THE INFLUENCE OF MEFLUIDIDE, A PLANT GROWTH REGULATOR, ON PLANT GROWTH, TUBER DEVELOPMENT, STORAGE CAPABILITIES, AND PROCESSING QUALITY OF POTATOES (*SOLANUM TUBEROSUM* L.)

A Thesis

Submitted to the

Faculty of Graduate Studies

The University of Manitoba

by

Grace Masala Zulu

In Partial Fulfillment of the

Requirement for the Degree

of

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ABSTRACT

Zulu, Grace Masala. M.Sc., The University of Manitoba, October 1983. The Influence of Mefluidide, a Plant Growth Regulator, on Plant Growth, Tuber Development, Storage Capabilities, and Processing Quality of Potatoes (Solanum tuberosum L.). Major Professor: Dr. M.K. Pritchard

Field and growth chamber experiments were conducted to investigate the effect of mefluidide {N-2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino]phenyl]acetamide} on plant growth, tuber development, storage capabilities, and processing quality of potato (Solanum tuberosum L.) cultivars Russet Burbank, Norland, and Norchip.

In field treated tubers, mefluidide tended to slow down the rate of loss of sucrose in all cultivars. Total as well as marketable yield seemed to have been reduced while specific gravity varied depending on the cultivar. There was a tendency to increasing specific gravity in Russet Burbank and Norchip with increasing rates of mefluidide from 0.25 to 1.00 kg ai/ha then declined at the 2.00 kg ai/ha rate. Chip color was lighter in mefluidide-treated Norchip tubers than in the controls.

Skin russetting increased in mefluidide treated tubers. Skin cross sections in Norland and Norchip indicated an increase in thickness of the suberized layer in treated tubers. Skin color in Russet Burbank and Norchip tubers darkened while in Norland, the skin changed from red to yellowish brown. The amount of anthocyanin was reduced in mefluidide treated Norland tubers. Flesh color was not affected in any of the cultivars.

In storage, mefluidide delayed sprout growth in Norland and Norchip, but caused excessive weight loss in all treated tubers. Tubers treated with mefluidide after harvest responded similarly in skin russetting, skin color change, and sprout growth to field treated tubers.

In the growth chamber, mefluidide at 0.02 mg/ml retarded shoot growth and tended to reduce shoot fresh and dry weights, and early tuber fresh weight in Norland and Norchip potato plants. Root fresh and dry weights were slightly increased. The 0.02 mg/ml mefluidide treatment also caused a temporary plant distortion in early stages after treatment. All mefluidide treated plants had light green newly formed leaves while older leaves had necrosis on leaf tips and margins soon after treatment.

FOREWORD

This thesis is presented in the form of two manuscripts. The first manuscript is intended for publication, possibly in the American Potato Journal. A general discussion of the results and suggestions for further work are included after the manuscripts.

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INTRODUCTION

The high quality standards of the processing industry necessitate stringent control over cultural and management practices for potatoes (Solanum tuberosum L.) which are to be processed into french fries and chips. Potatoes must be chemically mature at harvest, must be handled properly to reduce bruising, and must be stored under conditions which prevent the accumulation of reducing sugars and minimize losses.

Mefluidide {N- 2 ,4 dimethyl-5-[[(trifluoromethyl) sulfonyl] amino] phenyl] acetamide} is a growth retardant which has been reported to improve skin development, enhance maturity, and increase specific gravity and yield when applied to the plant before harvest. Enhanced skin development will not only reduce bruising damage during handling but also will lower water loss in storage and reduce disease entry into the tubers.

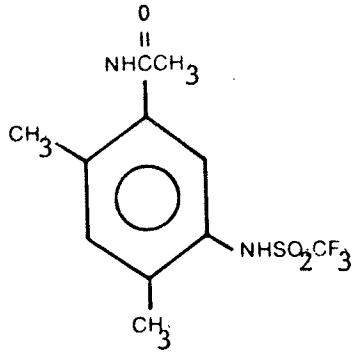
Enhancement of chemical maturity (genetically inherent minimum sugar content) at harvest, would reduce the accumulation of reducing sugars in storage and produce a superior processed product. An increase in the dry matter content as measured by a high specific gravity reading, would increase the processed yield of potatoes.

This investigation was undertaken to determine the effect of mefluidide on skin development, tuber maturity, specific gravity, yield and storage capability of potatoes when the chemical was applied to the plants approximately four weeks before harvest. Three cultivars, Russet Burbank, Norland, and Norchip were evaluated for their response to mefluidide. A growth chamber study was conducted to determine the effect of mefluidide on plant growth and on tuber initiation and development.

LITERATURE REVIEW

Mefluidide--A Plant Growth Retardant

Plant growth retardants are synthetic plant growth regulators which retard plant growth while evoking no severe plant abnormalities (Staby 1973). Mefluidide{N-2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino]-phenyl]acetamide}, also known as MBR 12352, is a plant growth regulator and a herbicide (structure below).



As a herbicide, mefluidide has been reported to selectively control troublesome weeds in soybeans (Glycine max (L.) Merr.), peanuts (Arachis hypogaea L.) and cotton (Gossypium hirsutum L.) (Mcwhorter and Barrentine 1979; Gates 1975). As a plant growth regulator, Gates (1975) reported that mefluidide at rates of 0.28 to 1.14 kg ai/ha suppressed growth and seed head formation of turf grasses, enhanced root growth and color development of turf grass, suppressed vegetative growth in trees and woody ornamentals, stopped growth of the apical meristem and increased secondary branching in peach (Prunus persica (L.) Batsch). Arnold and Aldrich (1982) reported a delay in bloom in mefluidide-treated peach trees. He also found high fruit yields in peach trees treated with 0.24 and 0.49 g/L

mefluidide. Rates of 0.56 to 2.24 kg ai/ha mefluidide increased the amounts of recoverable sugar from sugar-cane (Gates 1975). Sterrett (1979) reported that mefluidide reduced height and leaf area of ten-day-old bean (Phaseolus vulgaris L.) plants. He also reported sprout growth inhibition of California privet (Lingustrum ovalifolium Haask) by the chemical. Rao and Harger (1981) found that mefluidide reduced height of soybeans at 1.00 kg ai/ha mefluidide. Truelove et al. (1977) found that mefluidide at the highest concentrations used in their experiments reduced plant height and fresh and dry weights of stems and roots while low concentrations had a stimulatory effect on corn growth. The growth reduction was accompanied by necrosis of leaf tips and margins with some plant distortion. Mefluidide also reduced the amount of chlorophyll a in treated corn leaves (Truelove et al. 1977).

Mode of Action: The mode of action of mefluidide as well as other growth retardants is not clear. It is generally assumed that these compounds have more than one in vivo action. Halevy (1963) reported that growth retardants increase the peroxidase and indoleacetic acid oxidase activity thus affecting the level of auxins in the tissue. Similar results were reported by Cleland (1965), and Kuraishi and Muir (1963). Growth retardants have also been reported to affect membrane structure and permeability. These compounds may affect the biosynthesis of steroids which are components of cell membranes (Douglas and Paleg 1974; Staby 1973; Grunwald 1971).

The effect of growth retardants is usually counteracted by the application of exogenous gibberellic acid (Zeevaart 1964; Lockhart 1962). This indicates that one of the effects of these compounds is the inhibition of gibberellin biosynthesis (Paleg et al. 1965). Other workers (Coolbaugh et al. 1982; Coolbaugh and Hamilton 1976; Barnes et al.

1969; Dennis et al. 1966; Harada and Lang 1965) also reported similar results. The ineffectiveness of growth retardants as inhibitors of such gibberellin action as: the stimulation of amylase formation in barley endosperm (Paleg et al. 1965) and retardation of leaf senescence in Rumex obtusifolius L. (Harada 1966) where gibberellin biosynthesis is not involved indicates that these chemicals affect gibberellin biosynthesis and not its actions. Possible sites of inhibition along the gibberellin biosynthetic pathway have been located (Coolbaugh et al. 1978; Wylie et al. 1970; Barnes et al. 1969). Lockhart (1962) used the principle of reaction kinetics and concluded that a specific interaction exists between growth retardants and gibberellins.

The effect of mefluidide on plant growth seems not to be solely due to inhibition of gibberellin biosynthesis. Truelove et al. (1977) working with corn, found that the dwarfing effect caused by mefluidide was not reversed by the application of exogenous gibberellic acid. It is possible that mefluidide changes the membrane structure and permeability because St. John and Hilton (1973) found that perfluidone, a chemical related to mefluidide, affected synthesis of netural and polar lipids which are components of cell membranes.

Jersey and Glenn (unpublished) found that mefluidide exhibited auxin-like activity. At low concentrations of 10^{-6}M, they found that mefluidide stimulated incorporation of ^{14}C-leucine into protein. Truelove et al. (1977) found similar results and they also found that high levels of mefluidide reduced the incorporation of ^{14}C-leucine into protein. It is possible that mefluidide affects DNA-directed RNA synthesis which in turn affects the rate of protein synthesis (Jersey and Glenn unpublished). This could be a possible explanation of the stimulatory effect on plant growth of low levels of mefluidide observed by Truelove et al. (1977) in corn.

Mefluidide is a very stable molecule and it has been proven that mefluidide per se rather than a metabolite is the active molecule (Field and Whitfor 1982; Jersey and Glenn unpublished). In their experiments, Jersey and Glenn (unpublished) found that the removal of the methyl group from carbon four did not alter the activity of mefluidide while the removal of the acetamide group reduced the leucine incorporation into protein. Removing the trifluoromethyl sulfonyl amino group eliminated the activity. These results could support the findings of Bloomberg and Wax (1978a) who found soybeans to be tolerant to mefluidide because they metabolized the compound rapidly to water soluble products while common cocklebur (Xanthium pensylvanicum Wallr.) had a slower rate of metabolism to less toxic compounds, hence was sensitive to mefluidide.

Absorption, Translocation, and Site of Action of Mefluidide: The possible sites of action of mefluidide appear to be the apical meristem and the axillary buds (Gates 1975). The compound is transported from the point of application to the site of action mainly through the phloem vessels (Bloomberg and Wax 1978b; McWhorter and Wills 1978). Bloomberg and Wax (1978b) also showed the absorption of labelled mefluidide from the nutrient solution into roots then upwards in the plants. Their results indicated that mefluidide can also be translocated through the xylem.

Absorption and translocation of mefluidide has been found to differ between species. Bloomberg and Wax (1978b) showed that giant foxtail (Setaria faberi Herrm.) and common cocklebur absorbed less mefluidide than soybeans but both weed species translocated more of the chemical to meristemic tissue than soybeans. This could partly explain why the two weed species are more sensitive to mefluidide.

Environmental conditions have also been reported to influence absorption and translocation of mefluidide, McWhorter and Wills (1978) working with johnson grass (Sorghum halepense L.), common cocklebur, and soybeans found that more mefluidide was absorbed and translocated at high temperatures and relative humidities. Bloomberg and Wax (1978b) also reported similar results.

Age and type of tissue also affect absorption and translocation of mefluidide. McWhorter and Wills (1978) found that immature leaves absorbed more mefluidide than mature ones while in the stem tissue, the opposite was true. Translocation to untreated plant parts was more from older stem tissue than from young stem tissue and leaves.

Plant Growth, Tuber Initiation and Enlargement

Tuber Initiation--The tuberization process involves tuber initiation and tuber enlargement, the latter being the first visible sign of tuber formation (Chapman 1958). This process takes place at the tip of specialized stem organs called stolons.

The factors which induce tuberization in potatoes and in other tuberous plants is not well defined (Stallknecht 1972). Werner (1934 and 1940) reported that tuberization is a result of the concentration of soluble sugars rising to some critical level in the plant and that factors causing a shift to more carbohydrate, such as short days, low temperatures, and low nitrogen, will result in tuberization. Under conditions which favor vegetative growth, the carbohydrate concentration at the stolon tip is not enough to cause tuberization. Frier (1977) found a positive correlation between tuber initiation and development and the accumulation of assimilates in leaves. Lawrence and Barker (1963) and Gregory (1956)

indicated that sugars are not sole determinants of tuberization but that they must be present for tuberization to take place.

Some workers (Obata-Sasamoto and Suzuki 1979; Mingo-castel et al. 1974; Kumar and Wareing 1973; Chapman 1958; Gregory 1956) indicated that tuber initiation is due to a specific stimulus or a complex of stimuli which are hormonal in nature and which are produced more favorably under conditions which favor the inhibition of shoot growth such as short days, low temperatures (Chapman 1958; Gregory 1956), or a high carbon/nitrogen ratio (Krauss and Marchner 1971). Elevated levels of carbon dioxide in the soil may also favor the tuberization process (Mingo-castel et al. 1976).

The stimulus once produced has been found to persist in plants even after putting such plants under non-inductive conditions for a long time (Kumar and Wareing 1974; Gregory 1956). Grafting experiments (Kumar and Wareing 1973; Chapman 1958; Gregory 1956) showed that the stimulus was transmissable from induced to non-induced plants. The origin of the stimulus was believed to be the young apical leaves (Chapman 1958) and/or the old mother tuber (Okazawa and Chapman 1962). Lawrence and Barker (1963) reported that this stimulus was present in sprouts of stored potatoes and stems of growing potatoes but it is diluted or lost by periods of prolonged vegetative growth when the carbohydrate level is low. Once present, the stimulus is found in the entire plant (Gregory 1956) and it moves predominantly basipetally (Kumar and Wareing 1973; Chapman 1958; Gregory 1956). Tuber development normally occurs in the lower most bud on the stem (Kumar and Wareing 1973) but Chapman (1958) found that interference of stimulus transport to underground parts causes tuberization in the aerial buds.

A number of compounds with growth regulatory properties have been implicated in inducing tuber initiation. Abdullah and Ahman (1980) found that abscisic acid (ABA), a naturally occuring growth inhibitor, increased tuber formation. El Antably et al.(1967) found that Solanum tuberosum clones which form tubers at any photoperiod, formed more tubers when abscisin was added. Contrary to these results, Claver (1970) found that although ABA inhibited shoot and root growth, it also inhibited tuber formation of young potato sprouts. Smith and Rappaport (1969) also found that ABA did not induce tuber formation in intact plants.

Tuber initiation has been related to reduced levels of gibberellin (Obuta-Sasamoto and Suzuki 1979; Kumar and Wareing 1973). Okazawa (1960) observed inhibition of tuber initiation when gibberellin was applied to plants grown under short days. Kumar and Wareing (1974) reported that when grown under short day conditions, gibberellin levels were lowered while the levels of growth inhibitor increased. They thought that a fraction of the growth inhibitor could be the tuberization promoter. Abdullah and Ahmad (1980) found that adding ABA with gibberellic acid (GA_3) caused tuberization. But Claver (1970) and Smith and Rappaport (1969) believed that ABA was not the inhibitor in relation to tuberization. Kumar and Wareing (1974) stated that tuberization is likely due to a balance between gibberellin and some type of inhibitors.

Obuta-Sasamota and Suzuki (1979) found that auxin concentration was high early in tuber growth and that it dropped during the development stage. They concluded that tuberization is stimulated by the presence of auxin. Kumar and Wareing (1974) found that low concentrations of IAA stimulated while high concentrations inhibited tuber initiation.

Okazawa (1969) observed a sharp increase in cytokinin immediately after onset of tuberization. Sattelmarcher and Marschaner (1978) observed that the increase in cytokinin was caused by a reduction in nitrogen supply to plants. When they added more nitrogen seven days after tuber initiation, the tubers reverted back to stolon growth. Obuta-Sasamoto and Suzuki (1979) found that cytokinin levels increased with plant development and Mingo-castel et al. (1976), and Palmer and Smith (1969) believe that it may control the change from stolon growth to tuber formation. Palmer and Smith (1969) concluded that cytokinin regulates the rate of cell division and the direction of cell elongation, and forms new attraction sites for assimilates in potato tubers.

Stallknecht (1972) found that coumarin, a phenolic compound induced tuberization in potatoes and that tubers in coumarin culture were bigger and formed earlier than those in kinetin culture.

Other compounds like maleic hydrazide (Harmey et al. 1966) and chlorocholinchloride (CCC) (Dyson 1965; Kumar and Wareing 1974) have been found to induce tuberization. Kumar and Wareing (1974) also found that CCC nullified the effect of gibberellin on tuber initiation. Ethephon, a compound which produces ethylene as a breakdown product, was found to influence rhizome initiation but there was a decrease in the number and weight of tubers per plant with increasing concentration (Langille 1972).

Tuber Enlargement--Once the tuber has been initiated, cell division begins in all tissues of the young tuber which continues to grow by the production of new leaf primodia, buds, and internodes from the apical meristem and the division and expansion of cells in the expanding internodes with the differentiation of new leaves from the meristem keeping pace with internode expansion (Milthorpe and Moorby 1979).

Tuber volume arises mostly from cell division and to some extent from cell expansion (Reeves et al. 1973; Plaisted 1957). Cell division and expansion are not uniform throughout the tuber (Milthorpe and Moorby 1979).

Tuber enlargement seems to be under the influences of the tuberization stimulus (Ewing 1981). Bodlaender et al. (1964) reported that long days or high temperatures have an adverse effect on the potato plant after tuber initiation. They reported that under such conditions, tuber enlargement could slow down or be stopped completely and the tuber could revert to stolons resulting in a final low yield of poorly shaped tubers.

Individual tubers have been reported to grow at different rates at different times (Milthorpe and Moorby 1979). This could be partly due to photosynthate supply as tubers have been reported to compete for substrate. The rate of increase in the tuber weight is determined at the time of tuber set and its duration depends on the maintenance of photosynthetically active leaves (Milthorpe and Moorby 1979).

Burton (1966) reported a theoretical daily increase in total fresh weight of 1,8 tonnes/ha/day if there is no cloud cover and the temperature is 20°C, which is optimum for photosynthesis. However, under normal field conditions, weight increase of 400 kg/ha/day could be expected.

High temperatures reduce tuber weight with high night temperatures reducing yield more than high day temperatures (Gregory 1965). These yield reductions are due to high respiration rates rather than reduced photosynthate production (Wivutvongvana 1979). Heat stress reduced the amount of assimilate available to the tuber (Ewing 1981). Short days and cool temperatures favor assimilate accumulation (Gregory 1965). Heat stress and heat-induced moisture stress affect the relationship

of hormones, enzymes, and membranes and cause a shift in metabolic balance (Ku and Edwards 1976).

Ku and Edwards (1976) estimated an optimal temperature for net photosynthesis in potatoes to be between 16 and 25°C. Burton (1981) stated that the optimum temperature for photosynthesis was 20°C for European cultivars and every 5°C rise in leaf temperature causes a 25 percent reduction in the rate of photosynthesis.

Long days will reduce tuber yield particularly in the early crop (Bodlaender et al. 1964). Such conditions favor vegetative growth (Kumar and Wareing 1973 and 1974).

Yield reduction occurs in potatoes when the crop is under moisture stress, moreso during the bulking period than at any other growth stage (Van Loon 1981). In order to obtain maximum yield, soil moisture should not be allowed to drop below 50 percent of the crop-available water during tuber bulking period (Fulton and Murwin 1955; Blake et al. 1955; Bradley and Pratt 1954). Van Loon (1981) stated that the reduction in yield from moisture stress was due to reduced leaf area and/or reduced photosynthesis per unit leaf area. Bradley and Pratt (1955) found that dry soil conditions delayed tuber initiation and if water stress occurs during this stage, less tubers are formed per plant.

Zandstra et al. (1969) reported that high levels of nitrogen reduced early tuber yield while potassium consistently increased early tuber yield. Emmond (1970) reported that higher rates of nitrogen and phosphorus reduced yield.

Plant stresses also cause poor tuber quality (Iritani 1981). The degree of influence of stress depends on the stage of the plant and size of the tuber at the time of stress. Early stress has been found to be

more detrimental than late stress (Iritani et al. 1973). Iritani and Weller (1973), Nichols and Ruf (1967), and Robins and Domingo (1956) found that stress affected the shape of tubers. Hiller et al. (1979) reported temperature and water stress might be responsible for hollow heart formation. The distribution of sugars and starch within the tuber have been reported to be influenced by stress (Shekhar and Iritani 1978). Stress also influences tuber texture and causes off-flavors (Iritani 1981).

Sucrose Rating

One of the major factors limiting the quality of potatoes for processing is the amount of reducing sugar at harvest or in storage. Starch, the major polysaccharide found in potatoes, is converted to sucrose (Isherwood 1973) which is in turn hydrolysed to glucose and fructose through the action of invertase (Pressey 1969). The two reducing sugars, glucose and fructose, react with the amine group of certain amino acids at high temperatures during frying, causing a non-enzymatic browning reaction which make the products unacceptable on the market (Owings et al. 1978; Weaver et al. 1978). Although sucrose does not participate in the darkening reaction, it has an impact on sweet taste, it produces off-flavors of processed products, and it influences, to some degree, the texture after cooking (Iritani and Weller 1977).

The hydrolysis of starch is caused by any form of stress such as low temperature, high temperatures of above 25°C (Timm et al. 1968), poor air circulation in storage, and carbon dioxide build-up in storage.

For long-term storage of potatoes, the storage should prevent rots, sprouting, and excessive moisture loss (Paez and Hultin 1970) and this can be achieved by storing tubers at low temperatures of about 2°C with a high relative humidity. However, such low temperatures are responsible for large accumulation of sugars which lead to deterioration of internal quality

of tubers (Isherwood 1973 and 1976; Shekhar and Iritani 1978; Iritani and Weller 1977). The accumulation of sugars is considered as a protective mechanism against cold temperatures since a potato tuber does not show breaks in mitochondrial respiration with decreasing temperature as is characteristic of chill sensitive plants (Workman et al. 1979; Paez and Hiltin 1970).

Potatoes can be reconditioned, i.e., lowering reducing sugar levels, by elevating the storage temperature before marketing (Isherwood 1976; Iritani and Weller 1977 and 1978). However, in some cultivars such as Russet Burbank, the basal portion accumulates two to three times more reducing sugars than the apical portion. As a result, even after reconditioning the basal portion still contains more sugars than the apical end (Otazu and Secor 1981; Iritani and Weller 1978; Shekhar and Iritani 1978). This causes a situation known as sugar-end which makes french fries non-uniformly colored. The reconditioning procedure is also time consuming and expensive.

The storage quality of processing potatoes has been found to be influenced by tuber maturity at harvest. Sowokinos (1971) suggested the use of sucrose synthetase enzyme as a common maturity index. The enzyme is found in large amounts in immature potatoes where it is thought to participate in sucrose cleavage before incorporation into starch. As the rate of growth and starch formation drops, the sucrose synthetase level also drops at a varietal-dependent rate. A minimum amount of three units[1] of sucrose synthetase per gram of tuber has been reported to indicate maturity (Sowokinos 1971). This method has not been favored because of difficulties associated with handling of the enzymes.

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[1]One unit of enzyme is that amount which catalyzes the liberation of 1 μ mole of fructose per hour.

Peterson et al. (1981) and Owings et al, (1978) indicated that respiration rates could be used as an indicator for tuber maturity. They found that immature tubers respired at a rapid rate which decreased as the growing season progressed reaching lowest rates when tubers matured.

Sowokinos (1978) reported that maturity is dependent on the amount of sucrose at harvest. In his experiments, Sowokinos (1978) found a relationship between harvest sucrose content and potato storage life. Using the Sucrose Rating analysis (SR = mg sucrose/gram of tuber) he found that potato cultivars varied in the amount of sucrose present. From his work, he found that potatoes with SR values of $\leq$ 2.8mg sucrose/gram of tuber stored better and for a longer time than those with higher SR values. Potato cultivars which were capable of reaching SR values of $\leq$ 2.8 mg sucrose/gram of tuber were termed as good processors because they produced chips of acceptable color straight from storage at intermediate temperatures. Such potatoes accumulated less reducing sugars in storage because their initial sucrose content before storage was low. Good processors which are capable of reaching low SR values may be poor processors if harvested immaturely (Sowokinos 1978).

Other than determining maturity, Sucrose Rating can be used for the following:

1. Rapid detection of variation in sucrose content caused by field stresses such as moisture, nutrients, temperature, and disease (Sowokinos 1971),

2. Detecting storage stresses such as poor ventilation, high carbon dioxide tension, and disease as these will cause an elevation in sucrose (Mazza 1980),

3. Detecting the breaking of dormancy which causes increase in sucrose at any temperature (Dwell and Stallknecht 1978),

4. It can be used in selecting early from late maturing cultivars in the breeding program (Sowokinos 1978),

5. It can help in deciding the order of harvesting in the fields (Chubey 1980).

6. It can be used to help farmers decide whether they can mix potatoes from different fields before harvesting (Chubey 1980).

7. It can be used to help farmers decide as to when they can kill potato vines (Sowokinos 1978).

8. Potential maturity problems can be detected two to three weeks before harvest and this could lead to adjustment in culture, storage, and utilization practices (Sowokinos 1978).

The starch conversion taking place in storage is:

Starch ----> Sucrose ----> Reducing Sugars

The key step between Starch ----> Sucrose is the critical one which needs to be blocked since Sowokinos (1978) found that the velocity of reducing sugar production is dependent on the concentration of sucrose. However, blocking this reaction has not been successful because of lack of knowledge on the physiochemical mechanism and the biochemical pathway of starch hydrolysis (Isherwood 1973). Isherwood (1976) indicated that the sweetening process in potatoes occurs in two phases. In Phase I, which lasts for approximately four days, there is a rapid increase in certain phosphatesters and in Phase II, there is an increase in sucrose and respiration while the increase in reducing sugars follows later.

Pollock and Reeves (1978) and Isherwood and Kennedy (1975) suggested that the accumulation of sugar in storage was due to the activation of starch hydrolyzing enzymes by low temperatures, specifically sucrose phosphate synthetase, because its increase parallels that of reducing sugars under such conditions (Slabnik et al. 1968; Pressey 1970). Shekhar and Iritani (1978) and Isherwood and Kennedy (1975) found an increase in inorganic phosphorus with decreasing temperatures. A positive correlation was found between inorganic phosphorus and percentage reducing sugars (Shekhar and Iritani 1978). The inorganic phosphorus is

An activator of phosphorylase which favors an increase in starch to sugar conversion, and an inhibitor of ADPG pyrophosphorylase which is a key enzyme in starch synthesis (Preiss and Kosgue 1976).

Others (Shekhar et al. 1979; Isherwood 1976; Lynons 1973; Itzhak et al. 1971) have suggested that low temperatures affect membrane permeability and that amyloplast membranes surrounding starch granules are changed, allowing degradative enzymes access to the starch grains. This condition is enhanced by water stress during growth of the tubers and the membrane change is reversible except in senescing tubers (Shekhar et al. 1979; Isherwood 1976).

The accumulation of sugars at low temperatures has been linked to the Cyanide Resistant Respiration (CRR) mechanism (Sherman and Ewing 1982). This refers to cellular respiration insensitive to inhibition by terminal inhibitors and inhibitors which act between b and c type cytochrome (Solomos and Laties 1975). Treating potato tubers with cyanide, ethylene, acetaldelyde, ethanol, or acetic acid was found to stimulate respiration and sucrose production (Janes et al. 1979; Rychter et al. 1979). The stimulation effect of these compounds has been connected with the activation of CRR. When potatoes were put under low temperatures ($1^{o}C$) together with cyanide, Sherman and Ewing (1982) found a further increase in respiration and sugar accumulation suggesting that CRR is partially involved. When CRR is operational, ATP levels increase and sucrose formation seems to serve as a sink for the ATP produced (Solomos and Laties 1975). Amir et al. (1977) and Isherwood (1976 and 1973) also found that the ATP produced is responsible for sugar accumulation.

Specific Gravity

Specific gravity 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). It is widely accepted by the potato processing industry as a measure of potato quality for processing, since there is a high positive correlation between specific gravity and dry matter content or total solids (Johnston et al. 1970). Dry matter content of potatoes is important because it determines the weight of processed products which can be obtained from a given weight of raw tubers. It is, therefore, used to calculate the price of raw potatoes before they are processed (Fitzpatrick et al. 1969).

Dry matter content is also important in relation to texture of cooked or baked products, the higher the dry matter the better the texture. Sharma et al. (1959) found that tubers or parts of tubers with high specific gravity, i.e., high dry matter content, were firmer after cooking than those with low specific gravity.

Iritani and Weller (1976) found a high correlation between dry matter content and reducing sugar accumulation in storage. These workers showed that potatoes with high specific gravity accumulated less sugars in storage and such tubers showed less differences in amount of reducing sugars between the stem and the bud portion. Lyman and Mackey (1961) showed that high specific gravity tubers needed a shorter conditioning time after 1 - 2 months of storage than did the low specific gravity tubers. Fitzpatrick et al. (1964) noticed that loss of weight in storage was greatest in potatoes having lowest solids content.

Lyman and Mackey (1961) found that specific gravity influenced chip color. In their experiments, tubers with high specific gravity consistently produced chips of lighter color than did tubers of low specific

gravity. Lulai and Orr (1979) found a linear increase in chip yield with increasing specific gravity. Sayre et al. (1975) also observed an increase in french fry yield with increased solids content. Lulai and Orr (1979), Kunkel et al. (1951), and Terman et al. (1950) found that potatoes with high dry matter content had a low oil absorption when utilized for chips.

Specific Gravity Determination: Three methods have been used to determine specific gravity:

(i) Brine solution method (Iritani and Weller 1976; Woodbury Weinheiner 1965);

(ii) Hydrometer method (Kunkel and Holstad 1972);

(iii) Weight in air/weight in water method (Redshaw and Fong 1972; Fong and Redshaw 1972; Young et al. 1964).

The last method is most commonly used as it is the quickest, most accurate and versatile technique.

Factors Affecting Specific Gravity: Environmental conditions as well as management practices have an effect on specific gravity. Motes and Creig (1970) found that soil moisture stress depressed specific gravity and that this response was variety dependent. High soil temperatures have been associated with low specific gravity (Motes and Creig 1969). Low temperatures and adequate moisture have been shown to be more beneficial to potatoes harvested later in the growing season (Motes and Creig 1969).

Although high fertilizer rates are associated with high yield, Emmond (1970) working with the variety Norland, found an inverse relationship between fertilizer rates and specific gravity. These results were similar to those found by Zandstra et al. (1969). Dubezt and Bole (1975) White et al. (1974), and Findlen (1960) showed that potassium reduces specific gravity of potatoes. Dunn and Nylund (1945), and Dunn and Rost

(1945) showed that potash fertilizer containing chloride lowered dry matter content of potatoes. Timm et al. (1963) and Maas (1968) found that nitrogen tended to reduce specific gravity because it delays maturity as it causes extensive plant growth. This seems to agree with the work of Sweetman (1933) and Lyman and Mackey (1961) who found that immature tubers had low specific gravity. Hope et al. (1960) also found that dry matter content increased in potatoes receiving no nitrogen. The effect of phosphorus has been found to be variable. Zandstra et al. (1969) found that phosphorus fertilizer decreased specific gravity. Kunkel et al. (1963) found that phosphorus had no effect on specific gravity.

Skin Development

The periderm can be defined as a protective tissue which usually replaces the outer tissues of stems and roots that undergo secondary thickening (Cutter 1978). It mostly arises from the cork cambium (phellogen) derived from the hypodermis. Young tubers have in addition a superficial periderm derived from the epidermis (Artschwager 1924). About 6 - 10 layers of cells are usually present but this can be modified by environment. A single periderm cell is almost brick shaped. Its walls become suberized later and this makes this layer impervious to gases (Artschwager 1924).

Lenticels develop on the periderm and the number varies depending on the size of the tuber, soil type under which the tuber was grown, and the weather (Cutter 1978). Meinl (1966) reported that moisture stress was important in lenticel development. These pores function in gas exchange. Hayward (1974) reported that fine outgrowths seen in the pores act as regulators of water loss,

Factors regulating the formation of the periderm are not well understood (Cutter 1978). Hormones are thought to be involved in periderm formation. Cutter (1978) stated that formation of the phellogen is inhibited by hormones produced by the actively growing shoot apex or young shoots.

Potatoes, when injured respond to the wound by the formation of a periderm referred to as "wound periderm" (Cutter 1978). Wounding stimulates cell division and this is followed by deposition of suberin (Lipetz 1970). During curing of potatoes, even in uninjured tissue, thickening of the skin occurs (Smith 1977).

The periderm is essential in the storage of potatoes because its development results in resistance to bacterial and fungal diseases (Smith and Smart 1955; Weiss et al. 1928). Moisture and weight loss are reduced and the subsequent shrivelling is prevented (Smith 1977).

The formation of the periderm varies between varieties (Struckmeyer and Binning 1983; Smith and Smart 1955). Vigor of the plant has an influence on the periderm development (Struckmeyer and Binning 1983). Murphy (1968) reported an increase in periderm development due to vine killing. Struckmeyer and Binning (1983) reported that the concentration of vine desiccant also influences the development of the periderm.

Artschwager (1927) found that no wound periderm developed at temperatures below 7°C while its development was most rapid at 35°C. Smith and Smart (1955) found that suberin or periderm was formed at 21°C to 27°C while lower temperatures resulted in less suberin deposition. Yamaguchi et al. (1964) working with Russet Burbank also found that thick periderm formed at high temperatures and such potatoes were more russeted than those grown under cool temperatures.

Certain chemicals have been reported to affect wound periderm development. Dainello and Fontenot (1971) found that Polyram, a complex of Zineb and polyethylene thiuramdisulfide applied as 7 percent dust to tubers had a favorable effect on suberization but did not stimulate wound periderm in the cultivars La Chipper, Red Lasoda, and L-31-155. Audia et al. (1962) found that isopropyl N-(3-chlorophenyl) carbomate (CIPC) inhibited periderm development in Katahdin potato tissues while suberin was less affected. Craft and Audia (1958) reported similar results. Audia et al. (1962) and Hendel (1957) reported that CIPC prevented cell division just below the cut surface of a potato although the cells were enlarged. Cunningham (1953) reported that the methyl ester form of naphthaleneacetic acid (MENA) delayed suberization and prevented periderm development in potato tissue while 2, 3, 5, 6- tetrachloronitrobenzene caused irregular development of suberin and delayed development of periderm. Struckmeyer and Binning (1983) found that paraquat treated tissues differentiated more periderm than Dow General (dinoseb) while diquat resulted in the least periderm development. As a result, paraquat gave the greatest resistance to disease organisms. However, all treatments were inferior to the controls. Weiss et al. (1928) reported that suberization alone did not prevent penetration of organisms such as Fusarium caeruleum (Lib.). Sacc.

Simonds et al. (1953) found that all the ortho-dihydric phenols used in their experiments, except protocatechuic acid, stimulated the formation of a thicker protective layer than was found in the controls, Dithane Z-78 delayed suberization while resorcinol, a meta-dihydric phenol, inhibited the process. Variation in thickness of suberized layers within individual tubers were shown. They also reported that

physical properties such as color, toughness, and elasticity of wound coverings formed were different between treatments.

In their work, Simmonds et al. (1953) thought that resorcinol retarded the process because of its interference with the action of tyrosinase, an enzyme thought to have a significant role in suberization. Johnson and Schaal (1952) thought that chlorogenic acid, one of the ortho-dihydric phenols used by Simmonds et al. (1953), acts in a manner similar to a wound healing hormone traumatin described by Bonner and English (1953). Johnson and Schaal (1952) thought that both chlorogenic acid, a substrate for tyrosinase, and the enzyme were involved in suberization.

Hollow Heart

Arteca et al. (1980) defined hollow heart as a hollow area or cavity formed within the tuber. This cavity is usually corklined and discolored. Before any cavity is formed, a necrotic area is noticed in the pith region of the tuber (Reeves 1968; Levitt 1942). Later, the areas of dead cells become surrounded by a wound cambium layer several cells in thickness (Dean et al, 1977). If the disorder progresses, a hollow area develops. The size of the cavity correlates with the size of the tuber. Sometimes the disorder does not progress beyond the stage of initial cell death, so the result is a brownish, discolored area in the pith tissue commonly referred to as "brown centre". This disorder is physiological in nature and it is affected by growth conditions (Hiller et al. 1979).

Two theories on the causes of hollow heart have emerged. Hiller et al. (1979), Crumbly et al. (1973), and Dinkel (1960) indicated that

hollow heart may initially be caused by subjecting potato plants to stress after tuber initiation. In the experiments of Crumbly et al. (1973), the stress factor was moisture. They reported that under moisture stress, the small tubers convert stored starch to soluble sugars which results in a reduction in water potential in the tuber. When the water demand in the plant is lower, the water is translocated rapidly into the tuber causing cell enlargement in the perimedullary region where water potential would be lowest. Growth differential between cells in the pith region and perimedullary region causes a rupture which develops into a cavity as growth resumes (Levitt 1942). Dinkel (1960) showed reabsorption of water, mineral nutrients, and carbohydrates from small tubers to tops causing injury to the tubers. The injured cells were unable to divide or enlarge even after stress was alleviated. Wolcott and Ellis (1959) found that small tubers were completely absorbed under stress conditions. The big tubers would not deplete their reserves possibly because they have a priority for carbohydrates over small tubers. Arteca et al. (1980) reported the shifting of calcium in tubers under stress. This shifting of calcium is thought to be involved in hollow heart formation. Low calcium in hollow heart tubers may be involved in weakening or destruction of cell walls and membrane integrity subsequently causing hollow heart.

The second theory on the cause of hollow heart states that it is induced by rapid tuber enlargement and that stress is not necessary for its induction. This theory is based on results from Norgold Russet and Russet Rural (Moore and Wheeler 1928; Nelson and Thoreson 1974). The work of Krautz and Lana (1942) may support both theories because plant defoliation experiments increased hollow heart by causing stress (theory one) or by delaying senesence so tubers enlarged rapidly during the cool wet fall weather (theory two).

Factors Influencing Hollow Heart: Hollow heart has been reported by a number of workers to be more prevalent in large tubers (Finney and Norris 1978; Nelson and Thoreson 1974; Kallio 1960; Nylund and Lutz 1950; Levitt 1942). It can also occur to a lesser extent in smaller tubers (Kallio 1960; Levitt 1942). The severity of the disease varies with the growing area, growing season, variety (Harvey 1938), and cultural practices.

Nelson (1970) found that hollow heart was serious when the stand was thin. Nelson et al. (1979) found that close spacing was very effective in reducing hollow heart. Thin stands reduce competition between plants, thus causing the plant to grow vigorously and maintain rapid rate of tuber growth (Nelson et al. 1979). Rapid vine growth during tuber enlargement has been shown to enhance hollow heart (Krautz 1947; Levitt 1942).

Potassium has been found to reduce hollow heart (Nelson 1970; Kallio 1960). However, in soils with high potassium, application of potassium reduced hollow heart whereas in soils with potassium deficiency, its application increased hollow heart (Moore 1927 and 1926). Nitrogen was found to increase the incidence of hollow heart (Kallio 1960). This is in contrast to the results of Button and Hawkins (1958) who found that soil and foliar application of nitrogen did not increase the incidence of hollow heart in the cultivar Katahdin. Harvey (1938) found that when Irish Cobbler potatoes were grown on various soils, the incidence of hollow heart increased in the order: light sandy soil, clay loams, gumbo, sandy shallow peat, deep peat.

Nelson et al. (1979) found that the incidence of hollow heart was lowest in Norgold Russet when temperatures following tuber initiation and rainfall were low. Hiller and Koller (1982) found that high soil moisture increased hollow heart severity. Van Denburgh et al. (1979) found that

plants that set tubers before warm weather exhibited extensive brown centre development. Nelson (1970) also found that temperatures below normal favor development of hollow heart.

Hollow heart was found to increase with an increase in the number of days and amount of rainfall between tuber initiation and plant killing (Nelson et al. 1979). Wolcott and Ellis (1959) found that injury was more severe in cultivars grown under conditions of artificially maintained moisture supply than when grown under drought conditions. These two researchers found that necrotic symptoms were first observed during or just after periods of rising temperature or of improved moisture situations following periods of low temperature or drought. They believed that the effects of temperature and moisture are not direct but act indirectly by regulating the basic metabolism of the plant. This contradicts Van Denburgh et al. (1979) who showed that the effect of low temperature is directly on the tubers rather than on the entire plant.

Root pruning was found to reduce hollow heart (Nelson and Thoreson 1974). This treatment was found to be effective only when done early in the season. They found that sub-lethal rates of dinoseb, a potato vine killer, had a similar effect though not as pronounced as the root pruning treatment.

Detecting Hollow Heart Tubers: Hollow heart is difficult to detect by a non-destructive method because hollow heart tubers look normal from the outside. Differences other than the cavity or brown centre have been found but they are not helpful in sorting defective tubers. Crumbly et al. (1973) working with Irish Cobbler observed that tubers with hollow heart grew at a faster rate than normal ones. Jadhav et al. (1980) found that tubers

with hollow heart and black heart contained more glycoalkoid than normal ones. Arteca et al, (1980) showed that tubers with hollow heart showed nutrient relocation or shifting.

Tuber sizing and specific gravity have been used in the separation of hollow heart tubers from normal tubers (Finney and Norris 1978; Nelson et al. 1979; Nylund and Lutz 1950). An X-ray technique is also used as a non-destructive detection of hollow heart (Finney and Norris 1978 and 1973; Nylund and Lutz 1950; Harvey 1938). Birth (1960) also described a technique of non-destructively detecting internal discoloration in potatoes by light transmittance.

M A N U S C R I P T S

The Influence of Mefluidide on Yield, Maturity, Specific Gravity, Skin Set, Storage Performance and Chip Color of Potato (*Solanum tuberosum* L.) Cultivars Russet Burbank, Norland and Norchip.

Abstract

Mefluidide {N- 2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino] phenyl] acetamide} a plant growth regulator was applied to the foliage of potatoes (Solanum tuberosum L.) before harvest to determine its effects on yield, maturity, processing quality and storage characteristics. Mefluidide tended to slow down the rate of loss of sucrose in the potato cultivars Russet Burbank, Norland, and Norchip. Total as well as marketable yield was reduced in all cultivars while specific gravity varied depending on the cultivar. There was a tendency to increasing specific gravity in Russet Burbank and Norchip with increasing rates of mefluidide up to 1.00 kg ai/ha then declining at 2.00 kg ai/ha. In Norland, specific gravity decreased in treated tubers.

Skin russetting increased in mefluidide-treated tubers. There was an increase in thickness of the suberized layer of treated Norland and Norchip tubers. Skin color in Russet Burbank and Norchip darkened while in Norland it changed from red to yellowish brown. The amount of anthocyanin was reduced in mefluidide treated Norland tubers. Flesh color was not affected in any of the cultivars. Lighter chips were produced from mefluidide-treated Norchip tubers.

In storage, mefluidide delayed sprout growth of Norland and Norchip potatoes and caused excessive weight loss in all treated tubers of all cultivars.

Tubers treated with mefluidide after harvest responded similarly in skin russetting, skin color change, and sprout growth to field treated tubers.

Introduction

The acceptance of potatoes for processing into french fries and chips depends on the tubers having low amounts of reducing sugars, having a high specific gravity, and being relatively free of bruising and disease.

It is known that tubers with large amounts of reducing sugars produce an unacceptable product when processed. The reducing sugars present in these tubers react with certain amino acids during frying and cause excessive browning in french fries and chips (Owings et al. 1978; Weaver et al. 1978). Sowokinos (1978) reported that tubers with low amounts of sucrose at harvest stored better and accumulated less reducing sugars when stored at intermediate temperatures.

Research has shown that a thick skin on tubers reduces bruising at harvest, lessens disease attack, and reduces water loss in storage (Struckmeyer and Binning 1983; Smith and Smart 1955). Currently, growers often mechanically or chemically vine-kill potatoes before harvest to enhance skin set while the tubers are still in the field in order to reduce bruising and damage during harvest and handling.

Potato tubers with a high specific gravity are better suited for processing as they absorb less oil during cooking and give a higher recoverable yield after processing than tubers with lower specific gravity (Lulai and Orr 1979). Potatoes with high specific gravity usually accumulate less reducing sugars in storage (Iritani and Weller 1976).

Mefluidide, a plant growth retardant with herbicidal properties, has been reported to improve skin development, enhance maturity, increase specific gravity, and increase yield in Kennebec, Denali and Russet Burbank cultivars of potatoes (Parker personal communication). Mefluidide might be

affecting plant growth by affecting DNA-directed RNA synthesis which in turn affect the rate of protein synthesis (Jersey and Glenn unpublished). Truelove et al. (1977) suggested the possibility of mefluidide changing the membrane structure and permeability.

The purpose of this study was to determine the effects of mefluidide on skin development, chemical maturity, specific gravity, yield and storage life of potato cultivars Russet Burbank, Norland and Norchip when applied to the crop before harvest.

Material and Methods

Field experiments were conducted near Carman, Manitoba in 1981 and 1982 on a sandy loam soil. Two cultivars of potato, Norland and Russet Burbank were used in the trials in both years while Norchip was included in 1982. The experimental design was a randomized completed block with randomization of mefluidide[1] rates within each block. There were four replications. Each plot was a single row 15 m long in 1981 and 18 m long in 1982. The experimental area was sprayed with Eptam (3.5 kg ai/ha) before seeding for weed control. Seeding was done on May 17 in 1981 and on May 31 in 1982. Plant spacing was 95 cm between rows. Within row spacing was 42 cm for Russet Burbank, 22 cm for Norchip and 29 cm for Norland. Seeding was done using an Iron Age Single Row Manual Feed Planter. Fertilizer was applied at planting at 76 kg/ha N, 76 kg/ha P_2O_5, and 76 kg/ha K_2O. Hilling was done when plants were about 30 cm high. Weeding was done by hand throughout the growing period. Plant counts were done on July 7 in 1981 and on June 26 in 1982.

Mefluidide at 0, 0.25, 0.50, 1.00 or 2.00 kg ai/ha was applied one month before harvest in all the cultivars in both years. In 1981, a hand held single, flat-fan nozzle sprayer was used, while in 1982, a CO_2 backpack sprayer with a single, flat-fan nozzle was used. The output for both sprayers was 150 L/ha at 276 kPa pressure.

In 1981, Norlands were sprayed with mefluidide on August 7 and were harvested on September 10. Russet Burbanks were treated on September 2 and were harvested on October 2. In 1982, Norlands and Norchips were

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[1]Mefluidide was obtained from 3M, Agricultural project, St. Paul, Minnesota.

treated on August 16 and were harvested on September 13 and 15, respectively. Russet Burbanks were treated on September 3 and were harvested on October 24.

Sucrose determinations were done on potato samples every seven days from the time of treatment to time of harvest. From each plot, 6 m were used for sucrose determination for both cultivars in 1981 and for Russet Burbanks in 1982 while 9 m were used for Norchips and Norlands in 1982. The remainder of the plot was used for the determination of yield, specific gravity, hollow heart, storage, skin set, and in the case of Norchips, chip quality.

Evaluations

Sucrose Rating (SR) Determination (as described by Sowokinos 1978)

Sucrose Extraction: Five average sized tubers were selected from each sample of tubers harvested from five plants per treatment. The tubers were washed, peeled, and cut into small pieces and 200 g of the pieces were taken and the juice was extracted from them in a Braun vegetable juicer. Cold water was slowly poured into the juicer to remove as much sucrose from the pulp as possible. The extract volume was taken to 430 ml with cold water and it was allowed to settle in an ice bath for 1 hour after which it was poured into bottles and stored at -20°C.

Anthrone Preparation: Anthrone was prepared by mixing 150 mg anthrone with 106 ml diluted sulfuric acid (H_2SO_4). The H_2SO_4 was diluted by adding 76 ml concentrated H_2SO_4 to 30 ml of water. The anthrone solution was stirred for approximately 2 hours to dissolve all the anthrone and was stored in a brown bottle at 4° C. New anthrone was made after every two weeks.

Sucrose Determination: The microdetermination of sucrose developed by Van Handel (1968) was used. The tuber extract was removed from the freezer and was defrosted at room temperature. The extract was diluted by adding 1 ml extract to 4 ml water, then 0.1 ml of the diluted extract was placed into a test tube. Each sample was run in triplicate and reagent blanks of 0.1 ml water and sucrose standard (0.1 ml = 0.1 mg) were run to verify each group of determinations. To each test tube, 0.1 ml 30% KOH was added. The mixture was heated at 100°C for 15 minutes to destroy reducing sugars. The samples were then cooled to room temperature and 3 ml of anthrone reagent were added. The samples were incubated in a water bath at 40°C for 40 minutes after which they were allowed to cool to room temperature and absorbance readings were taken at 620 nm. Sucrose Rating (SR) was calculated from the equation:

$$OD_{extract} \times 0.1 \text{ mg Sucrose} \div OD_{STD} \times 107.5_{\substack{\text{dilution} \\ \text{factor}}} = \text{mg sucrose/g tuber} = SR$$

where

$OD_{extract}$ = Absorbance reading of the extract

OD_{STD} = Absorbance reading of the standard

The dilution factor was calculated from the equation:

$$\frac{430 \text{ ml (total extract)}}{0.1 \text{ ml (assay volume)}} \times 5 \text{ (extract dilution} \div 200 \text{ g tuber} = 107.5)$$

The dilution factor sometimes changed, depending on the total extract volume.

Yield

Tubers were machine harvested using a McEvan Tougard Single Row Potato Harvester with bagger. Grading was done within 10 days after harvesting and tubers were placed in the following categories:

(i) Undersized--tubers less than 5 cm in diameter

(ii) Marketable size--tubers between 5.00 and 8.75 cm diamter

(iii) Oversized--tubers greater than 8.75 cm diameter

Total tuber weight as well as weight per category were determined. Malformed tubers were also recorded.

Specific Gravity

Clean tubers were taken from the marketable grade and were weighed first in air, then in water using a Mettler PL 3000 balance. The water temperature was maintained at approximately 18°C. Specific gravity was calculated from the formula:

$$\text{Specific Gravity (SG)} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

Hollow Heart

Tubers were grouped according to their sizes into three categories, i.e., less than 5 cm, 5 - 6 cm, and over 6 cm diameter within a treatment. Hollow heart was determined by cutting the tubers vertically in the middle. Percent hollow heart was calculated for each group.

Skin Measurement

Five tubers were taken from each treatment and five cross sections of the skin were randomly taken from each tuber and observed under a light microscope. Skin thickness was measured by connecting a TV screen to the microscope. The section was put onto a slide and was covered with a cover slip. The slide was then placed under the microscope. The image of the section was projected on the pre-calibrated screen and the thickness of the suberized layer was measured. A stage micrometer was used to calibrate the screen and this made it possible to convert screen measurements of millimeters to actual measurements in micrometers.

The tubers from the marketable grade were also rated visually for skin russetting and/or color on a scale of 1 to 5; 1 = heavy russetting and/or skin color change, 5 = no russetting and/or skin color change.

Anthocyanin Determination

Since mefluidide was seen to affect color in Norlands, in 1982 tubers from each treatment of Norland potatoes were taken for anthocyanin determination. The method used by Grill and Vince (1964) was adapted for this experiment. The skin from five tubers of each treatment was scrapped and 1 g of the scrapped skin was ground. To the ground tissue, 15 ml of 1% Hydrochloric acid (HCL) (v/v) was added and was left for 48 hours at 4°C. After 48 hours, the samples were centrifuged and the supernatants were diluted 1:1 with 1% HCL. Absorbance at 512 nm was recorded for the diluted supernatants using a Zeiss spectrophotometer.

Chip Quality

Five tubers were selected from the marketable grade of Norchip from each treatment. The tubers were washed, peeled and three slices 1 mm thick were taken from the center of each tuber. The chip slices were washed with lukewarm water to remove excess starch then they were wrapped in paper towelling to remove excess water. The frying was done in a Garland electric deep-fryer using Canola oil from Canada Packers Ltd. at 185° C. Chips were removed when bubbling ceased. After cooling them to room temperature, they were placed into plastic bags which were sealed until color rating determination. Color ratings were done by reading L-values of the chips on a Hunterlab spectrophotometer Model D25. The L-values were then converted to Agtrons using the equation:

$$\text{Agtron} = \text{HL} \times 1.24427 - 17.3943$$

where

HL = L-values

Storage

Tubers were weighed and placed in storage at 10°C and relatively humidity of 80% from September 1982 to May 1983. The tubers were checked twice a month for sprout growth. At the end of the storage period, tubers were weighed and their percentage weight loss was determined. To see if mefluidide would have a similar effect on tubers treated after harvest, untreated freshly harvested tubers were sprayed with mefluidide to wetness using a hand held mist sprayer at the same concentrations as those used in the field. The tubers were left to dry and were placed in the storage room and were checked twice a month for any visible changes.

Statistical Analysis

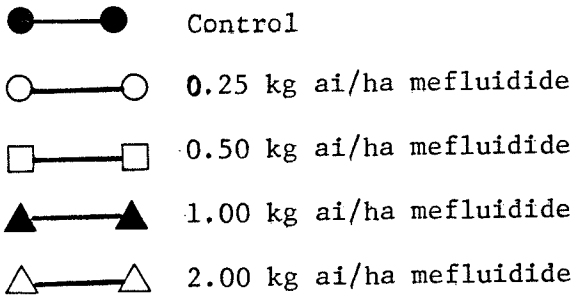
All the data except skin ratings were analyzed following the standard procedure for analysis of variance. Square root transformation, $x = \sqrt{x + .5}$, was done on sucrose rating and Norchip sprout growth data to reduce large variations observed within treatments. Analysis of covariance was done on yield data to correct for plant stand. Duncan's multiple range test or Least Significant Difference (LSD) test at 5 percent level were used to test differences between means.

Results and Discussion

Sucrose Rating

Sucrose Rating (SR) values for all potato cultivars except Russet Burbank in 1981 were highest at the time of spraying with mefluidide and decreased with time reaching lowest values at harvest (Figures 1, 2 and 3).

Figure 1. Changes in sucrose content from time of treatment to time of harvest in potato cultivar Russet Burbank foliar sprayed with mefluidide.



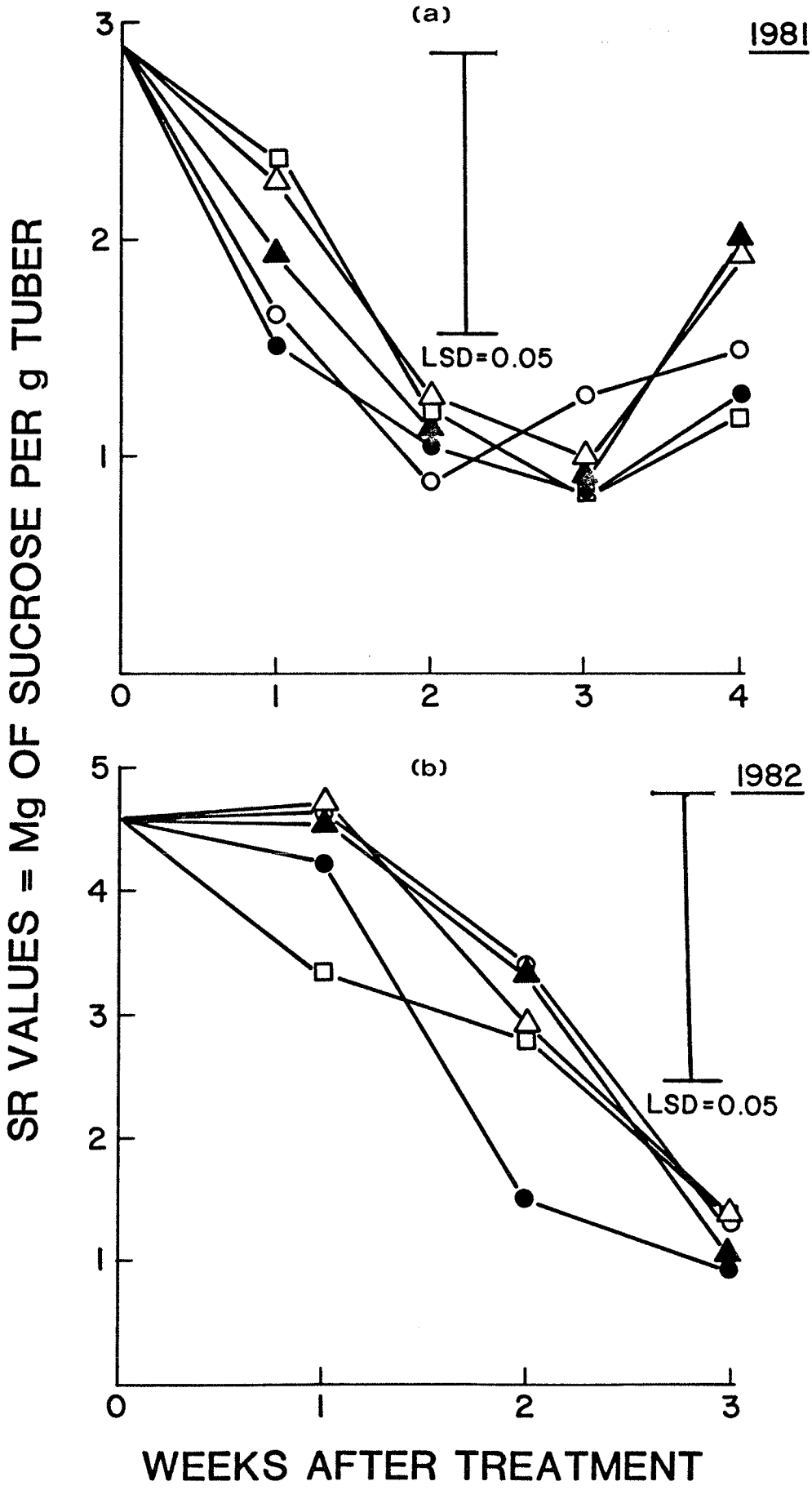
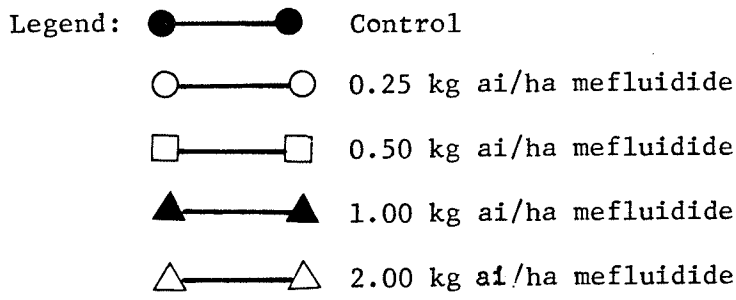

(a)
1981
LSD=0.05
(b)
1982
LSD=0.05
SR VALUES = Mg OF SUCROSE PER g TUBER
WEEKS AFTER TREATMENT

Figure 2. Changes in sucrose content from time of treatment to time of harvest in potato cultivar Norland foliar sprayed with mefluidide.



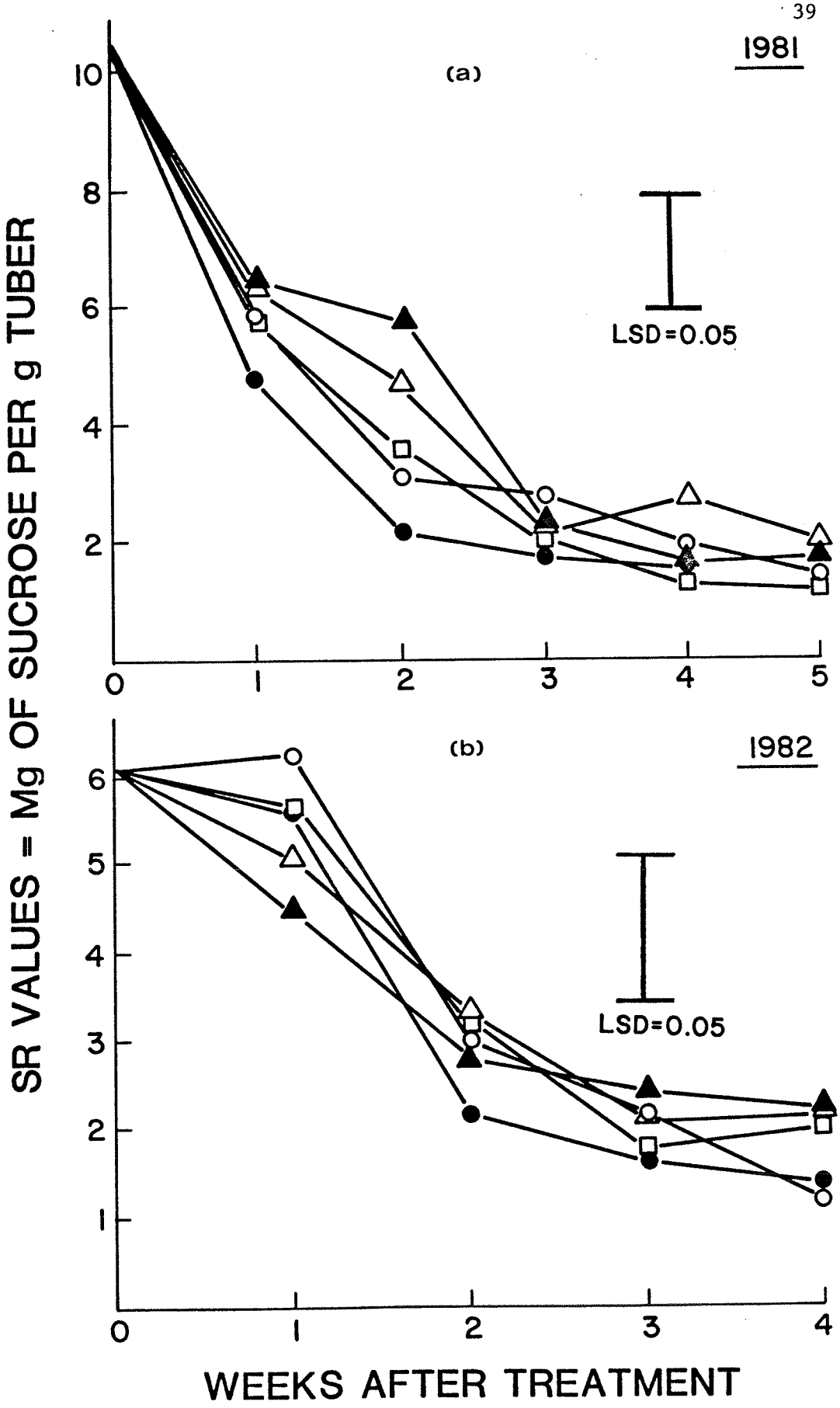
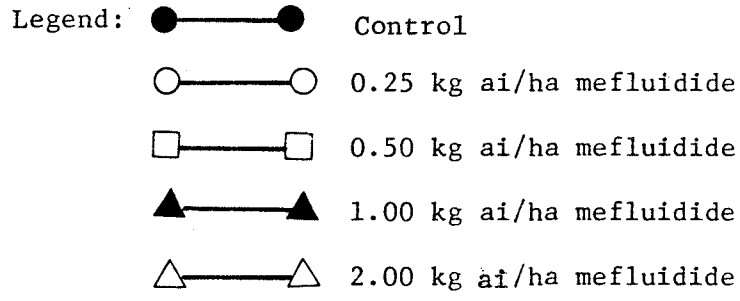
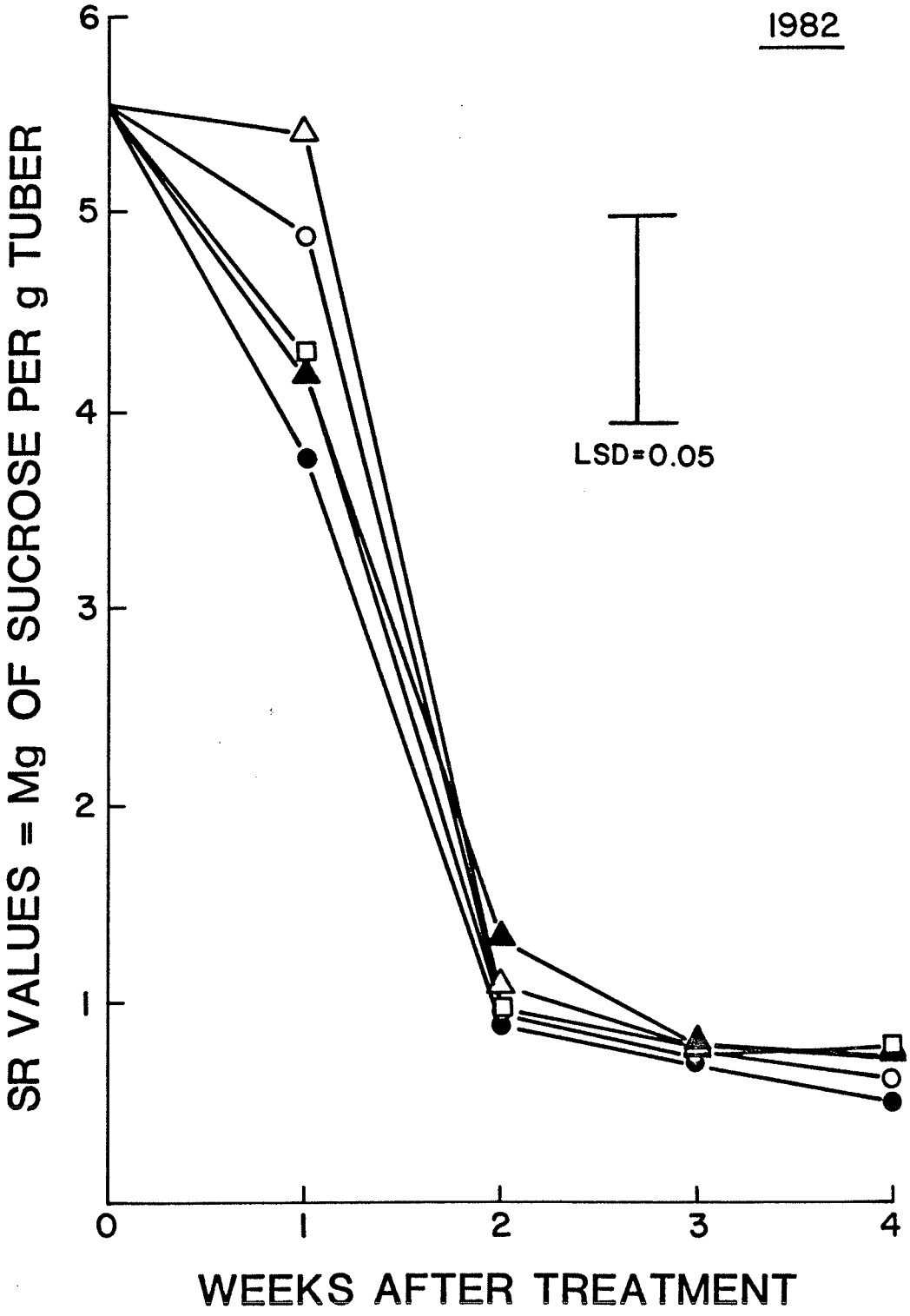

1981
(a)
LSD=0.05
1982
(b)
LSD=0.05
SR VALUES = Mg OF SUCROSE PER g TUBER
WEEKS AFTER TREATMENT

Figure 3. Changes in sucrose content from time of treatment to time of harvest in potato cultivar Norchip foliar sprayed with mefluidide.




1982
LSD=0.05
SR VALUES = Mg OF SUCROSE PER g TUBER
WEEKS AFTER TREATMENT
0
1
2
3
4
5
6

The largest drop in SR values occurred from the time of treatment (week 0) to the second week after treatment. Thereafter the decrease in SR values was not as pronounced indicating that the tubers were reaching chemical maturity. The SR values for Russet Burbank in 1981 showed an increase before harvest (Figure 1a). The high SR values observed at harvest for Russet Burbank in 1981 were likely a response to stress which was due to mechanical damage to the tops and tubers caused by a harvester passing over the plots before the last sampling date, Stress conditions have been shown to cause an increase in sucrose content of potato tubers (Shekhar and Iritani 1978; Iritani and Weller 1978). The SR values reported in this study are less than those reported by Sowokinos (1978). This is probably because of the differences in juicers used.

Mefluidide seemed to have increased the amount of sucrose in tubers as the control tubers generally had lower SR values throughout the sampling period for all cultivars tested. Statistically significant differences between treatments were difficult to determine because of the extreme variations observed between plots, between tubers within a treatment and between tubers within a vine (data not shown). Other workers have also reported large variations in sucrose content of potatoes. Iritani and Weller (1976) reported differences in sucrose content within a tuber. In our experiments, variations within a cultivar were largest in Russet Burbank with a coefficient of variation (CV) of 20 of the transformed data, followed by Norland with a CV of about 16 while Norchip was the least with a CV of about 11. The CV's of the raw data were three times these values.

Although mefluidide treated potatoes seemed to have reached SR values ($\leq$ 2.8 mg sucrose/g of tuber) acceptable for storage in processing tubers,

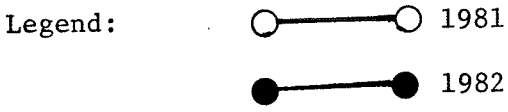
it is possible that the slight increase in sucrose observed in these tubers could be harmful to long-term-stored potatoes. Gates (1975) reported an increase in recoverable sugar in sugarcane due to mefluidide. It is, therefore, unlikely that mefluidide enhances chemical maturity of potatoes but in fact may retard it. It is possible that the other workers (Parker personal communication) who did the original work with mefluidide on potatoes did not look at the internal chemical composition of the tuber and suggested that mefluidide speeded maturity based only on the physical appearance of the tuber skin.

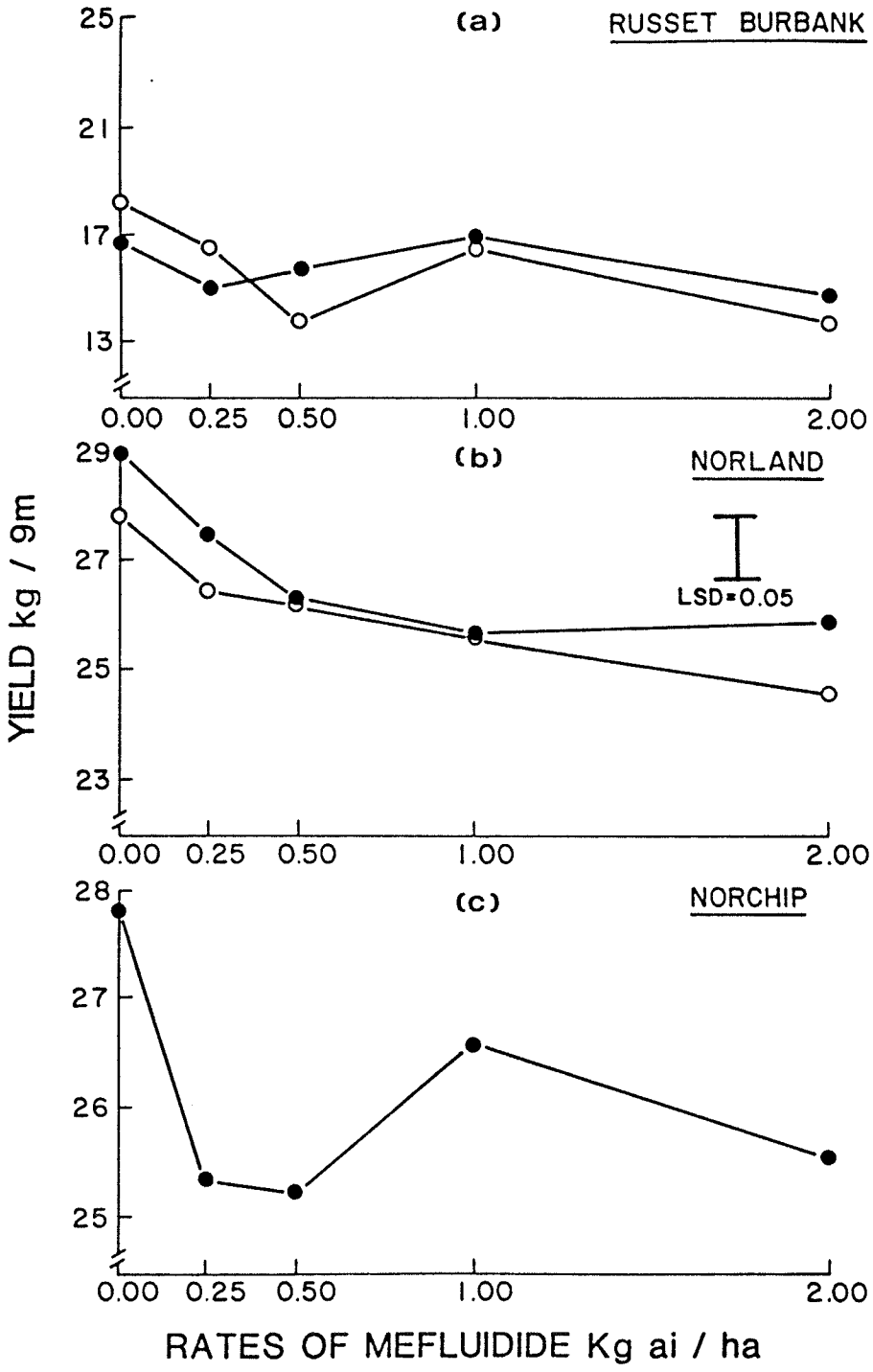
Yield

Mefluidide treatment tended to reduce total yields of potato tubers in all cultivars tested (Figure 4). Russet Burbank and Norland response to the chemical was similar in both test years (Figure 4a and 4b). Total tuber yield in Norland in 1982 was significantly reduced in the 1.00 and 2.00 kg ai/ha mefluidide treatments when compared to the control (Figure 4b). Though no significant differences were detected in Norland 1981 and Norchip (Figure 4b and 4c), the control treatments had higher total yields than all mefluidide treatments. Russet Burbank had a similar response despite the mechanical damage to most tubers one week before harvest in 1981 and the frost that hit the crop twice in 1982 (Figure 4a). The first frost which occurred seven days before treating the plants with mefluidide slightly damaged the crop. The second frost which occurred three weeks after treatment severely damaged the crop so the tubers were harvested before the anticipated harvest date.

Both Russet Burbank and Norchip showed a less reduction in total tuber yield at the 1.00 kg ai/ha rate over the other chemical rates.

Figure 4. Total yield of the potato cultivars Russet Burbank, Norland and Norchip to foliar mefluidide applied 3 to 5 weeks before harvest.




(a)
RUSSET BURBANK
25
21
17
13
0.00
0.25
0.50
1.00
2.00
(b)
NORLAND
LSD=0.05
29
27
25
23
(c)
NORCHIP
28
27
26
25
YIELD kg / 9m
RATES OF MEFLUIDIDE Kg ai / ha

However, these yields did not exceed the control yields. Previous research (Parker personal communication) had showed an increase in tuber yield in the cultivars Russet Burbank, Denali and Kennebec.

Marketable yield for all cultivars followed the same trend as the total yield (Appendix Table 1.) (no data were recorded for Russet Burbank in 1981). Oversized tubers (Appendix Table 2) and malformed tubers (Appendix Table 3) were also determined but no meaningful results were obtained.

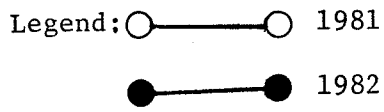
Mefluidide was shown to reduce potato vine growth and reduced early tuber fresh weight in the growth chamber studies performed (discussed in manuscript 2 of this thesis). A similar effect on the vine in the field could have been possible and this could have contributed to the yield reductions observed. Truelove et al. (1977) reported a reduction in chlorophyll a in mefluidide treated corn plants. Similarly this could have happened in the potato plants thus reducing the photosynthetic capacity of the leaves.

Specific Gravity

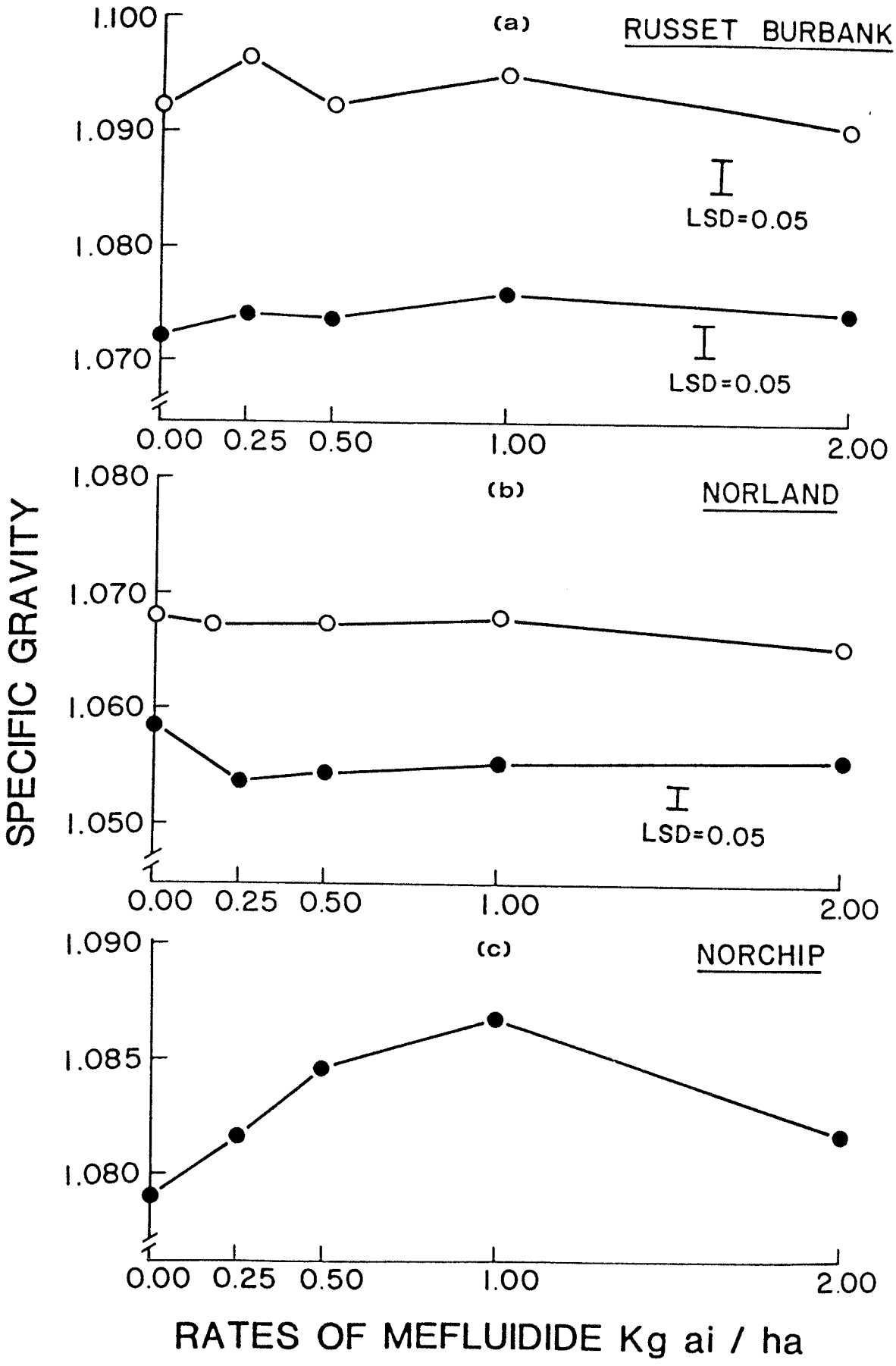
The specific gravity readings for the three potato cultivars (Figure 5) showed higher values in 1981 than in 1982 for Russet Burbank and Norland. Others (Lana et al. 1970) have reported specific gravity readings for a cultivar to vary from one year to another depending on environment.

There was a significant difference between treatments in Russet Burbank in 1981 (Figure 5a). Treatments 0.25 and 1.00 kg ai/ha mefluidide had the highest specific gravity readings but only the 0.25 kg ai/ha treatment was significantly greater than the control. In 1982, the 1.00 kg

Figure 5. Specific gravity of Russet Burbank, Norland and Norchip potato tubers treated with foliar mefluidide 3 to 5 weeks before harvest.



Note: differences in scale between Norchip and the other two cultivars.


(a)
RUSSET BURBANK
1.100
1.090
1.080
1.070
LSD=0.05
LSD=0.05
0.00 0.25 0.50 1.00 2.00
(b)
NORLAND
1.080
1.070
1.060
1.050
LSD=0.05
0.00 0.25 0.50 1.00 2.00
(c)
NORCHIP
1.090
1.085
1.080
0.00 0.25 0.50 1.00 2.00
SPECIFIC GRAVITY
RATES OF MEFLUIDIDE Kg ai / ha

ai/ha rate was the only treatment with a specific gravity reading significantly greater than the control. In Norchip, in 1982 (Figure 5c), there were no significant differences between treatments but a trend was observed with specific gravity readings increasing with increasing rates of mefluidide up to 1.00 kg ai/ha. The results for Norland for both years indicated a slight decrease in specific gravity due to mefluidide (Figure 5b). In 1981, the control had the highest specific gravity while in 1982, although no significant differences were detected, a similar trend as that in 1981 was observed.

The increase in specific gravity for Russet Burbank and Norchip due to mefluidide application could be of importance to the potato processing industry. Iritani and Weller (1976) reported that low specific gravity Russet Burbank potatoes tended to be more variable in sugar accumulation between stem and bud portions, and accumulated more sugars than high specific gravity potatoes. Potatoes with high specific gravity have also been reported to recondition better than low specific gravity tubers (Lyman and Mackey 1961). Chip and french fry quality is also improved with higher specific gravity.

Hollow Heart

The results obtained for hollow heart were not meaningful because of the extreme variability that was observed between plots (Appendix Table 4). Nelson and Thoreson (1974) reported that the extreme variability that occurs between plots made even eight replications insufficient to measure hollow heart differences between treatments that are large enough to be economically significant. Data (Parker personal communication) indicated an increase in hollow heart due to mefluidide treatment.

Tuber Skin Measurement

Mefluidide increased the thickness of the suberized layer of Norland and Norchip potatoes (Table 1). The thickness of the suberized layer increased with increasing rates of mefluidide. Skin thickness of Russet Burbank was not determined. Ratings for skin russetting and/or skin color change are shown in Figure 6. In all cultivars, russetting increased with increasing rates of mefluidide (Plates 1, 2 and 3). There were big differences in skin set between the control tubers and those treated with the highest rate of mefluidide (2.0 kg ai/ha) (Plate 4). Mefluidide caused skin russetting even in Norland and Norchip which are non-russetting cultivars under normal conditions. Enhanced russetting of white potatoes may be advantageous for fresh market as heavy russetting is often associated with a good table potato.

Mefluidide also affected the color of the treated tubers of the three cultivars tested. The Norland potatoes were the most severely affected (Plate 1). The skin lost its red appearance and developed more brown color as the rate of mefluidide increased. In Russet Burbank and Norchip, increasing rates of mefluidide caused darkening of the tubers (Plates 2 and 3). Although mefluidide affected the skin color of the tubers, no visible changes were noticed in the flesh of the tubers in any of the cultivars tested. Though mefluidide might have a favorable effect on skin development in potatoes, it would not likely be used in the fresh market of Norland because of its deterimental effect on the skin color.

Perhaps the most beneficial effect of mefluidide in the production of potatoes would be for enhancing the skin development on the tubers. Bruising and damage of tubers during harvest and handling of potatoes causes a great deal of product loss. Growers currently chemically or

TABLE 1. Effect of Mefluidide on skin thickness in the potato cultivars Norland and Norchip when applied as a foliar spray before harvest

Mefluidide (Kg ai/ha)	NORLAND		NORCHIP	
	Thickness of suberized layer (μ)	Range recorded in suberized layer thickness (μ)	Thickness of suberized layer (μ)	Range recorded in suberized layer thickness (μ)
Control	148.44 d*	108.33 - 180.56	153.00 c	125.00 - 191.67
0.25	170.35 d	111.11 - 238.89	168.76 c	136.11 - 219.44
0.50	203.33 c	166.67 - 277.78	215.22 b	161.11 - 263.89
1.00	288.85 b	225.00 - 330.56	317.67a	247.22 - 358.33
2.00	322.22a	250.00 - 372.22	318.96a	225.00 - 380.56

*Means with the same letters in a column are not significantly different from each other.

Figure 6. Ratings for skin russetting and color change in the potato cultivars Russet Burbank, Norland and Norchip after field application of mefluidide.

5 = normal skin

1 = very russetted and/or color change

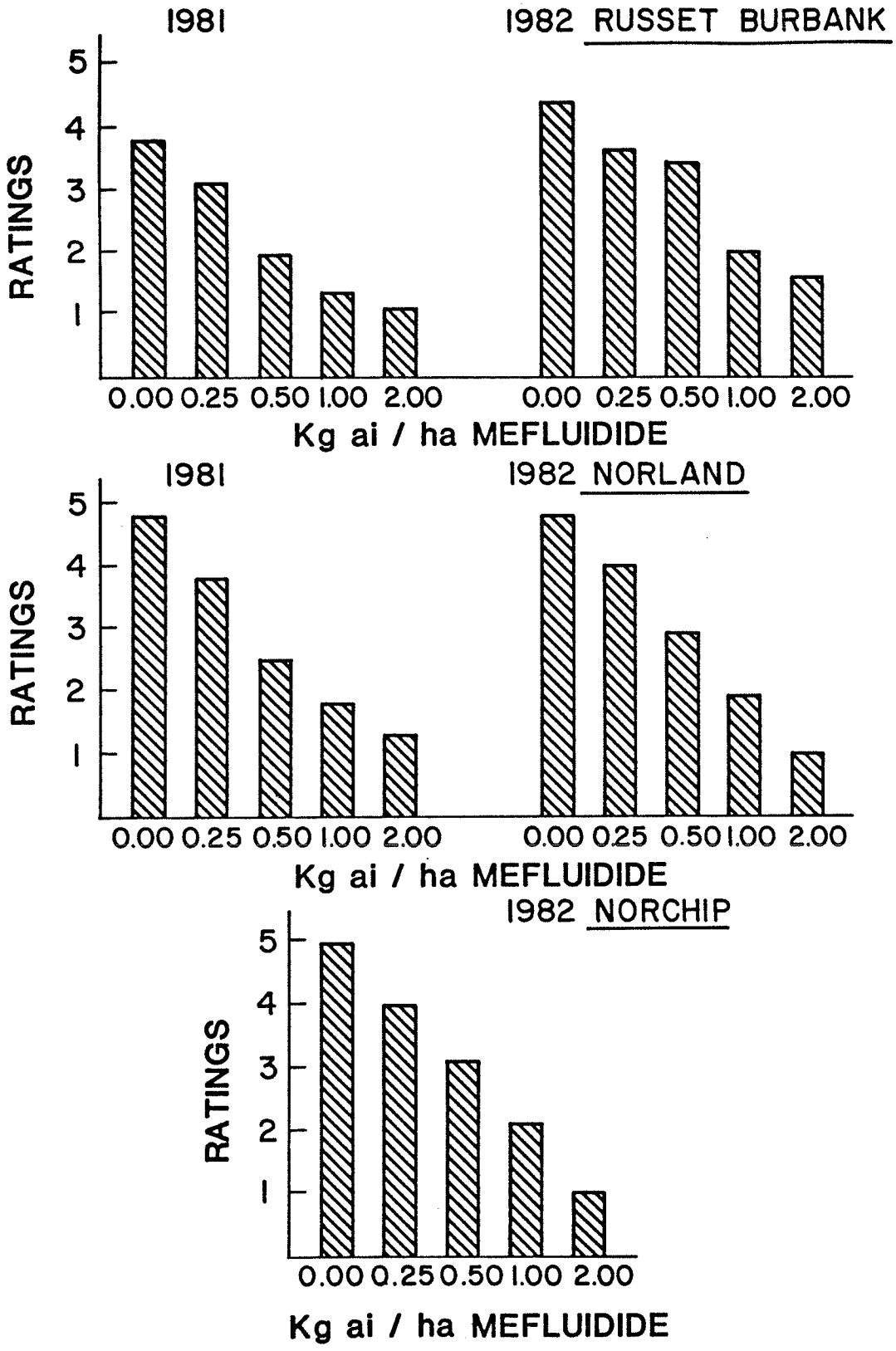
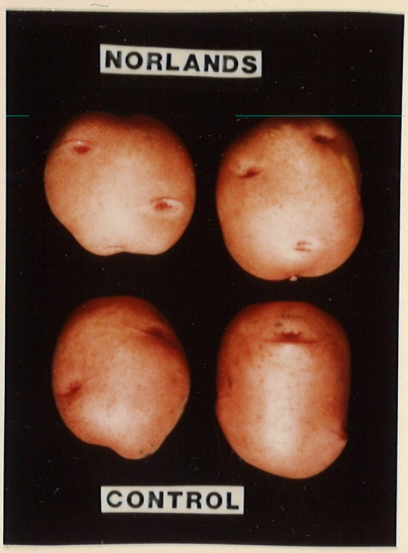
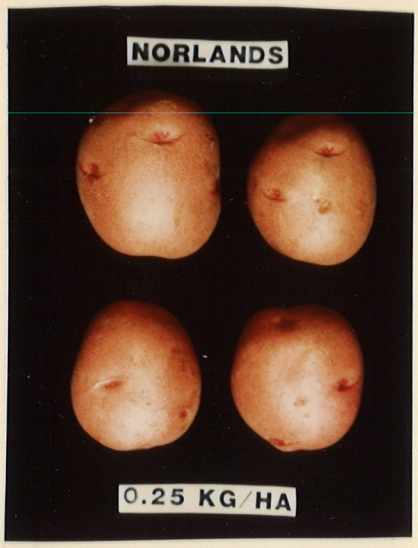
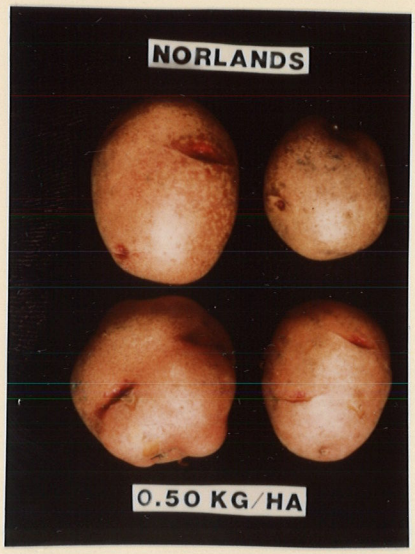
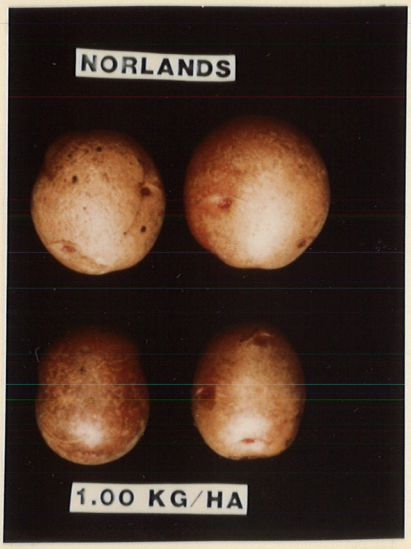

1981
1982 RUSSET BURBANK
RATINGS
5
4
3
2
1
0.00 0.25 0.50 1.00 2.00
0.00 0.25 0.50 1.00 2.00
Kg ai / ha MEFLUIDIDE
1981
1982 NORLAND
RATINGS
5
4
3
2
1
0.00 0.25 0.50 1.00 2.00
0.00 0.25 0.50 1.00 2.00
Kg ai / ha MEFLUIDIDE
1982 NORCHIP
RATINGS
5
4
3
2
1
0.00 0.25 0.50 1.00 2.00
Kg ai / ha MEFLUIDIDE

Plate 1. Skin russetting and changes in skin color of Norland potatoes foliar treated with mefluidide 4 weeks before harvest.


NORLANDS
CONTROL

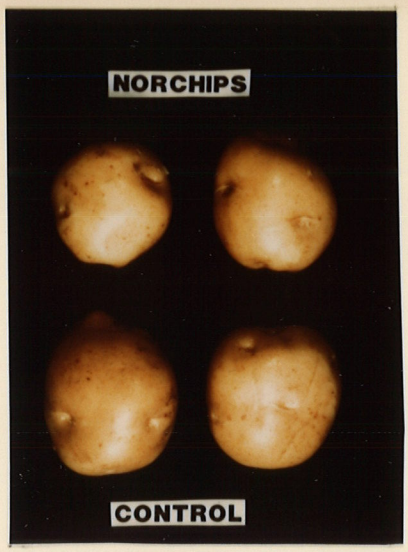

NORLANDS
0.25 KG/HA


NORLANDS
0.50 KG/HA

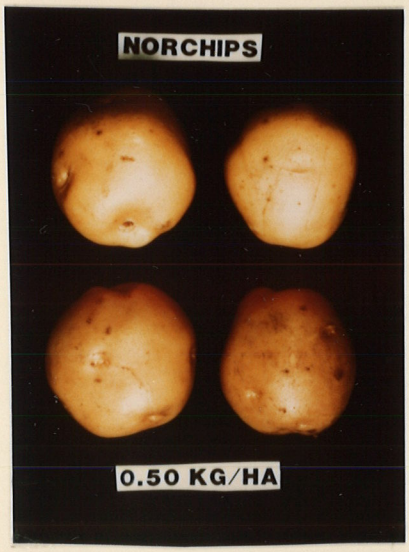

NORLANDS
1.00 KG/HA


NORLANDS
2.00 KG/HA

Plate 2. Skin russetting and changes in skin color of Russet Burbank potatoes foliar treated with mefluidide 4 weeks before harvest.


NORCHIPS
CONTROL


NORCHIPS
0.25 KG/HA


NORCHIPS
0.50 KG/HA


NORCHIPS
1.00 KG/HA


NORCHIPS
2.00 KG/HA

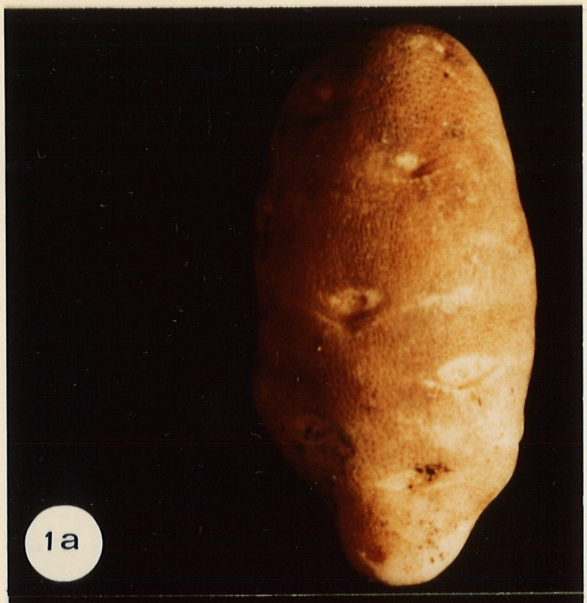
Plate 3. Skin russetting and changes in skin color of Norchip potatoes foliar treated with mefluidide 4 weeks before harvest.

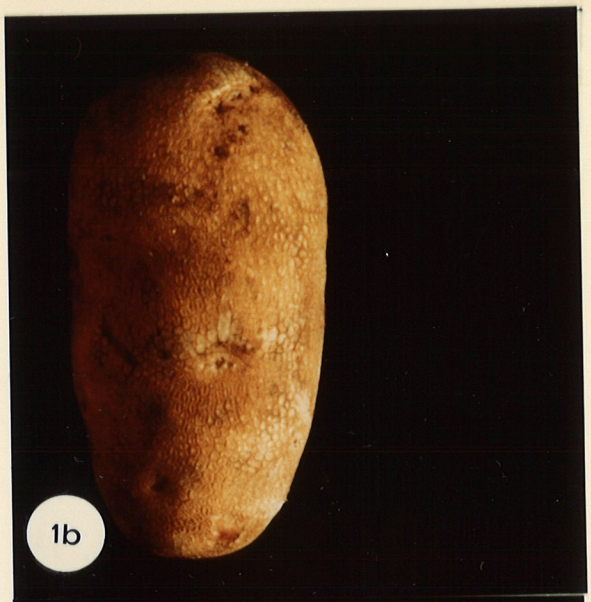
RUSSET BURBANK

Plate 4. Differences in skin set and color between control tubers and those treated with highest mefluidide rate (2.00 kg ai/ha).

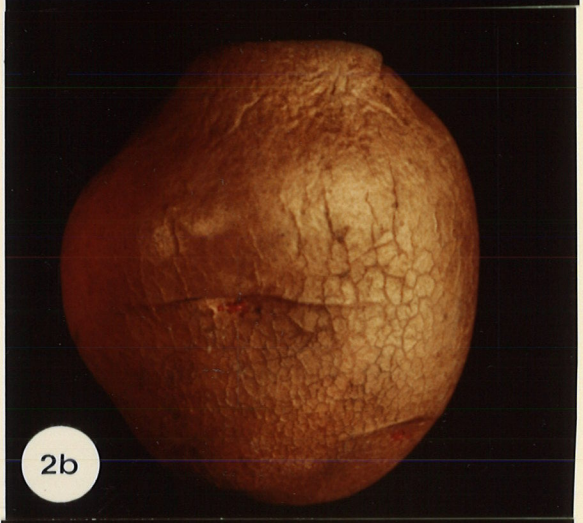
1 = Russet Burbank
2 = Norland
3 = Norchip

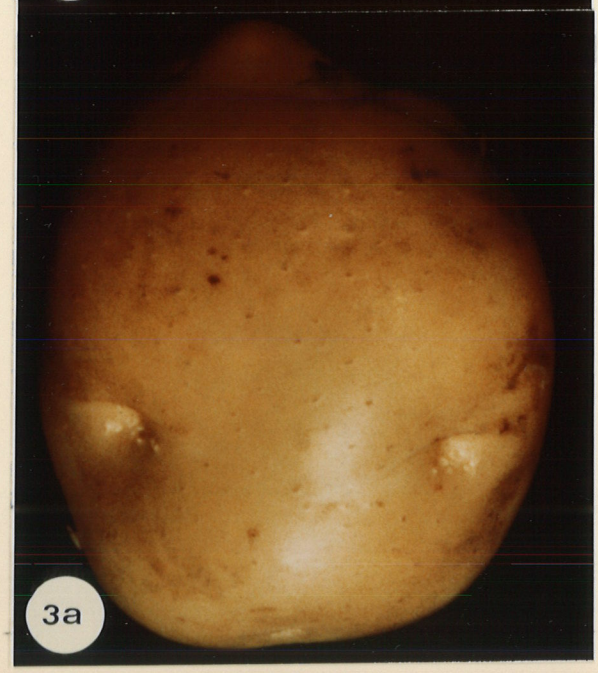
a = Control
b = 2.00 kg. ai/ha mefluidide

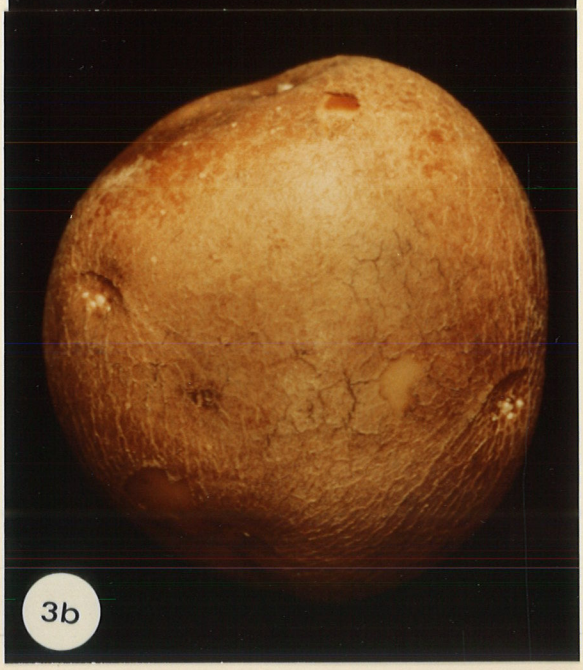

1a


1b


2a


2b


3a


3b

mechanically top kill many fields of potatoes before harvest to speed up skin set before harvest to reduce damage. A treatment such as mefluidide perhaps could be used to induce early skin development while still allowing tuber sizing since the tops are not killed.

Anthocyanin

Mefluidide decreased the amount of anthocyanin in Norland potato tubers as shown in Table 2. The amount of anthocyanin decreased with increasing rates of mefluidide.

The red skin color in Norland potatoes is due to anthocyanin pigments. It is likely that mefluidide bleached out the pigment rather than inhibited its synthesis since the tubers which were sprayed with mefluidide after harvest showed similar color losses as field treated tubers. The reduction in anthocyanin demonstrated that the apparent change in color of the tubers was in fact due to a change in skin components rather than just a masking effect of the heavy suberin development. Such an effect would not be desirable for a fresh market red potato.

Chip Quality

Chips from Norchip potatoes treated with mefluidide were lighter than untreated tubers as seen from the increase in Agtron readings up to 1.00 kg ai/ha mefluidide (Figure 7). Chips must have an Agtron reading of 38 and above to be acceptable for processing. Lower values indicate chips which are too dark in color. The 1.00 kg ai/ha mefluidide treatment was the only one that had an Agtron reading significantly greater than the control.

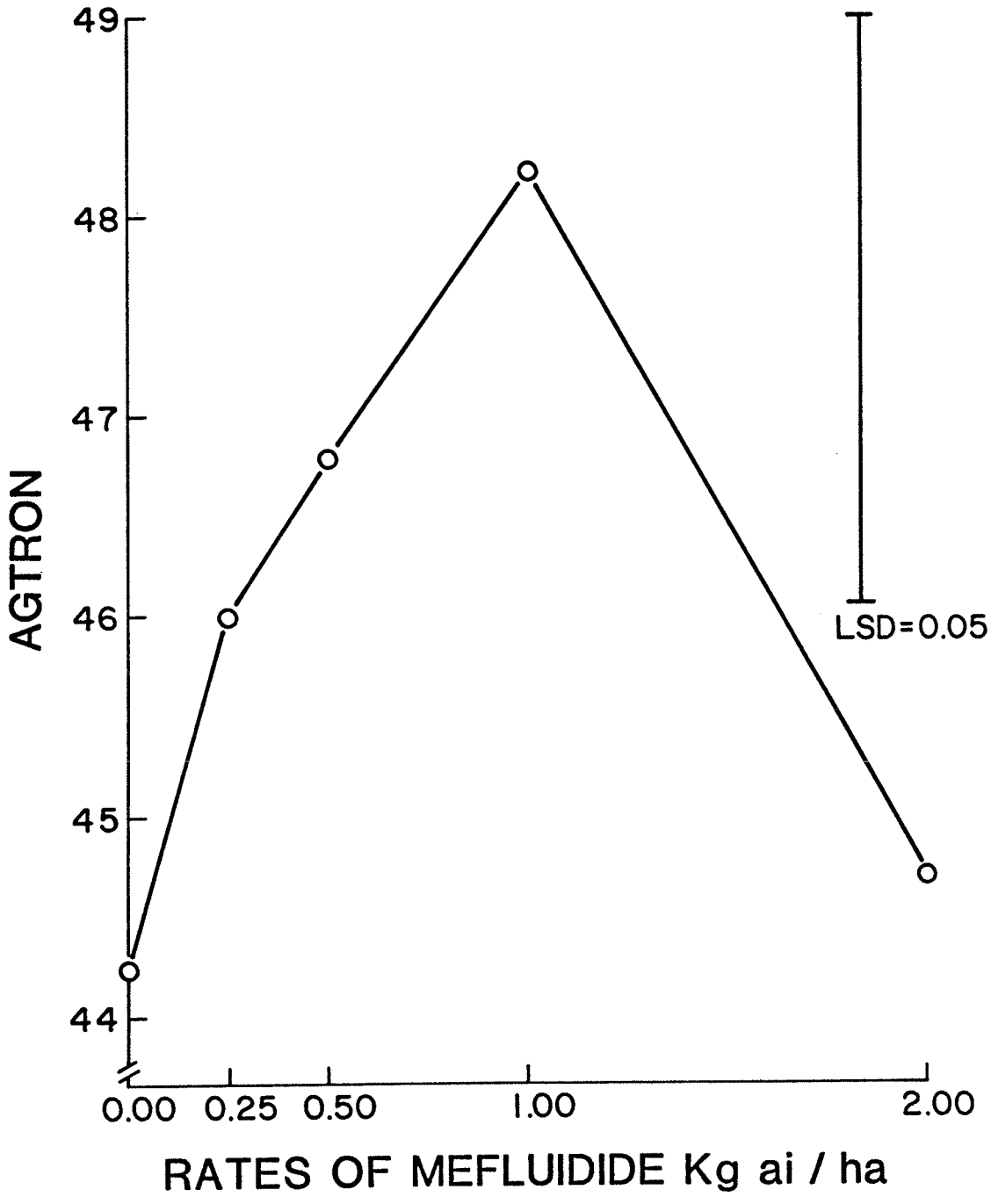
TABLE 2. Change in anthocyanin content of the tuber skin of Norland potatoes due to mefluidide applied to the foliage before harvest as measured by change in absorbance of skin extracts

Mefluidide (kg ai/ha)	Absorbance at 512 nm
Control	1.45#a*
0.25	1.18 b
0.50	0.78 c
1.00	0.66 c
2.00	0.41 d

lower absorbance represents lower anthocyanin content.

* Means with the same letters in a column are non-significantly different from each other.

Figure 7. The effect of mefluidide on chip color of Norchip potatoes when applied as a foliar spray before harvest.


49
48
47
46
45
44
AGTRON
LSD=0.05
0.00
0.25
0.50
1.00
2.00
RATES OF MEFLUIDIDE Kg ai / ha

Consequently no detrimental effects of mefluidide on the chipping quality were found and in fact a slight improvement in color was noted. The increase in Agtron readings coincides with the increase in specific gravity (Figure 5c). Lyman and Mackey (1961) also found that tubers with high specific gravity consistently produced chips of lighter color than did tubers of low specific gravity.

Storage

Mefluidide applied one month before harvest in the field delayed sprout growth in storage of Norland and Norchip (Tables 3 and 4). Russet Burbank did not show any sprout growth in any of the treatments throughout the entire storage period (data not presented). In Norland, sprouts were seen on the control and the 0.25 kg ai/ha mefluidide treatment by December 15. The 0.50 kg ai/ha mefluidide treatment showed sprouts by December 30 while most tubers in treatments 1.00 and 2.00 kg ai/ha mefluidide did not show any sprout growth until the end of the storage period. In Norchip, the control and 0.25 kg ai/ha mefluidide showed sprouts by January 15. The other treatments showed sprouts by February. The percentage of tubers with sprout lengths of <1 cm, 1 - 4 cm, or over 4 cm for Norland and Norchip are presented in Tables 3 and 4, respectively. The results indicate that in both cultivars, high mefluidide rates (1.00 and 2.00 kg ai/ha) had more tubers with short sprouts while low rates (0.25 and 0.50 kg ai/ha) had more tubers with long sprouts.

Mefluidide treated tubers lost more weight in storage than the control tubers. Loss in weight increased with increasing rates of mefluidide (Figure 8). Shrivelling due to weight loss also followed a similar pattern (Plate 5). Differences in weight loss between cultivars were

TABLE 3. Sprout length of Norland potatoes nine months after harvest after a pre-harvest foliar application of mefluidide

Mefluidide (kg ai/ha)	Sprout length (cm)		
	< 1	1 - 4	Over 4
	% of tubers		
Control	25.97 c*	49.87a	24.15a
0.25	35.51 bc	51.45a	13.08 b
0.50	47.09 b	42.04a	10.87 bc
1.00	71.45a	23.86 b	4.70 bc
2.00	81.80a	15.27 b	2.94 c

* Means with the same letters are non-significantly different from each other.

TABLE 4. Sprout length of Norchip potatoes nine months after harvest after a pre-harvest foliar application of mefluidide

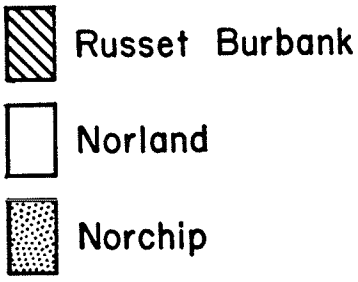
Mefluidide (kg ai/ha)	Sprout length (cm)		
	< 1	1 - 4	Over 4
	% of tubers		
Control	68.25 (8.25a) *#	31.75 (5.52a) #±	0.00
0.25	80.00 (8.91a)	20.00 (4.21a)	0.00
0.50	67.57 (8.17a)	32.44 (5.48a)	0.00
1.00	82.47 (9.00a)	17.54 (3.38a)	0.00
2.00	93.09 (9.67a)	6.91 (2.38a)	0.00

* Means with the same letters are non-significantly different from each other.

Square root transformation, $x = \sqrt{x + .5}$

± CV of transformed data = 43.62.

Figure 8. Percent weight loss after nine months of storage of the potato cultivars Russet Burbank, Norland and Norchip treated with a pre-harvest spray of mefluidide.



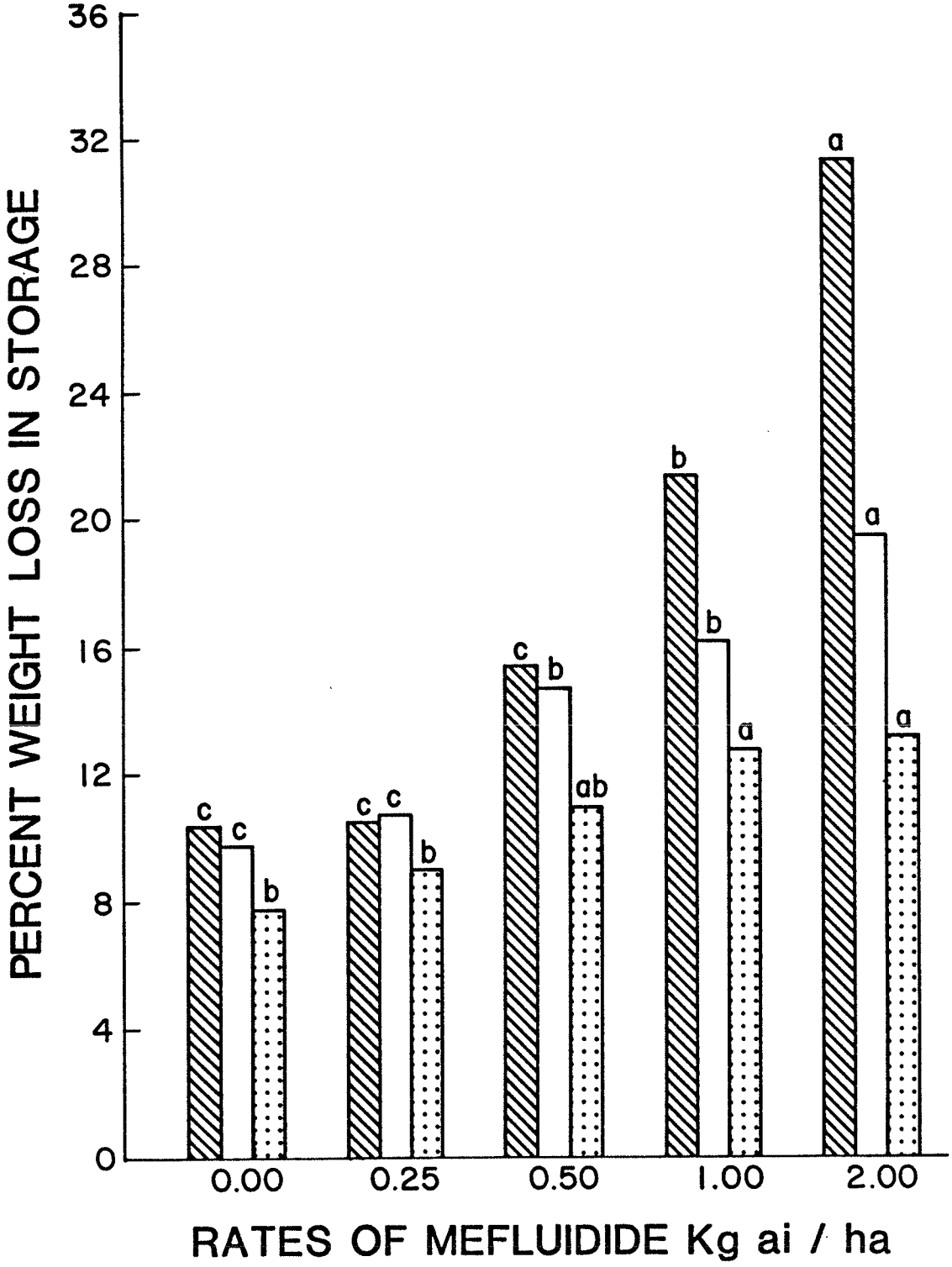
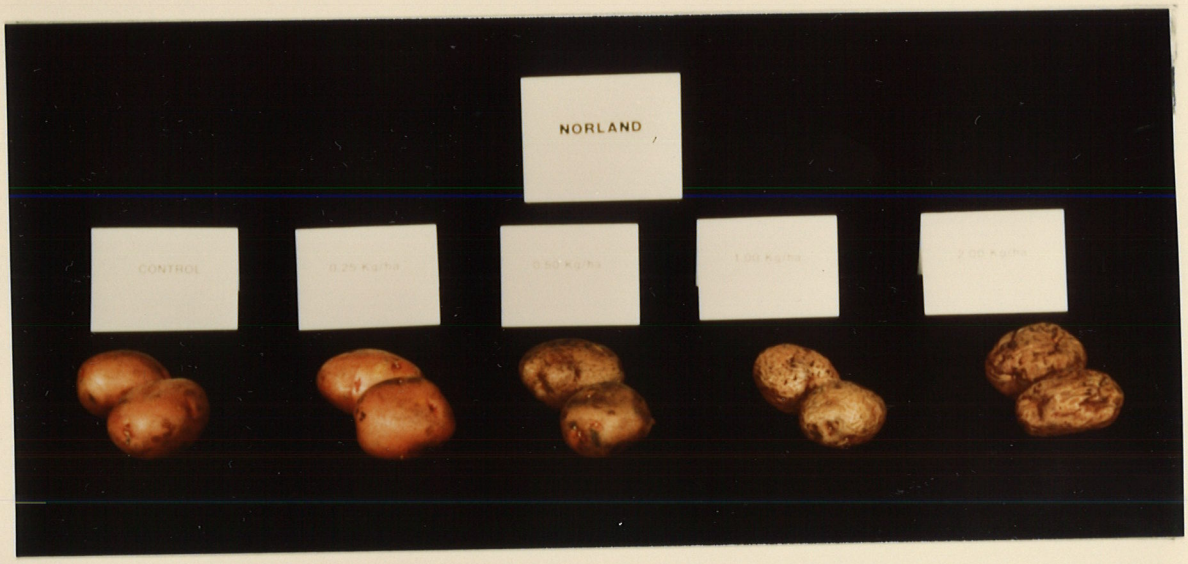
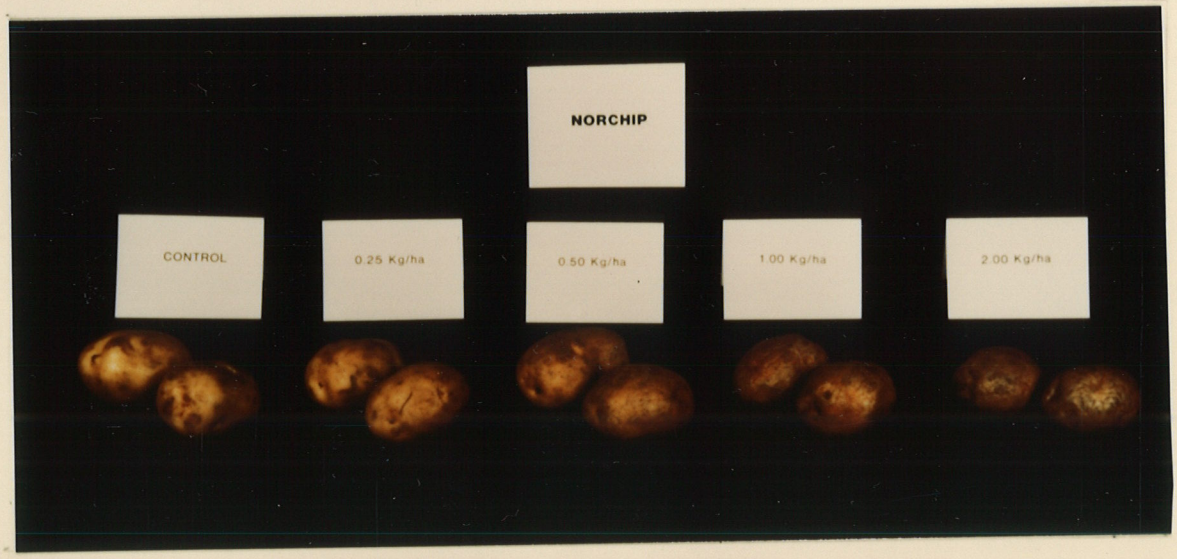

PERCENT WEIGHT LOSS IN STORAGE
36
32
28
24
20
16
12
8
4
0
c c b
c c b
c b ab
b b a
a a a
0.00
0.25
0.50
1.00
2.00
RATES OF MEFLUIDIDE Kg ai / ha

Plate 5. Differences in shrivelling due to weight loss between treatments within a cultivar

Treatments from left to right = Control, 0.25, 0.50, 1.00 and 2.00 kg ai/ha mefluidide.


RUSSET
BURBANK
CONTROL
0.25 Kg/ha
0.50 Kg/ha
1.00 Kg/ha
2.00 Kg/ha


NORLAND
CONTROL
0.25 Kg/ha
0.50 Kg/ha
1.00 Kg/ha
2.00 Kg/ha


NORCHIP
CONTROL
0.25 Kg/ha
0.50 Kg/ha
1.00 Kg/ha
2.00 Kg/ha

noticed with Russet Burbank losing the most weight, followed by Norland while Norchip lost the least. Excessive weight loss observed in mefluidide treated tubers cannot be easily explained. The thick skin induced by mefluidide is expected to restrict water loss and thus reduce weight loss. Morphological studies on the skin were not done but mefluidide might have affected the lenticels or caused the skin to have small cracks that water was easily lost from the tubers. Long term storage of mefluidide treated tubers might not be feasible unless excessive water loss is prevented.

Tubers treated with mefluidide after harvest responded similarly though not as distinctly as field treated ones. Results are presented in Figure 9 for skin rating and Tables 5 and 6 for sprout growth. Russet Burbank tubers did not show any sprout growth. Skin measurements and tuber weight loss were not determined on these tubers.

Figure 9. Ratings for skin russetting and color change in potato cultivars Russet Burbank, Norland and Norchip treated with mefluidide after harvest.

5 = normal skin

1 = very russetted and/or color change

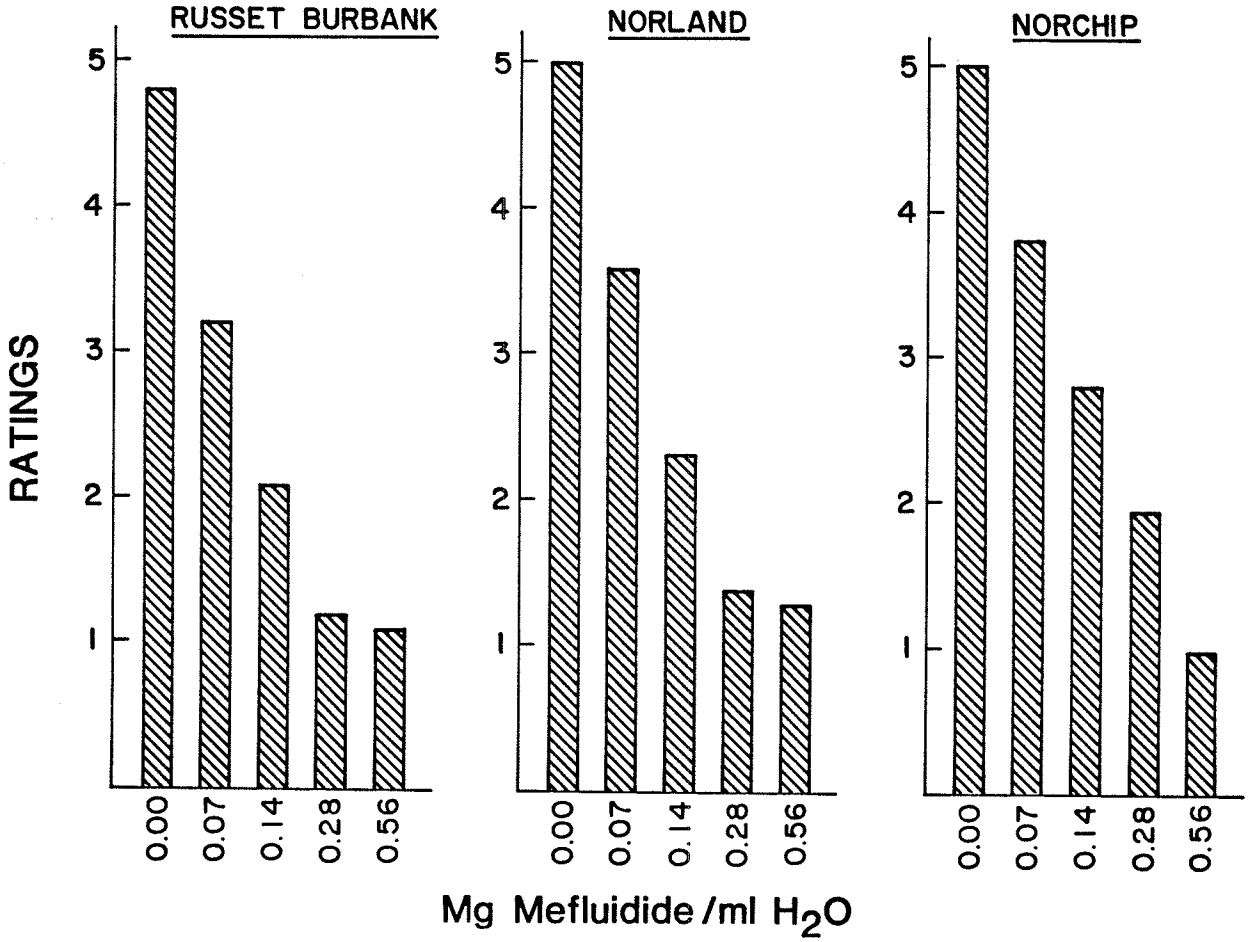

RUSSET BURBANK
NORLAND
NORCHIP
RATINGS
5
4
3
2
1
0.00
0.07
0.14
0.28
0.56
Mg Mefluidide /ml H_2O

TABLE 5. Sprout length of Norland potato tubers after nine months in storage after a post-harvest application of mefluidide to the tubers.

Mefluidide mg/ml H_2O	Sprout length (cm)		
	<1	1 - 4	Over 4
	number of tubers		
Control	0.00 c*	3.00a	4.00a
0.07	1.25 c	4.00ab	1.75 b
0.14	3.75 b	2.00 bc	1.25 b
0.28	5.50a	1.50 c	0.00 b
0.56	6.25a	0.50 c	0.25 b

* Means with the same letters in a column are not significantly different from each other.

TABLE 6. Sprout length of Norchip potato tubers after nine months in storage after a post-harvest application of mefluidide to the tubers.

Mefluidide mg/ml H_2O	Sprout length (cm)		
	<1	1 - 4	Over 4
	number of tubers		
Control	3.00a*	4.00a	0.00
0.07	4.00a	3.00a	0.00
0.14	3.25a	3.75a	0.00
0.28	3.00a	4.00a	0.00
0.56	3.75a	3.25a	0.00

* Means with the same letters in a column are not significantly different from each other.

The Effect of Mefluidide on Plant Growth

and Tuberization of Potato (*Solanum tuberosum* L.)

Cultivars Norland and Norchip

Abstract

Mefluidide {N- 2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl] amino] phenyl] acetamide} was applied either as a foliar treatment or in solution to potato (Solanum tuberosum L.) plants grown in solution culture or in vermiculite medium. A concentration of 0.02 mg/ml mefluidide retarded shoot growth and tended to reduce shoot fresh and dry weights, and tuber fresh weight in Norland and Norchip potato plants. Root fresh and dry weights were slightly increased at this concentration. The 0.02 mg/ml mefluidide treatment also caused a temporary plant distortion in early stages after treatment. All mefluidide treatments caused necrosis of leaf tips and margins, and decreased the green coloring of newly formed leaves soon after treatment.

Introduction

Mefluidide is a plant growth regulator with herbicidal activities. Gates (1975) reported suppressed growth and seed head formation, and enhanced root growth and color development of turf grasses by the chemical when it was applied at low rates. It has been found to inhibit plant growth and stimulate secondary branching in trees and woody ornamentals (Arnold and Aldrich 1982; Sterrett 1979). Mefluidide also has a dwarfing effect in soybeans (Rao and Hargar 1981) and young bean plants (Sterrett 1979). Reductions in height, fresh and dry weights, and chlorophyll have been reported at higher rates while low rates stimulated growth of corn plants (Truelove et al. 1977). Gates (1975) reported an increase in the amount of recoverable sugar from sugarcane treated with mefluidide. The chemical is also effective for weed control in soybeans, peanuts and cotton (McWhorter and Barrentine 1979).

Various growth inhibitors have been reported to affect plant growth and tuber initiation in potatoes. Abdullah and Ahman (1980), and El Antably et al. (1966) reported an increase in tuber formation in potato plants treated with abscisic acid. Calver (1970), and Smith and Rappaport (1969) found that abscisic acid inhibited tuber formation as well as shoot and root growth in potato plants. Compounds like maleic hydrazide (Harmey et al. 1966) and chlorocholinchloride (Kumar and Wareing 1974; Dyson 1965) have been found to induce tuberization in potatoes.

This investigation was conducted to determine what effects mefluidide has on plant growth and tuberization in potatoes grown in solution culture.

Materials and Methods

General

Seed tubers of potato cultivars Norland and Norchip were used in this investigation. The experiments were conducted in a growth cabinet or a growth room having 14 hours daylength with light from Gro-lux Ws V.H.O. lamps. The day and night temperatures in the growth cabinet were 20°C and 15°C, respectively, and in the growth room were 23°C and 16°C, respectively. The relative humidity was 65 - 70 percent. Experiments 1 and 2 were done in the growth cabinet while experiment 3 was done in the growth room. All experiments were in a randomized complete block design with two replicates and were repeated twice. The plants were sprayed with mefluidide at 0, 0.005, 0.01, or 0.02 mg ai/ml. Mefluidide solutions were prepared in 2% (v/v) acetone. Plant heights before spraying and at harvest were recorded. Foliage, root and tuber fresh and dry weights, and tuber and rhizome number were also recorded after harvest. Dry weights were obtained by oven drying the samples at 40°C. The samples were kept in the oven until constant weights were obtained.

Experiment 1: Effect of Mefluidide on Plant Growth and Tuberization--Foliar Application (Solution Culture)

Potato seed pieces of Norland were planted in vermiculite in the growth cabinet. After 15 to 20 days, plants of uniform size were selected and transferred into aerated half-strength Hoagland solution (Hewitt 1966), held in 3L ceramic jars. The jars were covered with wooden lids. One plant was inserted through a hole in the lid and was supported in place by cotton wool. A black polyethylene plastic sheet was placed around the base of the plant and surrounding the sides of the lids to exclude light. Seven days after the plants were put in nutrient solution, their heights were determined, they were removed from the growth cabinet, and were

sprayed to run off with mefluidide at the prescribed rates using a spray-cabinet. The treated plants were placed back into the growth cabinet after they were dry and were allowed to grow for 30 days before sampling.

Experiment 2: Effect of Mefluidide on Plant Growth and Tuberization--Root Application (Solution Culture)

The plants were set up similar to those in Experiment 1 except at treatment time when mefluidide was added to the nutrient solution. Mefluidide was left in the nutrient solution for 48 hours, thereafter the roots were washed and the fresh nutrient solution added. The treated plants were allowed to grow for 30 days before sampling.

Experiment 3: Effect of Mefluidide on Plant Growth and Tuberization--Foliar Application (Vermiculite Medium)

Because of problems associated with potato plants forming tubers in solution culture, potato seed pieces were grown in moist vermiculite held in wooden flats. Each flat contained three plants. The plants were maintained in this medium by watering them with water and nutrient solution alternatively. After 20 to 30 days, the plants were sprayed with mefluidide as in Experiment 1. After 30 days, the plants were harvested and sampled.

Statistical Analysis

The data were analyzed following the standard procedure for analysis of variance. Square root transformation, $x = \sqrt{x + .5}$, was done on percent height change from time of treatment to time of harvest, and on tuber fresh and dry weights for Norland and Norchip plants grown in vermiculite medium. A combined statistical analysis was done for Experiments 1 and 2.

Results and Discussion

Effect of Mefluidide on Plant Growth

The newly formed leaves in all mefluidide treated plants in both the nutrient solution and vermiculite medium started showing a light green color three to four days after treatment. Older leaves had a normal green color except for necrosis of leaf tips and margins. Slight plant distortions in the 0.02 mg/ml mefluidide treatment were noticed, especially in foliar treated plants in nutrient cultures and in the vermiculite medium. Later, plants resumed normal growth. The reduction in green coloring in newly formed leaves could be due to reduced chlorophyll levels. If mefluidide affects the synthesis of lipids, reduced synthesis of polar glycolipids would affect chloroplast structure and development and this would interfere with the greening process. Truelove et al. (1977) reported a 40 percent decrease in chlorophyll a in mefluidide treated corn leaves.

Mefluidide at high concentrations of 0.01 and 0.02 mg/ml reduced plant height in all experiments performed (Tables 7, 8 and 9). The 0.02 mg/ml mefluidide treatment significantly reduced plant height compared to the control for Norland in solution culture (Table 7) and Norchip in vermiculite medium (Table 9). No significant differences were observed in Norland plants gorwn in vermiculite although the 0.02 mg/ml mefluidide treatment had the lowest percentage change in plant height (Table 8). The low concentration of 0.005 mg/ml mefluidide, though not significantly different from the control, seemed to be stimulatory except in Norland plants grown in vermiculite where percentage change in plant height for this mefluidide rate was lower but not significantly different from the control (Table 8).

TABLE 7. Effect of mefluidide on the growth of Norland potato plants grown in solution culture in the growth chamber. Values are a combination of Experiment 1 (Foliar application) and Experiment 2 (root application).

Mefluidide mg/ml	SHOOT			ROOT		TUBER[1]				Rhizome No.
	% height change from time of treatment	FW[2] (g)	DW[3] (g)	FW (g)	DW (g)	FW (g)	DW (g)	% DW	No.	
Control	100.00[4]a[5]	145.70a	15.48a	62.06a	5.95a	2.86	0.43	15.03	5	14 b
0.005	104.56 a	141.25a	15.77a	59.08a	5.96a	5.50	0.85	15.43	11	32ab
0.010	89.58 ab	135.42a	14.42a	57.08a	5.06a	0.67	0.11	16.42	3	21ab
0.020	72.47 b	132.73a	16.39a	73.46a	7.49a	3.46	0.54	15.61	7	43a

[1]Statistical analysis was not performed on tuber FW and DW, % DW and tuber number.

[2]FW = Fresh weight.

[3]DW = Dry weight.

[4]Increament in height of Control from time of treatment to harvest expressed as 100 percent.

[5]Means in the same column followed by the same letter are not significantly different from each other.

TABLE 8. Effect of foliar applied mefluidide of growth on Norland potato plants grown in vermiculite medium.

Mefluidide mg/ml	SHOOT			ROOT		TUBER				Rhizome No.
	% height change from time of treatment	FW[1] (g)	DW[2] (g)	FW (g)	DW (g)	FW (g)	DW (g)	% DW	No.	
Control	100.00[3] (10.02[4]a[5])	75.35a	7.96a	32.49a	3.93a	110.37[4] (9.23[4]a)[6]	18.26[4] (4.33[4]a)[6]	16.55a	18a	23a
0.005	82.45 (9.11a)	83.83a	7.88a	33.79a	3.71a	119.49 (10.25a)	19.67 (4.49a)	16.46a	21a	25a
0.010	77.08 (8.81a)	91.00a	8.73a	34.68a	3.73a	112.81 (10.10a)	17.00 (4.18a)	15.07	17a	23a
0.020	71.75 (8.50a)	65.16a	6.20a	35.32a	3.79a	35.99 (5.87a)	5.75 (2.50a)	15.98a	16a	21a

[1]FW = Fresh weight.

[2]DW = Dry weight.

[3]Increament in height of Control from time of treatment to harvest expressed as 100 percent.

[4]Square root transformation, $x = \sqrt{x + .5}$

[5]Means in the same column followed by the same letter are not significantly different from each other.

[6]C.V. of transformed data = 32.00.

TABLE 9. Effect of foliar applied mefluidide on growth of Norchip potato plants grown in vermiculite medium.

Mefluidide mg/ml	SHOOT			ROOT		TUBER				Rhizome No.
	% height change from time of treatment	FW[1] (g)	DW[2] (g)	FW (g)	DW (g)	FW (g)	DW (g)	% DW	No.	
Control	100.00[3] (10.02[4]ab[5])	162.94a	13.65a	48.60a	4.99a	46.36 (6.85a)[6]	6.48 (2.64a)[6]	13.96a	7a	13a
0.005	137.71 (11.76a)	130.84ab	12.61a	72.21a	5.71a	18.95 (4.41a)	2.39 (1.70a)	12.61a	3a	11a
0.010	62.05 (7.91bc)	139.69ab	12.44a	72.55a	5.23a	17.03 (4.19a)	1.99 (1.58a)	11.68a	6a	15a
0.020	47.85 (6.95c)	105.42 b	9.98a	61.02a	4.77a	8.27 (2.96a)	1.09 (1.26a)	13.18a	3a	9a

[1]FW = Fresh weight.

[2]DW = Dry weight.

[3]Increament in height of Control from time of treatment to harvest expressed as 100 percent.

[4]Square root transformation, $x = \sqrt{x + .5}$.

[5]Means in the same column followed by the same letter are not significantly different from each other.

[6]C.V. of transformed data = about 40.00.

The stimulatory effect at low mefluidide rate and the inhibitory effect at high rates was also reported by Truelove et al. (1977) in corn plants. These workers reported that low levels of mefluidide stimulated incorporation of ^{14}C-leucine into protein while high levels inhibited the process. This could be a possible explanation for the effects of mefluidide on plant growth at different concentrations observed in this experiment.

Mefluidide tended to reduce shoot fresh and dry weights and slightly enhanced root fresh and dry weights in Norland and Norchip potato plants (Tables 7,8 and 9). No significant differences were observed between treatments except for Norchip where the 0.02 mg/ml mefluidide rate significantly reduced shoot fresh weight compared to the control (Table 9). Results obtained for rhizome number were not meaningful.

Lack of statistical significant differences between treatments for Norland shoot and root fresh and dry weights, and for Norchip root fresh and dry weight could have been partly due to variations between plants in number of main stems per plant and in growth rate between plants even though equal sized seed pieces were used (data not shown).

Effect of Mefluidide on Tuberization

Although mefluidide did not seem to have an effect on tuber number, it has a drastic effect on tuber fresh and dry weights on plants grown in vermiculite medium (Tables 8 and 9). Most tubers in the 0.02 mg/ml mefluidide treatment were very small and thus weighed less than an equal number of tubers in other treatments. It is not clear whether the reduction in tuber weight is indirect due to reduced shoot growth or whether it is a direct effect on the tubers. Plant to plant variation within

treatments made statistical significant differences not possible. No differences in percent tuber dry weight was observed between treatments indicating that mefluidide did not affect dry matter content of the tubers (Tables 8 and 9).

The effect of mefluidide on tuber initiation was not clear. Tuber formation in nutrient solution culture where uniformly sized plants were grown was not very successful in our experiments. Tubers formed only in one experiment of foliar applied mefluidide. In vermiculite medium, there is a possibility that mefluidide could have been applied to the plants after tubers had already initiated. The influence of mefluidide on tuber initiation could be best demonstrated on cuttings rather than on whole plants.

In a preliminary experiment not detailed here, some of the mefluidide treated plants were sprayed with gibberellic acid (GA_3). It was found that control plants and those treated with mefluidide developed tubers while GA_3 + mefluidide treated plants had no tubers but long stolons. Gibberellins have been reported to promote stolon growth and thus inhibit tuber initiation (Okazawa 1960). The lack of tuber formation in the GA_3 + mefluidide treated plants could have been due to the inhibitory effect of GA_3 and that mefluidide did not counteract the effect of GA_3. Further work is required to determine the influence of mefluidide on tuber initiation.

GENERAL DISCUSSION

Results from these experiments indicate that mefluidide has beneficial as well as deterimental effects on potato tubers. Although no significant differences were detected between treatments, mefluidide tended to slow down the rate of loss of sucrose in the tubers. Gates (1975) reported an increase in amount of recoverable sugar from mefluidide treated sugar cane plants. Mefluidide might be inhibiting or slowing down sugar to starch conversion in these plants. High sucrose content has been reported in stressed potato tubers (Iritani and Weller 1976). It is possible that mefluidide might be imposing stress on the tubers thereby causing increased sucrose content.

The increase in sucrose content caused by mefluidide could result in more serious problems for processing potatoes. Reducing sugar accumulation in storage is associated with high sucrose in the tubers at harvest (Sowokinos 1978). Tubers stored for processing should reach low SR values of $\leq$2.8 mg sucrose/g of tuber by harvest as they will be able to store longer without large accumulation of reducing sugars at intermediate storage temperatures (10^{o}C). However, mefluidide treated tubers were able to reach low SR values which would indicate processing maturity, but this could have been because of the suspected underestimation of SR values reported in this experiment.

Mefluidide increased specific gravity of Russet Burbank and possibly of Norchip while it reduced that of Norland potatoes. Russet Burbank and Norchip are the two most used cultivars for processing in Manitoba. The increase in specific gravity in these potatoes is desirable as such tubers accumulate less sugars in storage when compared to those with low specific

gravity (Iritani and Weller 1976). Such tubers also produce good quality chips and french fries. Less oil absorption and high yields of chips and french fries have been reported from high specific gravity tubers (Lulai and Orr 1979; Sayre et al. 1975). Lyman and Mackey (1961) found high specific gravity tubers to produce light chip color. Similarly in this study, light chip color was obtained in high specific gravity Norchip tubers. The rate 1.00 kg ai/ha mefluidide in the field experiment gave the highest specific gravity and Agtron readings. This rate may or may not be the one with the most desirable effects. Rates between 1.00 and 2.00 kg ai/ha mefluidide might be of significant importance to both specific gravity and chip color in Norchip potatoes.

Mefluidide at all rates tested, tended to reduce fresh tuber weight in the field and at the 0.02 mg/ml concentration in the growth chamber. Plants in the growth chamber showed reduced shoot height, and shoot fresh and dry weights while root fresh and dry weights were slightly increased at this rate. A light green color in newly formed leaves of all treated plants was noticed. The reduction in yield could have been indirectly due to reduced shoot growth or due to a direct effect of mefluidide on the tubers. Mefluidide at low rates did not reduce tuber fresh weight in the growth chamber experiments. It, in fact, appeared to have a stimulatory effect on both shoot growth and tuber yield. These results would suggest that the response of potato plants to mefluidide is dependent on the concentration of the chemical. Truelove et al. (1977) found mefluidide to increase the incorporation of ^{14}C-leucine into proteins at low concentrations while high concentrations inhibited the process. This could explain the stimulatory and inhibitory effects of mefluidide observed in this study. Mefluidide at 0.02 mg/ml applied on young plants might not reduce final

yield as plants resumed their normal growth later in the growing period. Dyson (1965) tested the effect of CCC (a growth retardant) on potato growth and found that its initial effect on plant growth was later overcome, so that the final yield was the same as the control plants. Early application of mefluidide on potato plants would be beneficial if the chemical is found to increase tuber initiation or cause early tuber initiation.

The unpublished date (Parker personal communication) indicated an increase in yield due to mefluidide in Russet Burbank, Denali, and Kennebec cultivars. In this study, Russet Burbank was mechanically damaged before harvest in 1981 and was frosted twice in 1982. The second frost was severe and led to early harvest of the crop. It would seem that mefluidide did not express its full effect on this cultivar in 1982. This might be a possible reason for the differences obtained between the results in this study and that of the other workers (Parker personal communication) for Russet Burbank.

Mefluidide caused russetting in Norland and Norchip, cultivars not known to russet under normal conditions. In Russet Burbank, russetting was increased in all mefluidide treated tubers. Cross section of the skin in Norland and Norchip showed a thick suberized layer. A thick skin is required in potatoes to reduce bruising at harvest and during handling. A thick skin should also reduce weight loss in storage by restricting water loss from the tubers. Disease entry would also be minimal. But the excessive weight loss that occured in mefluidide treated thick-skinned tubers could not be easily explained. Possibly the lenticels on the skin might have been altered or mefluidide caused the skin to have small cracks thus leading to easier moisture loss. The different cultivars responded differently with Russet Burbank having the most weight loss followed by Norland, while Norchip had the least weight loss.

The change in color in Russet Burbank and Norchip due to mefluidide

might be a minor problem since these tubers are mostly used for processing. But in Norland, a cultivar mostly used for fresh market, mefluidide would not likely be used because of its effect on the skin color. The red coloring on Norland potatoes was lost. The red skin in Norland as well as other red skinned potatoes is due to anthocyanin pigments. A test on anthocyanin content indicated a reduction in the amount of the pigment on treated tubers. It is likely that mefluidide bleached out the pigment rather than inhibiting its synthesis since tubers sprayed with mefluidide after harvest showed a similar effect.

In storage, mefluidide delayed sprout growth in Norland and Norchip potatoes. No data were recorded in Russet Burbank since all tubers in this cultivar did not have any sprouts even at the end of the storage period. The inhibition of sprout growth is desired in long term stored potatoes. Currently, other sprout inhibitors such as CIPC (isopropyl n-(3-chlorophenyl) carbomate) are used. Mefluidide might not be used as a sprout inhibitor in Norland because of its effect on the skin color. Its influence on tuber weight loss might make it impossible to be used on the other cultivars, too.

Mefluidide tended to slow down the rate of loss of sucrose in Russet Burbank, Norland, and Norchip potatoes. Yield was reduced in the field and at 0.02 mg/ml rate in the growth chamber. Mefluidide increased specific gravity in Russet Burbank and possibly in Norchip and decreased that of Norland potato tubers. It improved chip color in Norchip. Skin russetting was increased in Russet Burbank and it caused russetting in Norland and Norchip potatoes. Mefluidide also altered skin color in all three cultivars tested. In storage, mefluidide delayed sprout growth in Norland and Norchip and it caused excessive weight loss in all three cultivars. At a concentration of 0.02 mg/ml, mefluidide retarded shoot growth and tended to reduce shoot fresh and dry weights while root fresh and dry weights were slightly increased in Norland and Norchip potato plants.

SUGGESTIONS FOR FURTHER WORK

Further work on sucrose rating in mefluidide treated tubers, preferably from time of harvest to end of storage period, is required. This would help in determining whether the increase in sucrose content in mefluidide treated tubers observed in this study would lead to high accumulation of reducing sugars in storage.

Studies on the anatomy of the skin in mefluidide treated tubers is necessary in order to find out why these tubers lost so much weight in storage. The chemical might be of significant importance in Russet Burbank and Norchip potatoes.

More research on the effect of mefluidide on specific gravity of Russet Burbank and Norchip is required before any conclusions are drawn.

The role of mefluidide in hollow heart formation is needed as the preliminary data cautioned that an increase in this physiological disorder due to mefluidide may occur.

The effect of mefluidide on tuber initiation and early tuber growth is necessary in order to determine whether mefluidide causes early tuber initiation or would increase final yield if applied early in the growing season. The stimulatory effect in early tuber yield observed in some mefluidide treated tubers might be due to early tuber initiation. The use of cuttings as opposed to whole plants is highly recommended to reduce plant to plant variations observed in this study.

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A P P E N D I X

APPENDIX TABLE 1. Mean marketable yield of potato cultivars Russet Burbank, Norland and Norchip.

Treatment kg ai/ha mefluidide	Mean Yield, kg/9 m				
	Russet Burbank 1981*	Russet Burbank 1982	Norland 1981	Norland 1982	Norchip 1982
Control	-	10.64a	21.57a	25.66a	23.86a
0.25	-	10.77a	20.51a	24.44ab	20.79a
0.50	-	12.35a	21.31a	23.15abc	20.28a
1.00	-	11.52a	18.97a	21.65 c	21.97a
2.00	-	9.99a	19.23a	21.67 bc	21.40a

*Most tubers were mechanically damaged before harvesting; thus no marketable yield data were obtained.

#Means with the same letters in a column are not significantly different from each other.

APPENDIX TABLE 2. Percent oversized tubers of potato cultivars Russet Burbank, Norland and Norchip.

Treatment kg ai/ha mefluididce	Percent oversized tubers				
	Russet Burbank 1981*	Russet Burbank 1982	Norland 1981	Norland 1982	Norchip 1982
Control	-	0.00	7.69	0.00	0.72
0.25	-	0.00	5.40	0.37	0.89
0.50	-	0.11	5.13	0.00	3.17
1.00	-	0.12	0.60	0.85	0.56
2.00	-	0.00	0.39	0.38	0.98

*Most tubers were mechanically damaged before harvest.

APPENDIX TABLE 3. Mean values of percent knobness in potato cultivars Russet Burbank, Norland and Norchip.

Treatment kg ai/ha mefluidide	Percent knobness				
	Russet Burbank 1981	Russet Burbank 1982	Norland 1981	Norland 1982	Norchip 1982
Control	16.34	9.33	3.95	0.05	4.98
0.25	23.57	7.44	6.23	0.34	2.71
0.50	15.53	6.21	2.87	0.00	2.83
1.00	20.56	5.87	4.20	0.58	4.57
2.00	10.38	7.83	3.75	0.83	4.77

APPENDIX TABLE 4. Mean values of percent hollow heart in potato cultivars Russet Burbank, Norland and Norchip.

Treatment kg ai/ha mefluidide	Tuber diameter (cm)	Percent hollow heart				
		Russet Burbank 1981	Russet Burbank 1982	Norland 1981	Norland 1982	Norchip 1982
Control	< 5	4.93	5.24	0.00	0.00	0.00
	5 - 6	12.12	8.75	4.17	0.00	9.67
	>6	16.01	15.03	9.00	2.78	27.62
0.25	< 5	2.75	11.09	0.00	2.78	0.00
	5 - 6	0.00	7.88	0.00	0.00	5.63
	>6	36.00	18.75	16.00	0.00	26.79
0.50	< 5	10.71	15.46	0.00	0.00	5.00
	5 - 6	3.57	15.76	2.78	0.00	9.77
	>6	19.00	0.00	7.00	4.17	52.41
1.00	< 5	20.67	14.66	0.00	0.00	5.00
	5 - 6	7.01	15.28	0.00	0.00	9.09
	>6	21.00	6.25	9.00	4.17	48.81
2.00	< 5	5.96	23.11	2.08	0.00	4.17
	5 - 6	10.28	33.39	0.00	0.00	4.58
	>6	18.00	12.50	8.00	3.57	31.34