August 8) was highly significantly different from the chip color on harvest dates two (August 29) and three (September 21). The first harvest (August 8) produced chip color that was the least acceptable. Whereas chip color improved significantly from August 8 to August 29, delaying harvest beyond the later date did not affect chip color. K levels did not significantly affect chip color (Figure 6). However, the lowest rate of K (95 kg/ha) resulted in the darkest chips at all sampling dates though these differences were not significant. The 1988 results show a strong relationship between chip color and total reducing sugar levels. Chip color improved with decrease in reducing sugar levels.

TABLE 5

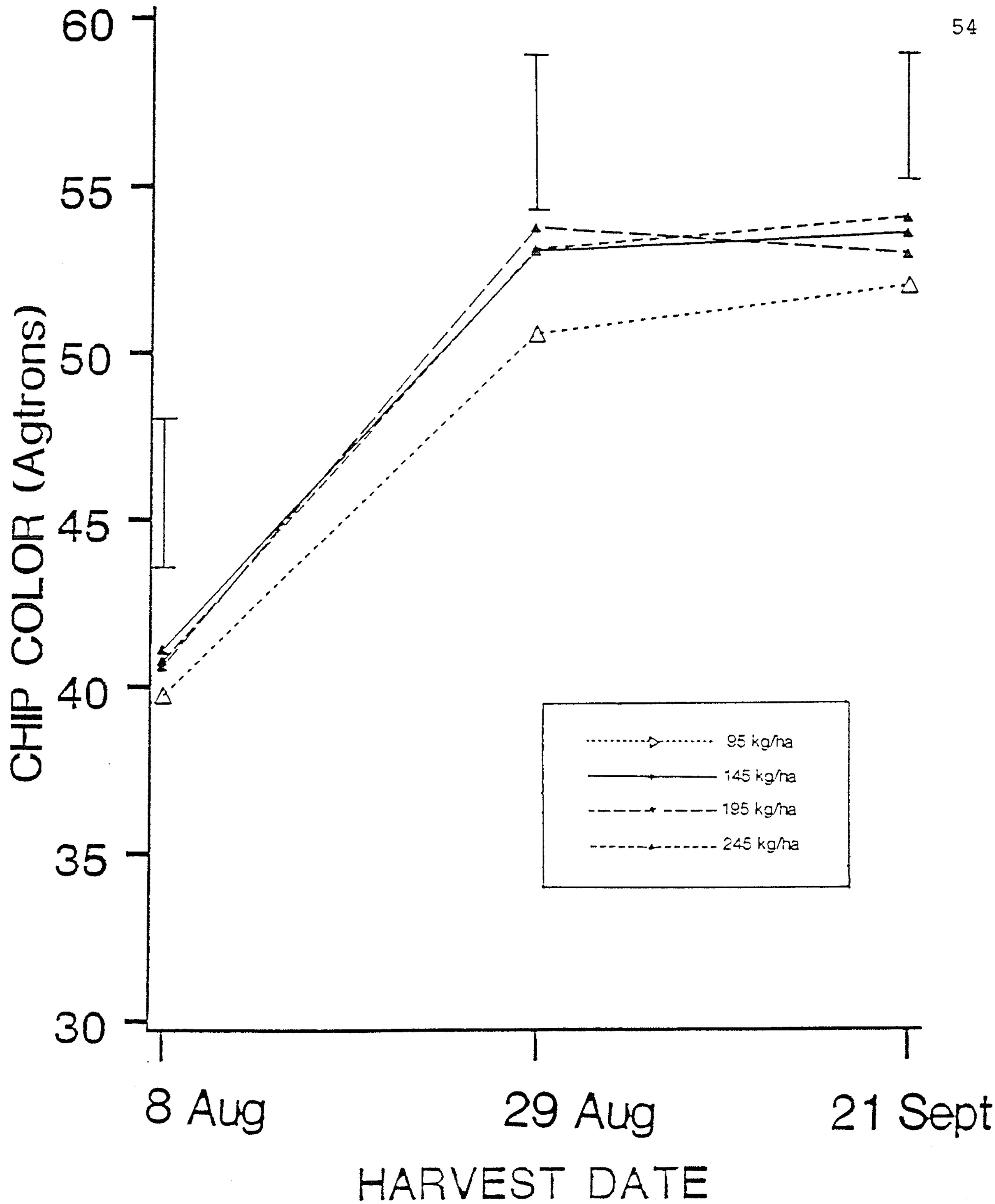
Effect of harvest date on chip color of Russet Burbank tubers for combined K levels in 1988

Harvest date	Chip color (Agtrons)⁺
August 8	41 a **
August 29	53 b
September 21	53 b

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference). Means with two asteriks are significant at p=0.01 (Least Significant Difference).

⁺A high Agtron reading means a lighter colored chip.

Figure 6: Effects of K on chip color of Russet Burbank tubers for three harvest dates in 1988
The vertical bars (I) at each harvest date represent the Least Significant Difference at p=0.05.


60
55
50
45
40
35
30
CHIP COLOR (Agtrons)
95 kg/ha
145 kg/ha
195 kg/ha
245 kg/ha
8 Aug
29 Aug
21 Sept
HARVEST DATE

4.1.4 <u>Bruise susceptibility</u>

In order to assess the effect of K on bruise susceptibility of tubers, potatoes were bruised in the laboratory and the bruised areas were rated visually using a scale of 0 to 6 as described in Materials and Methods. As previously mentioned Flooding of the 1987 plots caused rotting of tubers before they could be bruised. Thus sufficient samples were not available for 1987. The results for bruising are therefore based on the 1988 trial. An impact mass (consisting of the impact bar) of 389.49 g and two drop heights for the impact bar of 195 and 245 mm were used to bruise the tubers.

Since the objective of bruising the tubers was to determine susceptibility of tubers under each treatment to bruising, classes 0 (no bruise), 1 (slightly bruised), and 6 (split or shattering) were grouped into one category for simplicity. The theory behind this was that 0 and 1 could easily be interchangeable as the difference between them was minor. Class 6 was more likely the result of some tubers in classes 0 and 1 being more brittle and therefore splitting rather than deforming. Thus class 6 tubers could easily become class 0. The percentage of 0,1, and 6 represents the potential number of tubers from any treatment that will resist bruising. Thus the higher the percentage of the 0,1, and 6 categories the greater the potential to resist blackspot bruising. The remaining classes (2,3,4,5) actually represent those tubers which developed blackspot. In the text that follows, tubers in the 0,1,and 6 categories will be referred to as the 'resistant tubers' whereas those in the 2,3,4,and 5 categories will be referred to as 'blackspot tubers'. Statistics was not run on these data because of he subjective nature of the subjective nature of the data.

4.1.4.1 Drop height 195 mm

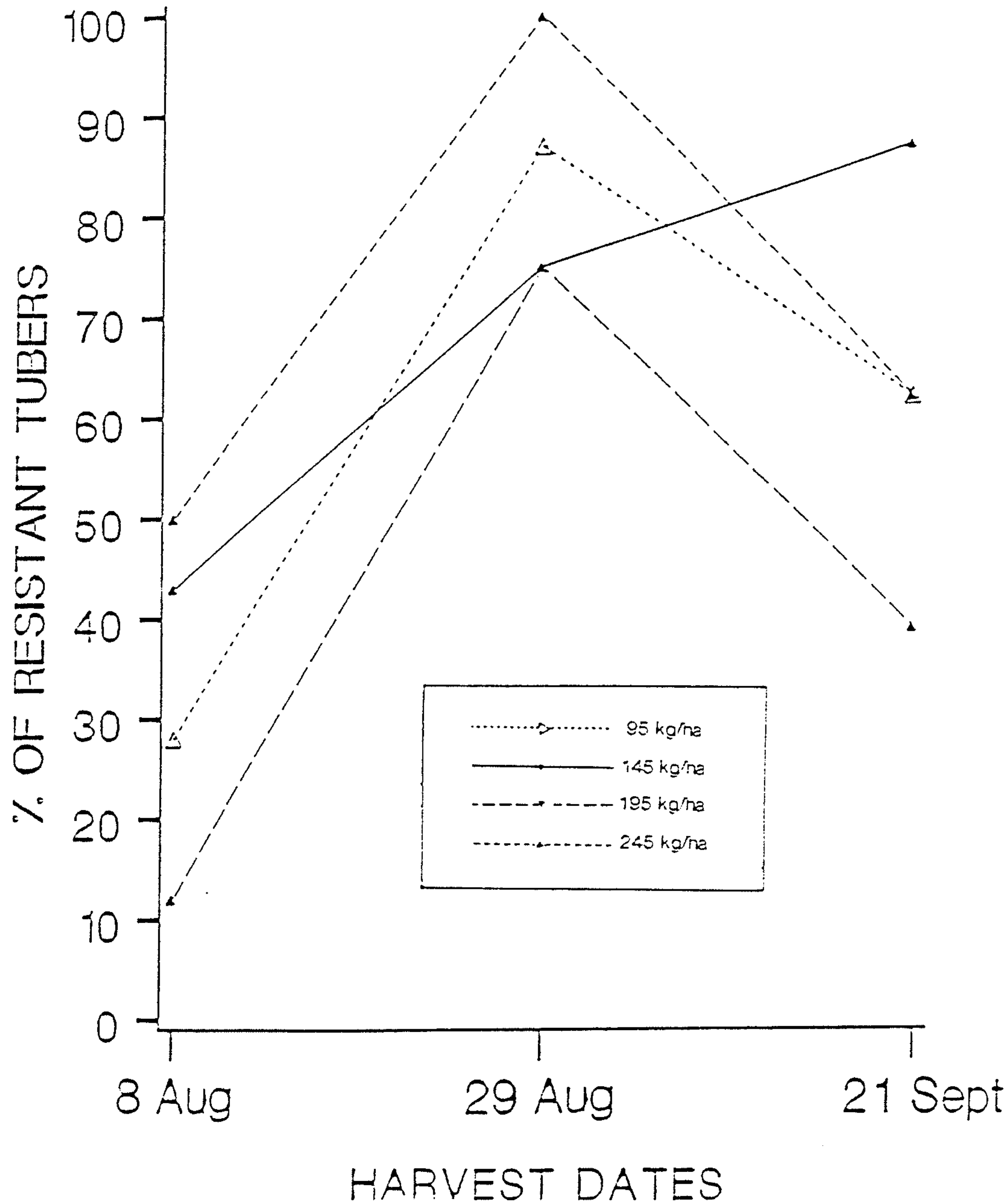
At a drop height of 195 mm, tubers from the 245 kg K/ha treatment had the highest resistance to bruising at the first harvest (August 8), with 50% of the tubers being in the category of resistant tubers (Fig 7). This treatment also had the highest percentage (100%) of resistant tubers at harvest two (August 29) decreasing to 62% at harvest three (September 21). With 43% resistant tubers at harvest one and 75% at harvest two the 145 kg K/ha treatment resulted in the highest number of resistant tubers at the third and final harvest (87%). Other than the 145 kg/ha treatment, the remaining treatments followed a consistent ranking in resistance to bruising at all three harvest dates.

4.1.4.2 Drop height 245 mm

At harvest one (August 8) the 95, 195 and 245 kg K/ha treatments had 50% resistant tubers (Fig 8). The 145 kg K/ha treatment had 37% of the tubers resistant to bruising. At the second harvest (August 29) all the tubers in the 145 kg K/ha treatment showed resistance to bruising while the 195 kg K/ha treatment was lowest at 62%. At third harvest

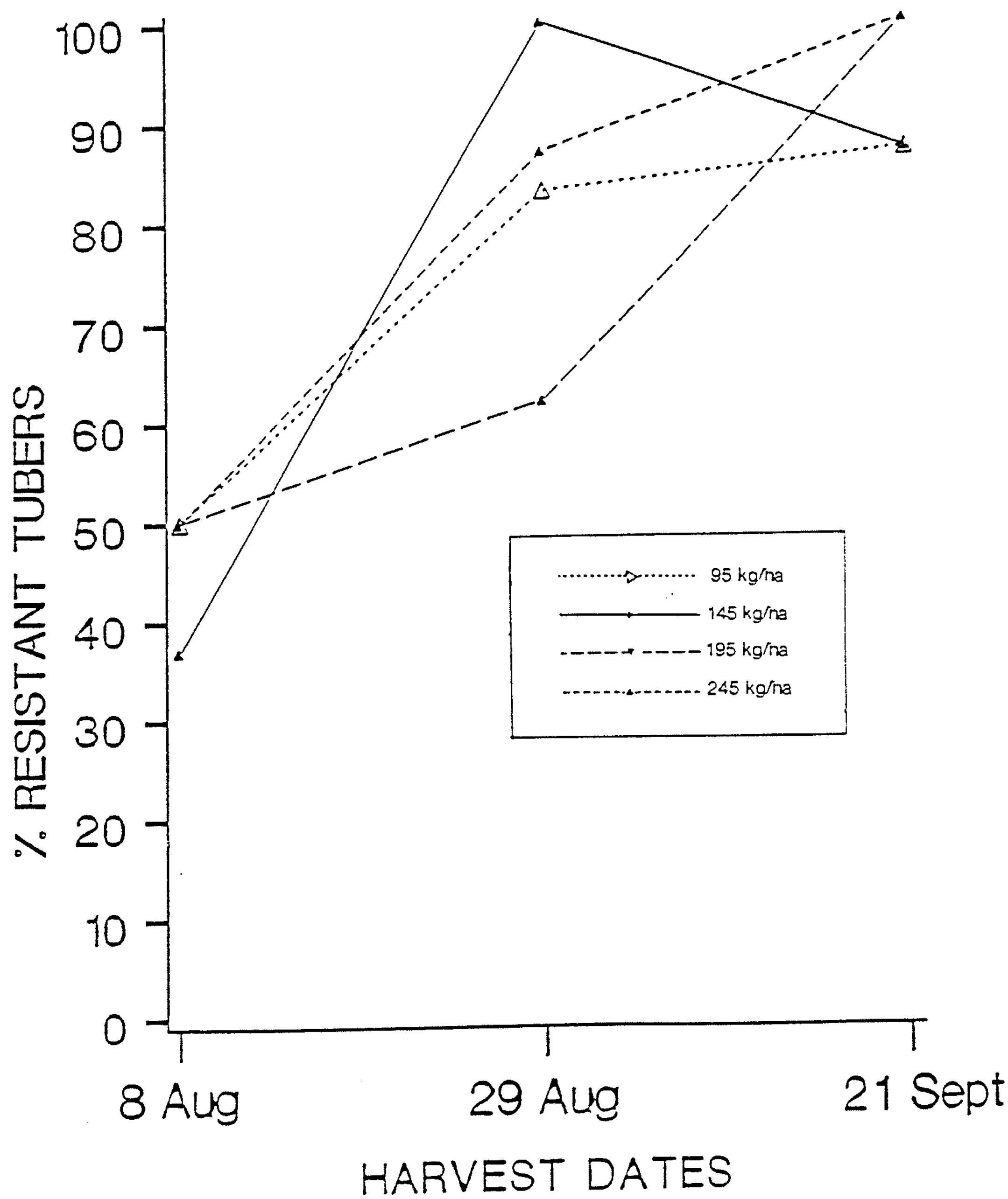
(September 21) the 195 kg K/ha and 245 kg K/ha treatments had the highest levels of resistant tubers at 100% each, whereas the 95 kg K/ha and 145 kg K/ha treatments had 87% resistant tubers.

Figure 7: % of Russet Burbank tubers from different K treatments resistant to bruising at the 195mm drop height in 1988



100
90
80
70
60
50
40
30
20
10
0
% OF RESISTANT TUBERS
95 kg/ha
145 kg/ha
195 kg/ha
245 kg/ha
8 Aug
29 Aug
21 Sept
HARVEST DATES

Figure 8: % of Russet Burbank tubers from different K treatments resistant to bruising at the 245mm drop height in 1988


100
90
80
70
60
50
40
30
20
10
0
% RESISTANT TUBERS
95 kg/ha
145 kg/ha
195 kg/ha
245 kg/ha
8 Aug
29 Aug
21 Sept
HARVEST DATES

Generally there was an increase in the amount of energy applied to the tubers when the impact bar was dropped from a 245 mm drop height resulting in more bruising compared to the 195 mm drop height, at each harvest date. The increase in number of splits from both the resistant and blackspot tubers raised the percentage of tubers in the resistant category as drop height was changed from 195 mm to 245 mm. All treatments showed a higher percentage of resistant tubers at the 245 mm drop height compared to the 195 mm height at the final harvest. Weather conditions (especially increased precipitation) must have played a major role in increasing the number of splits (class 6) at the 245 mm drop height (Figure 8). The tubers from the last harvest were picked at a time when the soil had received excessive precipitation during the previous week. The tubers must have absorbed excessive moisture, resulting in the higher incidence of splits than the previous two harvests. This observation agrees with Hughes (1980) who reported that increased turgidity and cell wall tension in the tuber increases cell wall failure during impact. He found that turgid tubers were more susceptible to cracking and splitting. This could probably have happened because the vines had died about two and a half weeks before the third harvest. The tubers thus had no avenue for water loss (by transpiration) to cause some dehydration. This has some serious implication in the field in that high moisture in the tubers would result in higher incidences of shatter bruise or splits. This could also imply that vine killing can contribute to shatter bruise if significant amounts of precipitation occur within the harvest period, because green vines are known to dehydrate tubers (Kunkel and Gardner, 1959).

It is difficult to rule out the evidence from Nilsson et al. (1958) who attributed blackspot to high moisture content in the cells. They report that high moisture content in cells resulted in less deformation as compared to cells with lower turgor pressure which deform to a greater extent. This should explain the increase in the percentage of bruised tubers at 245 impact height for most treatments on the September 21 harvest. Generally the 245 kg K/ha treatment had the highest percentage of resistant tubers at the 195 mm drop height on August 8 and 29, reducing to second place at the harvest of September 21. K is known to indirectly affect the tubers through its influence on vine and root condition and consequently tuber hydration (Hiller et al., 1985). It is therefore likely that if the soil moisture conditions for the September harvest had been favorable (i.e. less soil moisture, and active top growth) the tubers would have retained less moisture and thus reduced the percentage of bruised tubers. Thus the 245 kg K/ha would most likely have resulted in a higher percentage of tubers in the resistant category.

Based on this assumption, 245 kg K/ha would be the best K level to use as a remedy against bruising. Drop height 195 mm gave more favorable results as compared to 245 mm by having lower percentage of splits in all categories. Therefore as the drop height and impact velocity for the impact bar increases, the effect of K resistance to bruising is actually lost. Thus a combination of 245 kg K/ha, lower velocity of impact on potatoes, and a favorable moisture regime would greatly reduce both blackspot and shatter bruise.

A definite relationship does exist between the drop height of the impact bar and what actually happens in the field. After being uprooted by the digging share of the potato harvester, the tubers are passed on to moving conveyor chains, after which they may be dropped a distance of up to 2 m into collection trucks or bags. The damage to the tubers increases with increase in chain speed of the conveyors as the series of metal bars that constitute conveyors can be points of impact for the tubers. Potatoes can easily be bruised as they strike each other or other harder objects such as stones.

Whereas impact energy was varied in the experiments by changing drop height of the impact bar, energy absorbed by the potato in the field will vary depending on size of the potatoes as well as chain speed of the conveyors. A report prepared by the Department of Agriculture and Rural Development in New Brunswick (1968) mentions that tubers receiving injury in their study were 31% heavier than the uninjured tubers. Care must also be taken while unloading the harvested crop too as the drop height factor is also involved in these operations.

This study thus demonstrates the need for optimum tuber, machinery, and field conditions at harvest time. The results agree with studies conducted by Hesen and Kroesbergen (1960) and Smittle et al. (1974), in which distance of fall and size of tubers, and chain speeds were found to be important factors in bruise damage.

4.2 MOISTURE TRIAL

An attempt was made to subject Russet Burbank potatoes to three moisture levels in the field (after the flowering period) for at least four weeks before harvest during which soil samples for soil moisture determination were taken every two weeks. The tubers were then harvested and samples subjected to bruising and chip color tests. Moisture levels (available water to 90 cm depth) during the experimental period averaged as shown in Table 7. Field capacity and permanent wilting point for the soil type on which the trial was conducted averaged at 238 mm and 76 mm of moisture respectively for the 0 - 90 cm profile. All treatments were below field capacity and most of them were below permanent wilting point (P.W.P). Problems were experienced during the 1987 and 1988 trials with regard to field moisture conditions. Both years experienced prolonged drought periods which greatly reduced the moisture differences between the treatments. Drip irrigation had to be used on the drip line in 1988, in anticipation of another drought period after the

TABLE 6

Average available soil moisture levels in the 0 - 90 cm zone during the moisture stress trials

	Available water (mm)	
Treatment	1987	1988
Control	87	58
Drip line	70	113
centre row	72	61

*The figures for 1987 and 1988 represent the average available moisture to 90 cm depth during the experimental period.

1987 season. That accounts for the higher available water over the 1987 drip line treatment. The 1987 drip line treatment is lower in soil moisture than the control due to structural faults in the polyethylene tunnels caused by the north-south winds which created depressions in the polyethylene roofing. These depressions collected most of the precipitation which was supposed to have collected onto the treatment row at the edge of the structure. Thus the soil profile under the drip line did not receive all the run off from the structure. This was one of the reasons a modification had to be made during the 1988 trial.

The moisture under the centre row was higher than expected probably due to an unanticipated pattern in ground water movement in which some centre rows had excessive moisture in the 60 - 90 cm portion of the profile. Tuber moisture content was not significantly different between the treatments for both years (see Appendix).

4.2.1 Chip color

There were no significant differences between treatment for both years in chip color of tubers. All treatments produced chips of acceptable color (above 38 Agtron units) as shown in Table 8. The trials suffered extreme stress due to drought conditions that prevailed during the experimental period. In 1988 tuber size was very small indicating less photosynthetic and translocative activity during growth. This resulted in less sucrose and reducing sugars in the tubers, which translated into high chip quality. The low levels of sucrose and reducing sugars could have been due to early maturity of the tubers which could have been triggered by the drought conditions. Total reducing sugar levels were not significantly different between the treatments (see Appendix).

TABLE 7

Effect of different levels of soil moisture on chip color of Russet Burbank tubers

	Chip color (Agtrons)+	
Treatment	1987	1988
Control	55 a	57 a
Drip line	56 a	58 a
centre row	58 a	57 a

*Means with the same letter are not significantly different at p=0.05 (Least Significant Difference).
+Chips with high Agtron value have the lightest chip color.

4.2.2 Bruise susceptibility

The results for bruise susceptibility of tubers in the moisture stress trial are given in Tables 8 and 9. The 1987 results show that the centre row (72 mm of available water) and the drip line (70 mm available water) produced tubers that responded differently from the control (87 mm of available water). Whereas all the treatments behaved similarly under the 195 mm impact height, all the tubers from the control split under the 245 mm impact height giving 100% in the resistant category. At 195 mm impact height tubers from the drip line had 75% of tubers resistant while 25% experienced blackspot. At 245 mm impact height more tubers (75%) in the drip line experienced blackspot while the number of resistant tubers dropped to 25%. There were no differences between impact heights for the centre row. The centre row

TABLE 8

The percentage of bruise resistant and blackspot tubers in 1987

Treatment	Drop height of impact bar			
	195 mm		245 mm	
	Resistant	Blackspot	Resistant	Blackspot
Control	75	25	100	0
Drip line	75	25	25	75
Centre row	75	25	75	25

TABLE 9

The percentage of bruise resistant and blackspot tubers in 1988

Treatment	Drop height of impact bar			
	195 mm		245 mm	
	Resistant	Blackspot	Resistant	Blackspot
Control	100	0	100	0
Drip line	87	13	100	0
Centre row	100	0	100	0

had more resistant tubers at both heights. In 1988 the control (58 mm available water) had 100% of the tested tubers in the resistant category. The drip line (113 mm) had 87% of tubers in the resistant category. The centre rows under the structures (61 mm) had 100% resistant tubers. All the above were at an impact height of 195 mm. At an impact height of 245 mm all treatments had splits in the above category. This shift to splits shows how the benefits of low moisture can be lost as impact energy or velocity increases. These results confirm conclusions by Hughes (1980) who reported that increased turgidity in the tuber caused cell wall failure during impact, making the tubers more susceptible to splitting. Yet the results of this experiment conflict with those of Smittle et al. (1974) who found that blackspot susceptibility increased with dehydration. Thus a combination of low moisture and reduced impact at harvest time will result in less splits and blackspot.

Chapter V

CONCLUSIONS

The different levels of K applied did not have any significant effects on sucrose levels. Rather, harvest date greatly determined sucrose levels within the tubers as is expected. Sucrose levels were higher at the earliest harvest and dropped drastically at later harvest dates. Harvest sucrose content varied between the seasons depending on the environmental conditions.

Total reducing sugar levels in the tubers were lower in the 245 kg K/ha treatment as compared to the 95 and 145 kg K/ha treatments. Though not significant, chip color was highest in quality in the 245 kg K/ha treatment at the final harvest, and the 95 kg K/ha treatment consistently showed the lowest chip quality at all harvest dates. Harvest date affected chip quality in that the earliest harvested tubers produced darker chips upon direct chipping from the field, while later harvest produced lighter colored chips.

K, harvest date, energy or velocity of impact, and soil moisture had an effect on bruising. Although the relationship is a complex one bruise incidence increases with increase in impact energy. Thus reduction in forces of impact during harvesting by reduction in chain speeds and height of fall of potatoes should reduce blackspot as well as splits. K reduced bruising depending on the levels applied as well as date of harvest and field moisture conditions. The 245 kg K/ha treatment had a higher percentage of resistant tubers at the 195 mm drop height and was the most consistent in the percentage of resistant tubers at the 245 mm drop height. Thus 245 kg K/ha may be the more appropriate rate of K that would reduce bruising.

K increases or maintains the strength of cell walls as deficiency of K has been known to cause weakened cell wall structure in tissues (Cummings and Wilcox, 1968). Higher levels of K have also been known to increase the crude lipid and phospholipid content, whose higher levels have been known to reduce enzymatic darkening of bruised tubers (Mondy and Koch, 1978). High levels of K prevent the retranslocation of the element from older to young tissue (Penston, 1931). This should result in healthier top growth, which could play a major role in tuber dehydration through the transpiration process, where soil moisture conditions are favorable. Favorable soil moisture conditions are important because K is also known to allow plants to more effectively absorb water from the soil and make the tissue less susceptible to desiccation (Kunkel and Dow, 1961).

Field moisture levels between F.C. (238 mm) and P.W.P. (76 mm) did not show any differences in chip color, and all treatments produced acceptable chip color. Lower soil moisture conditions are important during harvesting as they contribute to less bruising. Lower soil moisture also aids in overriding some effects of high impact energy, as can be seen from the dripline data. In 1987, the dripline treatment had the least resistant tubers under the 195 mm drop height (Table 9) and 245 mm drop height (Table 8). The inconsistence in behavior of the dripline treatment between the two seasons could be attributed to differences in soil moisture levels between the seasons. Thus it is possible that there exists a critical point in moisture levels, beyond or below which tuber susceptibility is altered.

Since field moisture conditions presented the greatest problem during the experimental period a greenhouse approach would be helpful during future studies in order to effectively control the variables in the experiments.

LITERATURE CITED

Baver,L.D. 1956. Soil Physics. New York: John Wiley and Sons. pp 193 - 248.

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

Cummings, G.A., and Wilcox,G.E. 1968. Effects of potassium on quality factors - Fruits and Vegetables. In: The role of potassium in agriculture. (Eds. Kilmer, V.J., Younts, S.E., and Brady, N.C.) Madison, Winscosin: American Society of Agronomy. pp 243 - 267.

Duncan, H.J. 1973. Rapid bruise development in potatoes with oxygen under pressure. Potato Res. 16:306 - 310.

Dunn, L.E., and Nylund, L.E. 1945. The influence of fertilizers on the quality of potatoes grown in the Red River Valley of Minnesota Am. Potato J. 22:173 - 187.

Dwelle,R.B., and Stallknecht, G.F. 1976 Rates of internal blackspot bruise development in potato tubers under conditions of elevated temperatures and pressures. Am. Potato J. 53:235 - 245.

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.

Ghadge, A.D., Britton, M.G., and Jayas, D.S. 1987. Moisture content determination for potatoes. American Society of Agricultural Engineers. Paper #NCR 87-501.

Ghadge, A.D. 1988. Blackspot bruises in Russet Burbank potatoes subject to impact loads. Msc. Thesis, University of Manitoba.

Gray, D., and Hughes, J.C. 1978. Tuber quality. In: The potato crop. The scientific basis for improvement. (ed. Harris, P.M.). London: Chapman and Hall. pp 523 - 532.

Hausenbuiller, R.L. 1985. Soil science. Principles and practices. Iowa: Brown Publishers. pp 90 - 91.

Hesen, J.C., and Kroesbergen, E. 1960. Mechanical damage to potatoes. Euro. Potato J. 3:30 - 46.

Hiller, L.K., and Koller, D.C. 1982. Brown centre and hollow heart as a quality factor. Proc. Washington State Potato Conference 21:101 - 108.

Hiller, L.K., and Koller, D.C., and Thornton, R.E. 1985. Physiological disorders of potato tubers. In: Potato physiology (ed. Li, P.H.) Orlando, Florida: Academic Press Inc. pp 423 - 424.

Hodgson, W.A., Pond, D.D., and Munro, J. 1974. Pests of potatoes. Canada Department of Agriculture, Publication 1492.

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. 54:395 - 404.

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 Shewfelt, A.L. 1960. Measurement of chipping qualities in Manitoba grown potatoes. Canadian J. Plant Sci. 40:607 - 610.

Iritani, W.M. 1981. Growth and pre-harvest stress and processing quality of potatoes. Am. Potato J. 58:71 - 80.

Iritani, W.M., and Weller, L.D, and Russel, T.S. 1973. Relative differences in sugar content of basal and apical portions of Russet Burbank potatoes. Am. Potato J. 50:24 - 31.

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

Jamison, V.C. 1956. Pertinent factors governing availability of soil moisture to plants. Soil Sci. 81:459 - 471.

Kunkel, R., and Gardner, W.H. 1959. Blackspot of Russet Burbank potatoes. Am. Hort. Sci. Proc. 73:436 - 444.

Kunkel, R., and Dow, A.I. 1961. Possible functions of potassium in decreasing susceptibility of Russet Burbank potatoes to blackspot when bruised. Am. Potato J. 38:368 - 369.

Kunkel, R., and Gardner, W.H. 1965. Potato tuber hydration and its effects on blackspot of Russet Burbank potatoes in the Columbia basin of Washington. Am. Potato J. 42:109 - 124.

Kunkel, R., Hostad, N.M., and Russel, T.S. 1973. Mineral element content of potato plants and tubers vs. yields. Am. Potato J. 50:275 - 282.

Kunkel, R., Hostad, N.M., and Russel, T.S. 1978. Blackspot and potato fertilization in Washington's Columbia basin. Washington: Agric. Res. Cent., 1978, Bull. 862.

Larsen, F.E. 1961. External and internal (blackspot) mechanical injury of Washington Russet Burbank potatoes from field to terminal market. Am. Potato J. 39:2499 - 260.

Layman, S., and Mackay, A. 1961. Effect of specific gravity, storage and conditioning on potato chip color. Am. Potato J. 38:51 - 57.

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

Miller, D.E, and Martin, M.W. 1985. Effect of water stress during tuber formation on subsequent growth and internal defects in Russet Burbank potatoes. Am. Potato J. 62:83 - 89.

Mohsenin N.N. 1986. Physical properties of plant and animal materials. New York: Gordon and Breach Science Publishers, pp 492.

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

Moorby, J., Munns, R., and Walcott, J. 1975. Effects of water deficit on photosynthesis and tuber metabolism in potatoes. Aust. J. Plant Physiol. 2:323 - 333.

Mulder, E.G. 1955. Effect of the mineral nutrition of the potato plants on the biochemistry and physiology of the tubers. Neth. J. Agric. Sci. pp 333 - 356.

Nielson, L.W. (1968). Accumulation of respiratory CO_2 around potato tubers in relation to bacterial soft rot. Am. Potato J. 45:174 - 181.

Nilsson, S.B., Hertz,C.H., and Falk, S. 1958. On the relation between turgor pressure and tissue rigidity. II. Theoretical calculations on model systems. Physiologia Plant. 11:818 - 837.

Penston, N.L. 1931. Studies of the physiological importance of the mineral elements in plants III. A study of microchemical methods of the distribution of potassium in the potato plant. Ann. Bot. 45:673 - 692.

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

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

Probine,M.C., and Preston, R.D. 1962. Cell growth and the structure and mechanical properties of the wall in intermodal cells of Nitella opaca. II. Mechanical properties of the walls. J. Exp. Bot. 13:111 - 127.

Raper, H.S. 1927. The tyrosinase-tyrosine reaction. Biochem. J. 21:89 - 96.

Reeve, R.M. 1968. Further histological comparisons of blackspot, physiological internal necrosis, blackheart in potatoes. Am. Potato J. 45:391 - 400.

Robertson, I.M. 1970. Prediction of susceptibility to bruising (Abstract). Proc. Fourth Triennial Conf. Euro. Ass. Pot. Res. pp 245.

Sawyer, R.L., and Collin, G.H. 1960. Blackspot of potatoes. Am. Potato J. 37:115 - 126.

Schippers, P.A. 1971. Measurement of blackspot susceptibility of potatoes. Am. Potato J. 48:71 - 81.

Schwimmer, S., Bevenue, A., Weston, W.J., and Potter, A.L. 1954. Survey of major and minor sugar and starch components of the white potato. J. Agri. Food Chem. 2:1284 - 1290.

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

Singh, B.N., and Mathur, P.B 1938. 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 the physiological losses in weight of potatoes during storage. Ann. Appl. Biol. 25:68 - 78.

Smith, O. 1977. Potatoes: Production,storing, processing. In: The potato crop. (ed. Harris, P.M.). Westport, Connecticut:AVI Publishing Co. Ltd., pp 387 - 389.

Smittle, D.A., Thornton, R.E., Peterson, C.L., and Dean, B.B. 1974. Harvesting potatoes with minimum damage. Am. Potato J. 51:152 - 164.

Sowokinos, J.R. 1973. Maturation of Solanum tuberosum. I. Comparative sucrose and sucrose synthatase levels between several good and poor processing varieties. Am. Potato J. 50:234 - 244.

Sowokinos, J.R. 1978. Relationship of harvest sucrose content to processing maturity and storage life of potatoes. Am. Potato J. 55:333 - 334.

Sowokinos, J.R., and Preston, D.A. Principles and application of sucrose-rating (SR) analysis. Red River Valley Potato Facts 100:1 - 4.

Talburt, W.F., and Smith, O. Potato processing. Westport, CT.: AVI Publishing Co. Inc., 1975. pp 313 - 318.

Thornton, R. 1979. Potato tuber condition and the harvester operation. Potato Technology Series. Part 6:41 - 42.

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.

Veihmeyer, F.J., and Hendrickson, A.H. 1949. Methods of measuring field capacity and wilting percentage of soils. Soil Sci. 68:75 - 94.

White-Stevens, R.H., and Smith, O. 1945. Studies of potato storage on Long Island. Cornell University Agr. Expt. Sta. Ann. Report. 58:163 - 164.

Wilcockson, S.J., Griffith, R.L., and Allen, E.J. 1980. Effects of maturity on susceptibility to damage. Annal. Appl. Biol. 96:349 - 353.

Wilson, A.M., Work, T.M., Bushway, R.J. 1981. HPLC determination of fructose, glucose, and sucrose in potatoes. A research note. Journal of Food Sci. 46:300 - 301.

Wright, N.W. 1957. Blue spotting of potato tubers in British Columbia. Plant Disease Report 41:608 - 611.

Zulu, G.M. 1983. The influence of mefluidide, a plant growth regulator, on plant growth, tuber development, storage capabilities, and processing quality of potatoes (Solanum tuberosum L.). Msc Thesis University of Manitoba. pp 54.

Appendix A

TABLE 10

Total reducing sugar content in tubers of Russet Burbank potatoes grown under different moisture levels

	Control (mg/g)	Dripline (mg/g)	Centre row (mg/g)
1987	0.72	0.74	0.78
1988	0.80	0.70	0.78

TABLE 11

Tuber moisture content in Russet Burbank potatoes grown under different moisture levels

	Control (% f wt.)*	Dripline (% f wt.)	Centre row (% f wt.)
1987	76	77	77
1988	78	80	78

*% f wt. means percent fresh weight of tuber.