THE EFFECTS OF FIELD SPRAYS OF MALEIC HYDRAZIDE ON THE STORAGE LOSSES AND COOKING QUALITY OF POTATO TUBERS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

E. Lalekan Ayokunnu Are

1962

This is to certify that the

thesis entitled

The Effects of Field Sprays of Maleic
Hydrazide on the Storage Losses and
Cooking Quality of Potato Tubers.

presented by

E. Lalekan Ayokunnu Are

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Farm Crops

S. T. Dexter
Major professor

Date May 16, 1962

O-169

THE EFFECTS OF FIELD SPRAYS OF MALEIC HYDRAZIDE ON THE STORAGE LOSSES AND COOKING QUALITY OF POTATO TUBERS

By

E. Lalekan Ayokunnu Are

AN ABSTRACT

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Farm Crops

Year 1962

Approved S. G. Dexter

ABSTRACT

THE EFFECTS OF FIELD SPRAYS OF MALEIC HYDRAZIDE
ON THE STORAGE LOSSES AND COOKING
QUALITY OF POTATO TUBERS

By E. Lalekan Ayokunnu Are

The objectives of the investigation were to determine: the types of weight losses in stored potato tubers from maleic hydrazide treated plants, and the effect of maleic hydrazide on the cooking quality of such tubers.

Kennebec and Russet Rural potatoes were grown in several plots in 1960 and 1961. Half of the plots were sprayed with the diethanolamine salt of 6-hydroxy-3-(2H)-pyridazinone, i.e. MH-30, at blossom drop.

Yields and specific gravity of harvested tubers were not altered by MH-30.

Tubers from untreated and maleic hydrazide-treated plants stored at 41° F. lost 6.5% and 4% dry matter, respectively. Few sprouts were formed. At 60° F., tubers from maleic hydrazide-treated plants where few sprouts were formed and untreated plants with many sprouts lost 5% and 22% of their dry matter, respectively. Half of the dry matter loss in control tubers was due to sprouts. About

19% of the initial crude protein content of tubers from untreated plants was lost in sprouts. Maleic hydrazide did not improve the color of potato chips made from tubers stored at 41° and 70° F. In limited trials, maleic hydrazide-treated tubers conditioned a week faster than untreated tubers at 70° F. There was a direct correlation between the amount of total sugar in the tuber and the color of potato chips produced from such tubers. Chips of acceptable light color could only be made from tubers containing 0.05% or less of total sugar.

THE EFFECTS OF FIELD SPRAYS OF MALEIC HYDRAZIDE ON THE STORAGE LOSSES AND COOKING QUALITY OF POTATO TUBERS

By

E. Lalekan Ayokunnu Are

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Farm Crops

Year 1962

Dedicated

to

my mother, Christiana Nihinlola Alabi

who encouraged me as a boy

and to

my cousin, Amusa Olaniyi Lawal Are

who inspired me as a man.

ACKNOWLEDGEMENT

The author wishes to express his profound gratitude to Dr. S. T. Dexter and Dr. D. R. Isleib for their valuable assistance, suggestions and interest throughout the investigation and their helpful advice in preparing this thesis.

The author is also very grateful to Drs. D. H. Dewey, E. J. Benne and C. L. Bedford for their kindness in allowing me the use of their laboratory facilities.

Sincere thanks are also extended to Dr. N. R. Thompson, Dr. R. S. Baudurski, Dr. C. M. Harrison, Dr. R. R. Dedolph, Dave Maclean, Leslie Wilcox and John Showers for the various assistance rendered and to Mrs. Jody Levi who typed the first copy of the thesis.

Finally, immense gratitude is extended to the management of the Western Nigeria Development Cooperation, Ibadan, Nigeria, for their generous scholarship which made the study possible and to the chairman, Mr. Alfred Ogbeyiwa Rewane, for his encouragement throughout my stay in the U.S.A.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure

Page

Figure

INTRODUCTION

In the regions of the United States where the bulk of the nation's supply of potatoes is grown, harvest shortly precedes freezing weather, and the portions of the crop that are utilized during the following months--October to May--come from storage. Potatoes planted in spring and harvested in fall constitute about 66.4% of the total crop in the United States (72). About 75-80% of this crop is stored for direct consumer use and for processing into potato chips, french fries, and dehydrated potatoes. In many parts of the world, storage facilities are crude and haphazard even in regions where the tubers may constitute a large part of the diet, and deterioration in storage may lead to a greatly restricted food supply.

In general, potato tubers are stored to preserve their market and culinary qualities for consumption beyond the growing season. In order to prevent the development of certain fungous and bacterial diseases which induce rotting, and to retard shrinkage and sprouting, low temperatures of 38^{o}-40^{o} F. have been generally recommended for potato storage (67). Low temperatures slow the rate of metabolic

processes within the tuber, and there is an accumulation of sugar, which can be rapidly decreased by re-transformation to starch and by loss in respiration at higher temperatures, e.g., 60°-70° F. The accumulated sugar affects cooking quality by causing a sweet flavor and produces dark brown chips unacceptable to the potato chip industry.

Regardless of the varied attempts being made to properly store potato tubers, millions of dollars worth are lost annually. Loss of weight in the stored potato tubers is the result of desiccation, respiration and sprout growth. Sprouting is objectionable in that it decreases the carbohydrate and protein contents of the original tuber. Moreover, it also causes difficulties in washing potatoes (71). Sprouting can be controlled by proper temperature or by the use of chemical sprout inhibitors.

It has been claimed that maleic hydrazide is effective in inhibiting sprouting and reducing total weight loss of potato tubers in storage (35, 56). In the latter case, fresh weight loss of the edible tuber is sometimes as great as in the sprouted controls. Apparently, either increased desiccation or respiration of the treated tubers increases loss in fresh weight and compensates for the sprout loss.

The objective of this investigation was to determine: 1) the types of weight losses in stored potato tubers, 2) the relative magnitude of each type of weight loss, 3) the influence of maleic hydrazide and storage environment on these types of weight losses, and 4) the effect of maleic hydrazide on the cooking quality of the stored tubers.

REVIEW OF LITERATURE

Fundamentals of Storage of Potatoes

The dietary importance of potato tubers has led to many investigations seeking to determine the best means of preserving their culinary quality during storage periods.

Thompson and Kelly (70) summarized investigations in this area. They reported that to prevent excessive shrinkage and rotting, potato tubers should be held at 50°-60° F. and 85-95% relative humidity during the first week after harvest to heal the bruises. After this, storage at 38°-40° F. is desirable to extend the rest period and to prevent sprouting when the rest period is over. They also reported that the greatest shrinkage in storage occurs when sprouts appear, due to the translocation of carbohydrates from the tuber into the sprouts, increase in respiration rate and large increase in water loss from the sprouts.

During storage at low temperatures, the rate of respiration is reduced more than is the rate of conversion of starch to sugar, thus leading to sugar accumulation (67).

According to Appleman (4), good, vigorous tubers of most potato varieties sprout first from the buds on the terminal or seed end of the tuber. This inhibiting

influence of the terminal sprouts on the growth of sprouts from the other eyes on the tuber is known as "apical dominance." Appleman suggested that the cause of apical dominance was inherent in the tuber and that the degree of apical dominance might be employed as a practical index of vitality in seed tubers. In fact, he suggested a direct relationship between sprout vigor and the degree of apical dominance.

Storage in Relation To Cooking Quality

Wright *et al.* (73) reported an increase in sugar content as the storage temperature was lowered. This was accompanied by the lowering of cooking quality as denoted by flavor and texture. At temperatures below 50° and 60° F., sugars increased while starch decreased. They also stored potato tubers at 40°, 36° and 32° F. and after 6 weeks, transferred them to 70° F. for another period of 6 weeks. They noticed that the sugar content of those tubers previously stored at 40° F. was similar to what it had been when they were first put in storage, while those at 36° and 32° F. had relatively high sugar content.

Treadway *et al.* (71) observed that Katahdin potatoes stored at 34°-38° F. lost 3.8% of their starch during the

first 7 weeks of storage; but experienced only little additional loss as the duration of storage or temperature increased. A large increase in total sugars (primarily in reducing sugars) was found in potatoes stored at 34° and 36° F.; the greatest change taking place during the first 13 weeks in storage. Little sugar accumulation was recorded at 38°-42° F., whereas some decrease occurred between 50° and 60° F. With conditioning at 70° F., however, the sugar levels became lower in those samples from warmer storage than the levels of those stored at low temperatures.

The amount of sugars formed during cold storage of potatoes varies with variety as well as temperature (27). The extent of sugar disappearance which occurred on exposure to higher temperature was also found to be different in different varieties.

Appleman (3), studying the changes occurring in potatoes during storage reported that potato tubers which accumulated sugar during low temperature storage lost about 4/5 of that sugar through reconversion to starch and only 1/5 through respiration.

Appleman and Smith (5) proved conclusively that the initial high liberation of CO_2 from potatoes after a period

of cold storage was due to actual respiration and not simply to the output of excess CO_2 which was dissolved in the cold sap of the potato tissue. They also observed that during the period of the most rapid decline in the respiration rate at 86° F. of tubers previously held in cold storage, the percentage of both total and reducing sugars in the tubers was actually increasing. Further studies (5) by both men revealed that in potatoes, the shifting equilibrium between sugar and starch tended to attain stability with widely different percentages of sugar characteristic of the different temperature ranges. They inferred that these carbohydrate transformations in potatoes with temperature changes were the cause of the characteristic respiratory response with the same temperature changes. They concluded that the high initial respiration rate in potatoes when suddenly changed from a lower to a higher temperature was due to the "change of temperature effect." They showed by experiments that this "change of temperature affect" could be reproduced in the same lot of potatoes at least 3 times over a period of 5 months without much change in the typical respiratory response.

Treadway *et al*. (71) confirmed that sugar disappearance during conditioning was accompanied by gain in starch. However, they also pointed out that the total starch content of tubers decreased progressively.

Sweetman (67) noticed that boiling, as well as chipping quality of potatoes decreased at 40° F. storage, but that both qualities could be partially restored after 21 days at 68° F. The sweet flavor and off color in the chips were attributed to sugar accumulation at levels of 0.5% or higher of the fresh weight.

Denny and Thornton (26) found a direct correlation between the amount of reducing sugar rather than total sugars, in the juice of potato tubers and the extent of browning when chips were made from them.

Alexander *et al*. (1) reported that potatoes with higher specific gravity lost sugar more quickly than those with lower specific gravity.

Fischnich and Heilinger (34) observed that the chemical constituents of the potato tuber were primarily related to variety, both quantitatively and qualitatively, but that they could also be influenced by soil fertility, climate, disease, growing season and storage conditions. The organic

acid components are malic, lactic, succinic, tartaric, citric and oxalic. The protein content of the tuber, although only about 2%, was said to be highly nutritious.

Starch was suggested as the primary material respired at a rate of 1.2 to 2.5 milligrams dry matter per kilogram per hour (12). Changes in the starch-sugar ratio in the potato tubers were reported to be controlled by 3 factors:

(1) hydrolysis of starch to sugar,

(2) condensation of sugar back to starch, and

(3) oxidation of sugar during respiration.

Hensen (41) used the CO_2 liberated from potato tubers as an index of the intensity of their respiration. He pointed out that losses in tuber weight due to respiration were much smaller than those due to evaporation; he even suggested a ratio of 1:10, but gave no data on the dry matter content to substantiate this ratio. Starch loss was said to be responsible for tuber weight loss as a result of respiration. Moisture loss was thought to depend on the evaporation of water from the tuber skin and on the thickness of the cork layer of the tuber.

Chemical Sprout Inhibitors

Chemical inhibitors have been available for commercial application since about 1947 (68). Interest in the use of chemical inhibitors was stimulated by the work of Elmer (30), who discovered that volatile gases given off by apples applied to potato tubers, produced sprouts which developed abnormally. Several factors prompted the use of chemical inhibitors, viz.:

a) The need for keeping potatoes sprout-free while in transit during World War II, other than by refrigeration (68).

b) Potato processors using deep fat frying like to store their produce at 50° F. or higher for curing and color control. This puts a serious limitation on the use of temperature alone for the control of sprouting (68).

c) Potato processors buying their produce at periods of peak supply when prices tend to be low, need some method other than temperature manipulation to keep these potatoes relatively sprout-free (68).

d) Some high yielding potato varieties which also possess good cooking qualities have a short rest period (69).

Chemical inhibitors applied as dusts on tubers or as sprays to potato foliage have found commercial acceptance. Numerous chemicals which are effective for this purpose have not as yet been cleared by the federal government for commercial use; however, maleic hydrazide was recently given such clearance. It is noteworthy that maleic hydrazide has been tested more and has received a wider range of acceptance than any other commercial inhibitor in the United States. The greatest use of this chemical has been with potato processors (68).

The most promising chemical inhibitors in potato research programs are: tetrachloronitrobenzene (TCNB), maleic hydrazide (MH), methyl-ester of alpha naphthalene acetic acid (MENA), isopropyl-N-chlorophenyl carbamate (CIPC) and amyl and nonyl alcohols (68). Irradiation is also a very potent sprout inhibitor (68).

MH was reported to be effective for inhibiting sprout growth only if applied during the growing season (35). MENA, CIPC and TCNB, on the other hand, can be applied as dusts or sprays to potatoes going into storage. Amyl and nonyl alcohols, as well as MENA and CIPC have been applied as gases to potatoes after they are in storage. Irradiation

has a disadvantage in that it cannot be applied to potato tubers in the bin.

Denny et al. (25) used MENA incorporated into filter papers distributed among potato tubers stored in earthenware containers which were not tightly closed. The chemical was reported to inhibit the sprouting of the tubers. Sprouting was completely prevented for 1 year by an uninterrupted application of 400 milligrams per kilogram of tubers while inhibition was only barely perceptible with 10 milligrams per kilogram. The filter papers were found effective a second time in closed containers. For one year at 50° F., there was neither shrivelling of the tubers nor sprouting. The treated tubers made good chips, but it could not be recommended then for commercial use as the amount of the chemical in the tuber was not known.

Denny (24) in a later experiment found that not more than 5 mg. of the MENA was taken up by the tissues treated with 100 mg. per kilogram for 5 months. Of the 5 mg., 4/5 was in or on the skin of the tubers. The tubers, however, did not sprout properly when cut and planted, not even when treated with ethylene chlorhydrin.

Sawyer and Dallyn (62) showed that the application of

vaporized chemical inhibitors gave excellent sprout control with potatoes. Good results were obtained with CIPC at 250 mg. per bushel and with MENA at 500 mg. per bushel. Gaseous application was less expensive and gave better control of shrinkage and less sprouting than dust or aerosol application. It is free from dust, which is a problem with aerosol formulations.

Talburt and Smith (68) summarized that a gas application of MENA, CIPC and the alcohols (amyl and nonyl), had many advantages over the other methods of sprout control since the application may be delayed until a definite need arose for sprout control. The effects were longer lasting with such delayed application in storage than from an application of the same material at harvest. They further pointed out that all of the other methods of sprout control, which required an application before a need arose, were wasted during years when the rest period and cool storage temperatures were sufficient to keep the tubers in good condition for the storage period.

A characteristic common to all chemical inhibitors is that the mechanism that prevents cell division for sprouting, also prevents cell division for wound periderm formation (68).

<u>General Effects of Maleic Hydrazide</u>

Maleic hydrazide (MH) is commonly used in the form of the diethanolamine salt (MH-30) or as the sodium salt (MH-40) of 6-hydroxy-3-(2H)-pyridazinone. MH has been extensively evaluated and found to:

a) inhibit cell division but not cell expansion (31),

b) reduce respiration rate (44, 55),

c) destroy apical dominance (47, 56), and

d) to behave as an anti-auxin (7).

Schoene and Hoffman (63), working on tomatoes, turf and corn, described maleic hydrazide as a unique growth regulant. Since their work, many experiments have been performed and MH-30 has been shown to be both a plant growth inhibitor and a herbicide (75). It has found extensive use on many crops and was found to be relatively non-toxic to mammalian tissue (75). In fact, MH-30 applied at a rate of 1 gallon per acre on potatoes, showed no diethanolamine residue in the tubers (14).

MH functions as a herbicide by preventing the regrowth of rhizomes (11), preventing flowering and inhibiting germination to control annual weeds such as sandbur grass and wild oats (13, 53). Since MH is most active against young

vigorously growing plants, it exerts selective control on young weeds among mature plants.

As a growth inhibitor, MH inhibits cell division without affecting cell expansion (31). It also prevents the growth of suckers in tobacco and increases the yield of tobacco leaves (10). It finds application on lawn grasses where it reduces the frequency of mowing by reducing grass growth (76). Inhibition in grasses (22), however, shows variable response possibly due to the differences in rate of absorption which can be correlated with relative humidity (65).

MH inhibits sprouting of radish (28), sugar beets (74), potatoes (56) and onions (56). Other effects of MH include: inhibition of terminal growth to force axillary buds for increased flower production of chrysanthemums (9), reduction of respiration to decrease storage losses of sugar in sugar beets (74), suppression of apical dominance and bolting in vegetables (7), increase in percentage of protein in forage grass (64) and production of male sterile cucurbits (43), sorghum (52) and corn (54).

Effects of MH on Potatoes

Many papers have reported the effects of MH on potato tubers. Dipping potatoes in MH solution was demonstrated to be ineffective in reducing sprout growth although it checked fungous infestation (16, 32). This indicated that the chemical was probably not absorbed by the tubers. Marshall and Smith (51), however, working with Green Mountain potatoes, reported that a toothpick application of 0.25% MH by puncturing the tuber prevented any sprout from developing.

Experiments indicated that only a field spray application on potato vines was effective in retarding sprout growth of tubers in storage (35, 56). Later work showed that the time of application was very critical. Kennedy and Smith (47) observed that sprays applied early in the growing season caused increased tuber set and decreased yield. Other workers (56, 58) reported that satisfactory sprout control could be obtained from MH sprays applied several weeks before harvest. Sawyer and Dallyn (62) and Denisen (23) found a blossom drop (i.e., 8 days after full bloom) application most satisfactory as it gave less detrimental effects to the tubers than earlier sprays.

Isleib (45) working with Arenac, Kennebec, Russet Rural, Merrimack and Golden Chipper, observed that spraying 7-12 days after full bloom led to no reduction of yield or specific gravity of the tubers. In general, foliar spray applications of MH applied at blossom drop or 6 weeks before harvest of the tubers have been found to inhibit sprouting in tubers and to give no reduction in yields and no significant difference in the specific gravity of the tubers either before or after 5 months of storage (23, 35, 47, 58). A few workers (8, 15), however, did not obtain the above mentioned effects.

Accompanying a reduction in sprout growth and total weight loss in storage was the fact that there was an increase in the number of buds showing activity (47).

Paterson (56), applying a foliar spray of 500, 1000 and 2500 ppm of MH 1-7 weeks prior to harvest to Irish Cobbler, Pontiac, Russet Rural and Sebago potatoes observed that apical dominance of both tubers and individual sprouts on the tubers was destroyed. Paterson and Rao (56, 58) reported that the apical region of each tuber had complete sprout inhibition as contrasted with the basal region where incomplete inhibition was observed.

Highlands et al. (42) treated Kennebec and Katahdin potatoes in Maine with 1000 and 2500 ppm MH, 37, 27 and 20 days prior to harvest. After storing the tubers at 40° F. for 6 months, he found no significant differences in chip color or in reducing sugar content in tubers from treated and untreated plants. These results were confirmed by other researchers (48, 56).

Salunkhe and Wittwer (61) failed to obtain the above mentioned results. They reported potatoes treated with MH yielded golden yellow chips of good flavor and texture as compared with the burnt, dark brown and bitter chips produced from control tubers.

Klein and Leopold (49) suggested that MH acted as an auxin competitor in the presence of true growth regulators (indole acetic acid for example), increasing growth by as much as 30% at 1 ppm and inhibiting growth at high concentrations. Paterson (56) confirmed the growth promoting aspect of MH when he observed that low concentrations of MH applied shortly before harvest, in fact, stimulated sprout growth on potato tubers.

Greulach and Haesloop (38) reported that inhibition of cell division by MH accounted for practically all the

observed growth inhibition. Further work by Greulach (37) showed that MH definitely inhibited cell division but that its effects on cell enlargement were varied, although the cells in treated plants were often larger than those in controls. The amount of xylem and lignified interfascicular tissue was also greatly reduced, due to the inhibition of secondary meristematic activity. Maleic hydrazide may also have an effect on cell differentiation, as indicated by the fact that Greulach found guard cells ceased growing in various stages of ontogeny in treated bean and sunflower leaves, as well as a greatly reduced number of stomates per unit area. Other physiological effects of MH reported include: accumulation of carbohydrates, lowering of protein content and increasing non-protein nitrogen compounds, particularly leucine, and reducing the rate of transpiration from leaves.

Darlington and McLeish (20) working with MH on the mitosis of Vicia faba roots reported complete cessation of mitosis for 2 days in roots in water solution concentrations above 0.0005 M MH for 24 hours at 53.6°-60.8° F. Lower concentrations, however, did not stop mitosis, but breakage of chromosomes at mitosis was seen.

Inhibition of respiration by MH was reported by Naylor and Davis (55). Working with the root tips of peas, sunflower, corn, barley, tomato, oats and wheat, they suggested that MH possibly exerted its influence on growth by inhibiting respiration perhaps by affecting the normal function of dehydrogenase.

The results of Isenberg's study (44) support the conclusion that the principal effect of MH is the modification of the respiratory activity of the plant. The modification is said to be twofold in nature: low concentration of applied sprays stimulate respiratory activity, while high concentrations reduce or inhibit respiratory activity. This change in respiratory rate is generally accompanied by undesirable morphological changes in actively growing plants. These changes were not apparent in storage organs such as tubers and bulbs, although respiratory changes were detectable.

Fischnich et al. (33), working with potatoes and Jerusalem artichoke sprayed with MH before or during bloom, concluded that MH exerted a strong retardation effect upon growth and development of plants. The action presumably depends upon a strong inhibition of metabolic processes,

of respiration, as well as upon the inactivation or destruction of natural growth substances.

An anti-auxin action has been suggested by Audus (7) for MH. He also reported that growth inhibition caused by MH was relieved only by high concentration of IAA, indicating a mutual competition for the growth centers. MH was also found to inhibit cell division but not cell extension, and had no significant effect on indole acetic acid levels in growing tissues except at 10^{-3} M concentration. Audus also stated that many observations showed that carbohydrate metabolism was seriously disturbed by MH treatment in many different tissues. Such disturbed metabolism was usually characterized by an increase in sugars at the expense of polysaccharide reserves. It was also reported that some workers, however, showed that increase in sugars had no direct connection with growth inhibition. Petersen and Naylor (57) working on some metabolic changes in tobacco stem tips treated with MH proposed that a blockage of carbohydrate utilization might necessitate drawing on proteins as a source of respiratory fuel and so disturb protein metabolism and cell division. Inhibition of protein formation was also suspected.

Greulach (36) described work on starch metabolism of plants treated with MH. He found that MH did not block starch breakdown processes. He also suggested that MH blocked either hydrolysis or phosphorolysis, but certainly not both processes. In his second experiment, he found that MH did not block starch synthesis in bean and tomato plants.

Some enzyme systems are reported to be affected by MH. These include succinnic dehydrogenase (44), peroxidase, phosphatase and polyphenolase (40).

Inhibition of differentiation of tissue in the buds and root primordia of tubers and bulbs was reported (58). Sections of Irish cobbler tubers prepared after 5 months of storage at 55° F. showed no evidence of meristematic (phellogen) tissue in the periderm following treatment with MH. Comparatively little activity was seen in the buds (59).

The relative humidity of the atmosphere at the time of application markedly affected the rate of absorption of MH (65). The most rapid absorption occurred when leaf cells were turgid under high humidity conditions. MH from the diethanolamine salt formulation was better absorbed than the corresponding sodium salt at humidities above 40%.

This was probably due to the ability of the amine salt to absorb water from the atmosphere (21).

MH moves in the phloem (19) and translocation occurs both in an upward and downward direction from the point of application (50).

All the investigations have shown that MH is primarily an inducer of dormancy in potatoes. There are, however, conflicting reports on its mode of action, although it appears to inhibit cell division in the meristematic regions but not cell enlargement. A precocious maturation of tissues also occurs (31).

MATERIALS AND METHODS

The experiments were conducted between May 1960 and May 1962. Two recommended potato varieties in Michigan, Kennebec and Russet Rural, were selected for use in the experiments. They were grown at the Lake City experimental station during both 1960 and 1961. The potato vines were hand sprayed with MH-30 at a rate of 1 gallon MH-30 in 100 gallons of water (i.e., 3 lbs. active MH) per acre on August 4, 1960 and August 6, 1961. Each year the potato tubers were harvested in October and brought from the Lake City station to the Michigan State University campus at East Lansing in November where they were stored.

1960/1961 Experiments

A quantity of potato tubers from the 1960 crop, carefully selected for lack of bruising, rot, injuries or disease, were placed in storage for 6 months from November 17, 1960 to May 20, 1961, in the Farm Crops field laboratory. There were 2 storage environments:

a) A large room in the basement of the laboratory with a temperature of 60^{o} F. and relative humidity of about 70% at the start of the experiment. (In April

and May 1961, however, the temperature rose to an average of 62° F. while the relative humidity fell to 46%).

b) A controlled temperature room at 41° F. ±2°, with a relative humidity of 85-90%.

Each sample in storage weighed about 2500 grams. There were 2 replications. The samples were placed in mesh bags, which were in turn carefully placed in wooden boxes with openings at the sides, bottom and top to permit free air circulation in storage. Each mesh bag was numbered.

Gross weight readings were recorded at the beginning and at monthly intervals until the end of the sixth month. Sprout weight was obtained by difference by first weighing all the tubers with their sprouts intact, then breaking off all sprouts and reweighing the tubers alone. Observations were made as regards the nature of the sprouts and the condition of the tubers.

From the end of the third month in storage, a proximate feed analysis was made on each potato sample. This included determinations for ash, water, ether extract, crude protein, crude fiber and nitrogen free extract (NFE). Both tubers and sprouts were analyzed for these constituents.

In order to obtain a representative portion for chemical analyses, each sample was divided into 2 lots by count, based on the size of the individual tubers it contained. One lot was then thoroughly cleaned with a clean, soft cloth to remove all soil and sand particles in particular. The tubers were then cut into thin slices and weighed to determine their fresh weight. They were placed on trays and put in the drying oven at about 185°F. for 24 hours. After drying, the samples were again weighed to determine the loss in weight which was expressed as moisture loss. The dry samples were finely ground in a Wiley mill, thoroughly mixed, and stored in bottles with tight lids. This material was used for all chemical analyses.

The analytical methods used were standard laboratory procedures as described by the Association of Official Agricultural Chemists (6).

<u>1961/1962 Experiments</u>

On May 9, 1961, Kennebec and Russet Rural tubers were each planted in 11 ranges at the Lake City experimental station. Each plot, made up of 3 rows, was 9 feet by 24

feet and was approximately 1/200 acre. One plot out of every 2 was randomly chosen and was hand sprayed with MH-30 on August 6, 1961, 10 days after full bloom. The rate of maleic hydrazide application was, as in 1960, 1 gallon MH-30 in 100 gallons of water per acre.

At harvest in October 1961, only tubers from the middle row of each plot were collected, tagged and bagged for yield records. The tubers were later sorted and graded into US No. 1 (1 7/8 inch minimum diameter) and the B group (less than 1 7/8 inch). Specific gravity determinations were made, by weighing the tubers in air and then in water, using only US No. 1 tubers from each plot (46).

The tubers were put in 41° F. storage at East Lansing on the 12th and those at 70° F. on the 20th of November 1961. Each storage sample was about 2000 grams. Only healthy tubers were used.

Both storages had automatic devices for maintaining temperatures at 41° and 70° F., respectively. The 41° F. controlled temperature room operated at an average relative humidity of 85-90%, while the 70° F. cabinets averaged a relative humidity of 70% $\pm$ 2 for the storage period.

Weighings were carried out at monthly intervals. The

weight of tubers and sprouts was also determined.

Storage of tubers in the 70° F. cabinets was terminated at the end of the third month owing to excessive sprout growth. However, tubers in the 41° F. room were held there until April 21, 1962, i.e., for 5 months.

Respiration Studies

The method used in this experiment to measure the quantity of CO_2 evolved by the tubers was an adaptation of the Claypool-Keefer method (17, 29). The method and the apparatus used have been described in detail by Eaks and Pratt, with additions by Clerx and Dewey (Fig. 1). Healthy Kennebec and Russet Rural tubers were used. The experiments were conducted in 2 controlled temperature rooms.

10,000-gram samples of US No. 1 potatoes were placed in closed plastic pails for storage at 41° F. and 5000 grams for storage at 70° F. Each pail was fitted with hose connections to permit an air flow rate of about 200 ml./min. over the tubers. Air from each pail was run through the indicator solution (dilute $NaHCO_3$ containing bromthymol blue dye) to measure CO_2 production. Blanks were run for each period. Samples were examined

periodically for sprouting, mold growth and spoilage. Tuber weights were taken and corrections made whenever a spoiled tuber was removed. The amount of CO_2 evolved was computed and expressed as mg. CO_2/Kg-hr.

The respiration experiments were started on November 13, 1961, but no reading was taken until November 20, 1961, after which further readings were taken every 3 1/2 days--one at 11 p.m. on Mondays and the other at 11 a.m. on Fridays of each week.

After 10 weeks in storage, the sprouts of all the tubers kept at 70° F. were removed and weighed. Respiration data were recorded for another 5 weeks before the experiment was terminated after 15 weeks. The final weight of each sample was recorded. The newly regenerated sprouts were broken off from each sample and their weights recorded. The samples (tubers and sprouts separately) were then analyzed for dry matter content.

The respiration measurements for the tubers stored at 41° F. were also terminated after 15 weeks of storage. Final weight readings were made for each sample. However, a 4000-gram sample was taken from each lot and was continued in respiration studies at 70° F.

When the plastic pails were opened to examine and weigh the tubers, a tuber was removed from each sample for cooking to determine potato chip quality. This was done with a view of relating the respiration rate of each sample to the rapidity of conditioning for making potato chips.

Portions were removed with a cork borer from each of 6-7 tubers. This material was preserved in 80% ethanol for subsequent sugar analyses. A total sugar analysis was made using the pickled tuber samples at the beginning and at the end of the conditioning period.

Cooking Quality

This experiment was done in order to find out what effect maleic hydrazide had on cooking quality of potatoes. The tubers were washed with water and were cut longitudinally into halves, i.e. along the axis from the apex to the basal end. One of the 2 halves from each sample was boiled in water for about 25 minutes. They were pierced with a pointed instrument to determine when they were well cooked. Samples stored under the same storage conditions were all cooked together in one big aluminum pot divided into 8 compartments, one for each sample. When they were done, each sample was peeled and scored for color, flavor

and texture. The other half of the cut tuber was sliced with a chip slicer. Six or seven slices were picked from each sample and were soaked in cold water for about 10 minutes to remove adhering starch and to separate the slices (60). Then the slices were fried until they were sufficiently cooked in oil which had been preheated to 375° F. The slices were judged to be well fried when bubbling stopped in the oil. That was an indication of complete removal of water from the slices. During the rapid evaporation of water from the chips in the frying oil, the temperature of the oil fell rapidly to about 350° F.

Anatomical Studies

The purpose of this study was to ascertain whether the difference in loss of water and inhibition of sprouts in tubers from potato plants treated with MH-30 is due to the degree of cell differentiation. After 3 months of storage at 70° F., 10 potato tubers showing the typical maleic hydrazide effect of bunchy, rosette-like tiny sprouts were selected from treated tubers. Ten tubers were also chosen at random from the controls. All tubers were washed

and scrubbed with a soft, clean cloth to remove soil and sand particles.

With a 7/16 inch cork borer, 1/2 inch long pieces were taken from each of the 10 tubers in each sample, usually through the bud. After fixation and embedding, the pieces were sliced to a 12 micron thickness with a microtome, and were stained with safranine "O," crystal violet and orange G for microscopic examinations.

RESULTS

1960-61 Experiments

The results of the experiments conducted from November 17, 1960, to May 20, 1961, are shown in Tables 1a, 1b, 2a and 2b and Figs. 6a and 6b. From now on, potato tubers from MH treated plants will be designated MH tubers; while those from untreated plants shall be known as the control tubers.

MH Effects on Sprouting

Sprout weights expressed in grams per kilogram initial fresh weight of the tuber samples were recorded throughout the 6 month storage period as shown in Table 1a. Sprouting was effectively inhibited by MH when the tubers were stored at 41° and 60° F.

The effectiveness of MH in retarding sprout growth is also shown in Figs. 2, 3, 4, and 5. The photographs were taken on May 31, 1961, at the end of the storage period. Apical dominance was lost in MH-tubers. Sprouts of MH-tubers were rosette-like and bunchy as contrasted with the 1 or 2 vigorous apical sprouts of control tubers. The basal sprouts of MH-tubers were the most vigorous.

Table 1a. The weight of sprouts expressed in grams per kilogram initial fresh weight after various periods of storage.

STORAGE		Varieties and treatments	SPROUT WEIGHT AT THE END OF					
Temperature ^{o}F	% relative humidity		1 month	2 months	3 months	4 months	5 months	6 months
			g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
$41^{o} \pm 2^{o}$	85-90	Kennebec control	0.0	0.0	0.4	3.4	7.5	16.5
		Kennebec MH-30	0.0	0.0	0.0	2.4*	3.2	4.5
		Russet Rural control	0.0	0.0	0.0	2.4*	14.1	34.3
		Russet Rural MH-30	0.0	0.0	0.0	0.0	0.0	0.2*
60^{o}	70	Kennebec control	1.0	9.2	27.3	35.1	125.5	146.9
		Kennebec MH-30	0.0	0.4	1.4*	1.2*	2.8*	no sample
		Russet Rural control	0.3	3.8	22.1	49.9	117.2	130.1
		Russet Rural MH-30	0.0	0.0	0.8*	0.8*	2.7	3.8*

* Only 1 sample available for the data.

Fig. 1. Apparatus for measuring CO_2 production of potato tubers.

Fig. 2. A comparison of the condition of Russet Rural and Kennebec MH-tubers and control tubers after 6 months of storage at 60° F. and 70% relative humidity.

Fig. 3. A comparison of the condition of Kennebec and Russet Rural MH-tubers and control tubers after 6 months of storage at 41° F. ± 2° and 85-90% relative humidity.

RR. MH-tubers

RR. control tubers

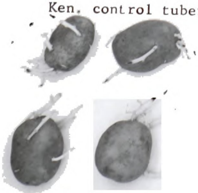
Ken. MH-tubers

Ken. control tubers

Ken. MH-tubers

RR. control tubers

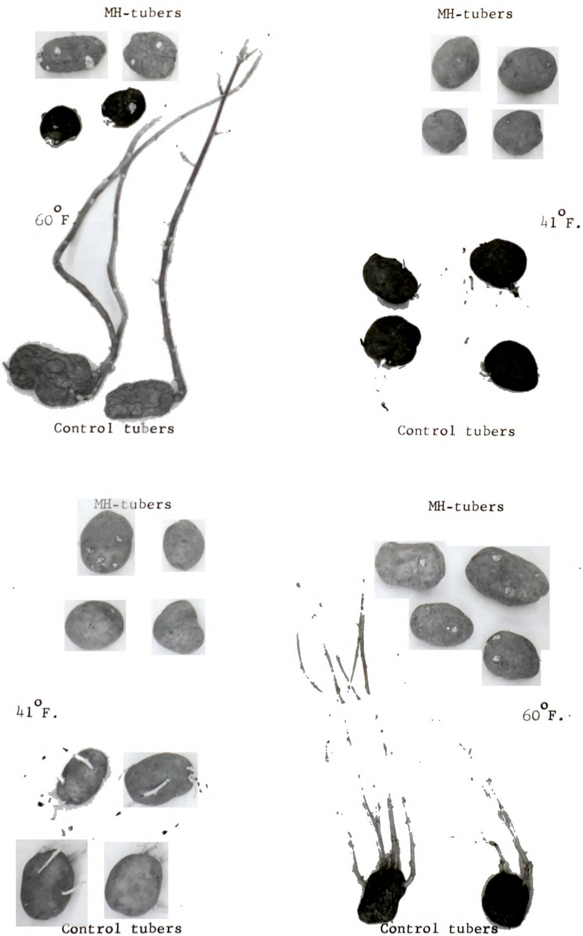
Ken. control tubers



RR. MH-tubers

Fig. 4. The condition of Russet Rural tubers after 6 months of storage at 60° F. and 70% relative humidity and 41° F. $\pm$ 2° and 85-90% relative humidity.

Fig. 5. The condition of Kennebec tubers after 6 months of storage at 41° F. $\pm$ 2° and 85-90% relative humidity and 60° F. and 70% relative humidity.


MH-tubers
60°F.
Control tubers
MH-tubers
41°F.
Control tubers
MH-tubers
41°F.
Control tubers
MH-tubers
60°F.
Control tubers

Weight Loss

Weight loss due to water evaporation and respiration were measured by weighing the samples at monthly intervals. The results obtained are shown in Figs. 6a and 6b.

When stored at 60° F., weight loss from the control tubers was greater than that from the MH-tubers only after the fourth month, but generally MH-tubers lost slightly more weight than the control tubers when stored at 41° F. ± 2°. Higher losses were experienced by Russet Rural control and MH-tubers than their Kennebec counterparts at both storage temperatures. However, both varieties lost more weight at 60° F. than at 41° F. The larger weight loss of MH-tubers stored at 41° F. ± 2° appeared to have compensated for sprout loss from control tubers. A combination of weight loss from dessication, respiration and sprout growth gave the total weight loss or shrinkage during the storage period. (See Table 1b.) Total weight loss was greater at the warmer storage temperature for both varieties. The control tubers lost more weight than the MH tubers.

The conditions of the tubers at the end of the 6 month storage period are illustrated by Figs. 2, 3, 4, and 5.

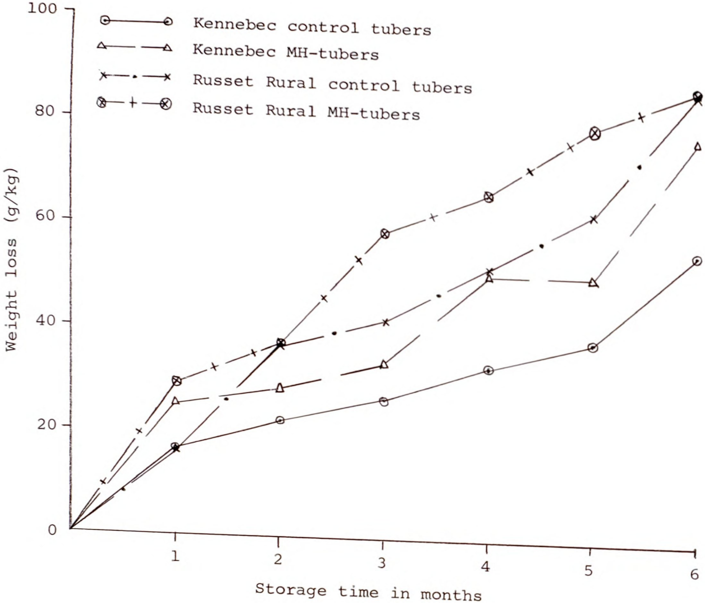


Fig. 6a. Evaporation and respiration losses from tubers stored at 41° F ± 2° expressed in grams per kilogram initial fresh weight after various periods of storage.

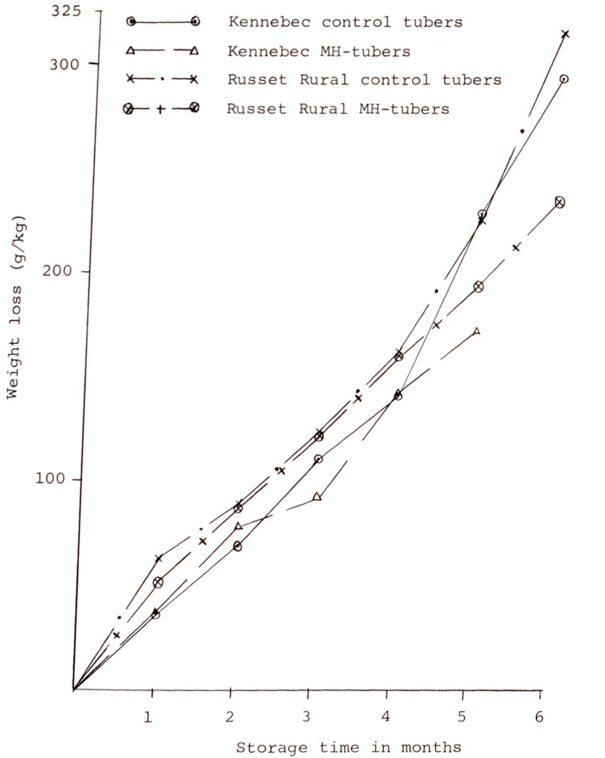


Fig. 6b. Evaporation and respiration losses from tubers stored at 60° F. expressed in grams per kilogram initial fresh weight after various periods of storage.

Table 1b. Sum of evaporation and respiration losses from tubers and weight of sprouts expressed in grams per kilogram initial fresh weight, after various periods of storage.

STORAGE		Varieties and treatment	WEIGHT LOSS AT THE END OF					
Temperature °F	% relative humidity		1 month	2 months	3 months	4 months	5 months	6 months
			g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
$41^{\circ} \pm 2^{\circ}$	85-90	Kennenec control	16.6	22.5	27.2	36.9	46.1	73.0
		Kennebec MH-30	25.8	28.8	34.0	53.8*	54.6	82.8
		Russet Rural control	16.4	36.5	42.2	55.3	77.8	122.1
		Russet Rural MH-30	29.9	37.3	59.7	67.1*	80.1	88.1*
60°	70	Kennebec control	37.3	77.7	137.7	177.3	354.9	441.1
		Kennebec MH-30	36.8	78.0	93.9*	143.8*	175.1*	no sample
		Russet Rural control	62.9	93.6	145.7	212.3	342.5	445.7
		Russet Rural MH-30	51.5	87.5	121.9*	161.3*	197.3	239.2*

* Only 1 sample available for data.

Tubers at 41° F. were firm and fresh; whereas, those at 60° F. were wrinkled although MH tubers had a better appearance than control tubers.

Chemical Composition of Tuber and Sprouts

A proximate feed analyses were made on tubers and sprouts at monthly intervals starting from the end of the third month. The results (see Tables 2a and 2b) indicated that weight loss from tubers was primarily a result of water evaporation, crude protein loss and the disappearance of NFE, i.e., the easily hydrolyzable carbohydrates.

No chemical analyses were made of sprouts from MH tubers or from control tubers stored at 41° F. ± 2°, since the quantity of sprout produced in each case was not enough for a proximate feed analysis.

1961-62 Experiments

Yield and Specific Gravity

Yield records and specific gravity measurements are shown in Table 3. Results obtained showed that the MH treatment neither reduced the total and U.S. No. 1 yield of tubers, nor did it have any effect on their specific gravity.

Table 2a. Chemical composition of potato tubers and sprouts from untreated and treated plants determined between the third and sixth months of storage and expressed in grams per kilogram of initial fresh weight of sample.

STORAGE		Varieties and treatment	ASH			
Temp. °F.	% relative humidity		3rd month	4th month	5th month	6th month
		TUBERS	g/kg	g/kg	g/kg	g/kg
41° ± 2°	85-90	Kennebec control	9.4	9.1	8.5	9.1
		" MH-30	9.6	9.2*	9.2	9.3
		Russet Rural control	9.9	9.9	9.8	9.8
		" " MH-30	10.1	10.2	9.8	10.0
		TUBERS				
60°	70	Kennebec control	9.1	8.8	7.9	7.3
		" MH-30	9.4*	10.0*	9.2*	-**
		Russet Rural control	10.0	9.6	8.6	8.2
		" " MH-30	10.5*	9.6*	9.8	10.0*
		SPROUTS				
60°	70	Kennebec control	0.3	0.8	1.2	1.5
		Russet Rural control	0.4	0.4	1.1	1.6

* Only 1 sample available for data. ** No sample.

CRUDE FIBER				ETHER EXTRACT			
3rd month	4th month	5th month	6th month	3rd month	4th month	5th month	6th month
g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
3.9	3.4	3.8	3.6	1.5	0.9	0.7	0.9
4.1	3.6*	3.7	3.9	0.9	0.9*	1.0	0.8
5.2	4.7	4.5	4.6	1.1	1.2	0.8	1.0
4.8	5.1*	4.5	4.1*	1.3	0.8*	0.8	1.0*
4.0	3.9	3.4	3.8	0.9	0.8	0.9	1.6
4.1*	3.8*	3.6*	-**	0.8*	0.7*	1.8*	-**
4.9	4.7	4.7	4.5	1.2	0.9	0.7	1.3
4.8*	4.5*	4.5	4.4*	1.1*	0.8*	0.6	2.3*
0.4	1.3	2.0	2.7	0.1	0.1	0.1	0.2
0.6	0.6	2.0	2.9	0.1	0.1	0.1	0.2

Table 2b. Chemical composition of potato tubers and sprouts from untreated and treated plants determined between the third and sixth months of storage and expressed in grams per kilogram of initial fresh weight of sample.

STORAGE		Varieties and treatment	WATER			
Temp. °F.	% relative humidity		3rd month	4th month	5th month	6th month
		TUBERS	g/kg	g/kg	g/kg	g/kg
41° ± 2°	85-90	Kennebec control	784.5	785.0	777.2	750.6
		" MH-30	777.8	765.7*	762.4	737.1
		Russet Rural control	765.7	758.7	740.9	697.8
		" " MH-30	753.0	741.5*	737.9	732.9*
		TUBERS				
60°	70	Kennebec control	683.0	652.1	488.8	418.7
		" MH-30	738.8*	683.1	651.2*	-**
		Russet Rural control	661.2	611.8	490.1	402.1
		" " MH-30	690.6*	646.5*	616.5	580.4*
		SPROUTS				
60°	70	Kennebec control	23.6	24.4	109.7	106.0
		Russet Rural control	16.9	45.1	103.3	108.6

* Only 1 sample available for data. ** No sample.

NITROGEN FREE EXTRACT				CRUDE PROTEIN			
3rd month	4th month	5th month	6th month	3rd month	4th month	5th month	6th month
g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
153.5	143.7	143.8	142.1	20.1	21.1	20.1	20.7
154.1	146.4*	148.8	147.0	19.7	20.0*	20.3	19.2
159.2	152.8	148.4	146.9	17.1	17.5	17.8	17.9
153.5	157.5*	148.0	145.4*	17.8	17.9*	19.0	18.5*
146.0	138.7	128.2	112.2	19.4	18.5	16.0	15.3
133.1*	136.8*	138.3*	-**	19.5*	21.8*	20.7*	-**
160.4	143.9	137.4	124.2	16.2	16.8	16.0	14.1
153.9*	158.5*	153.0	144.6*	17.3*	18.9*	18.4	19.1*
2.2	6.0	9.1	12.0	0.8	2.3	2.3	4.4
3.2	2.8	8.0	13.0	0.9	0.9	2.6	3.8

Table 3. Yield and specific gravity of Kennebec and Russet Rural tubers from plots sprayed and unsprayed with MH-30

Varieties and treatment	YIELD PER PLOT (LBS.) US No. 1	B Group	Total	Specific gravity
Kennebec control	48.9	3.3	52.2	1.077
" MH-30	48.4	3.5	51.9	1.076
Russet Rural control	48.2	4.7	52.9	1.077
" " MH-30	45.3	4.6	49.9	1.077

Total yield was, however, slightly decreased by the MH treatment in the Russet Rural. The above observations confirm the findings of the earlier researchers in this field (23, 45, 47, 58).

Weight Losses

Sprout weights were recorded for both storage environments. The results are shown in Table 4a. MH was effective in prolonging the rest period of the tubers at 41° F. It also reduced the amount of sprout growth at both 41° F. and 70° F.

Table 4a. The weight of sprouts expressed in grams per kilogram initial fresh weight, after various periods of storage.

STORAGE		Varieties and treatment	SPROUT WEIGHT AT THE END OF				
Temperature °F.	% Relative humidity		1 month	2 months	3 months	4 months	5 months
			g/kg	g/kg	g/kg	g/kg	g/kg
41°	85-90	Kennebec control	0.0	0.0	0.0	0.4	1.0
		" MH-30	0.0	0.0	0.0	0.0	0.4
		Russet Rural control	0.0	0.0	0.0	0.0	1.5
		" " MH-30	0.0	0.0	0.0	0.0	0.0
70°	70 ± 2	Kennebec control	0.0	14.2	44.0		
		" MH-30	0.0	10.2*	8.6		
		Russet Rural control	0.0	5.4	14.9		
		" " MH-30	0.0	2.5	3.7		

* Only 1 sample used.

Weight losses due to water evaporation and respiration were also measured. The results (see Table 4b) indicated that weight losses by MH-tubers and control tubers were similar.

The total weight loss or shrinkage was the same in both MH tubers and the control tubers at 70° F. up to the end of the second month in storage (see Table 4c). At 41° F., the MH tubers lost slightly more weight than the control tubers except in the first and fifth months.

The 70° F. experiment was terminated at the end of the third month due to excessive sprout growth of the tubers as shown in Figs. 7 and 8. By that time, the tubers at 70° F. were wrinkled. The appearance of the tubers stored at 41° F. for 5 months was good, but most of the tubers were beginning to lose their firmness.

Respiration Data

The CO_2 evolved was measured every 3 1/2 days. It was expressed as mg. CO_2/kg.-hr. The results obtained are shown in Figs. 9a, 9b, 10a and 10b. The rate of respiration of the tubers was higher at the warmer temperature than at the cold temperature as expected. The respiration rates of MH

Table 4b. Evaporation and respiration losses from tubers expressed in grams per kilogram initial fresh weight, after various periods of storage.

STORAGE		Varieties and treatment	WEIGHT LOSS AT THE END OF				
Temperature °F.	% Relative humidity		1 month	2 months	3 months	4 months	5 months
			g/kg	g/kg	g/kg	g/kg	g/kg
41°	85-90	Kennebec control	15.3	22.5	25.9	33.3	41.3
		" MH-30	12.3	22.9	27.8	36.2	38.8
		Russet Rural control	9.1	16.9	23.4	28.8	33.5
		" " MH-30	9.5	17.7	29.3	33.9	36.6
70°	70 ± 2	Kennebec control	30.6	57.9	82.1		
		" MH-30	33.0	63.5	76.0		
		Russet Rural control	46.6	70.1	99.3		
		" " MH-30	41.0	71.1	100.2		

Table 4c. Sum of evaporation and respiration losses from tubers and weight of sprouts expressed in grams per kilogram initial fresh weight, after various periods of storage.

STORAGE		Varieties and treatment	WEIGHT LOSS AT THE END OF				
Temperature °F.	% Relative humidity		1 month	2 months	3 months	4 months	5 months
			g/kg	g/kg	g/kg	g/kg	g/kg
41°	85-90	Kennebec control	15.3	22.5	25.9	33.7	42.3
		" MH-30	12.3	22.9	27.8	36.2	39.2
		Russet Rural control	9.1	16.9	23.4	28.8	35.0
		" " MH-30	9.5	17.7	29.3	33.9	36.6
70°	70 ± 2	Kennebec control	30.6	72.1	126.1		
		" MH-30	33.0	73.7	84.6		
		Russet Rural control	46.6	75.6	114.2		
		" "	41.0	73.6	103.9		

Fig. 7. The condition of Russet Rural tubers at the end of 3 months storage at 70° F. and 70 $\pm$ 2% relative humidity.

Fig. 8. The condition of Kennebec tubers at the end of 3 months storage at 70° F. and 70 $\pm$ 2% relative humidity.

Control tubers MH-tubers

Control tubers MH-tubers

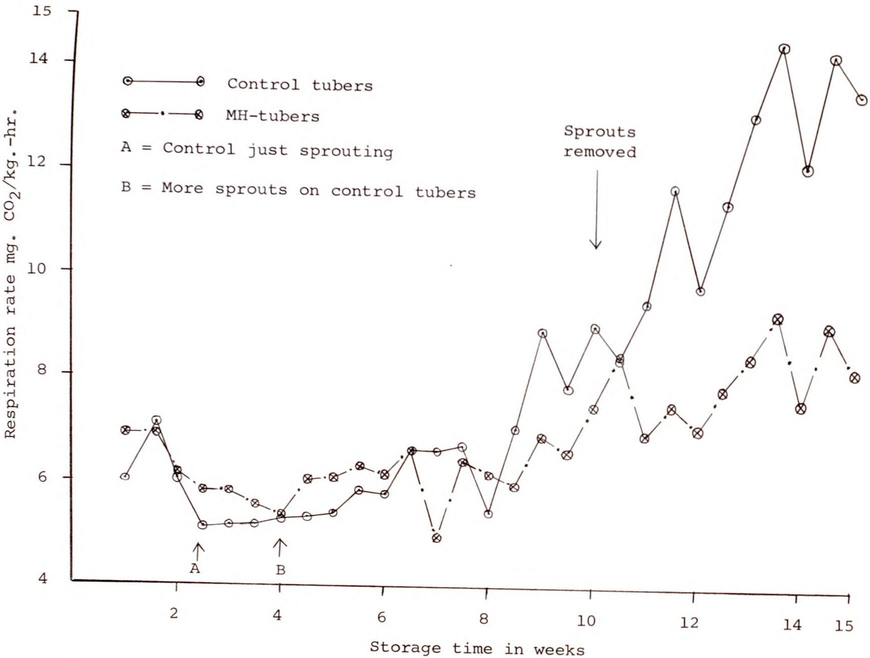


Fig. 9a. The effect of MH-30 on the respiration rate of Kennebec tubers stored at 70° F. and 70% relative humidity for 15 weeks.

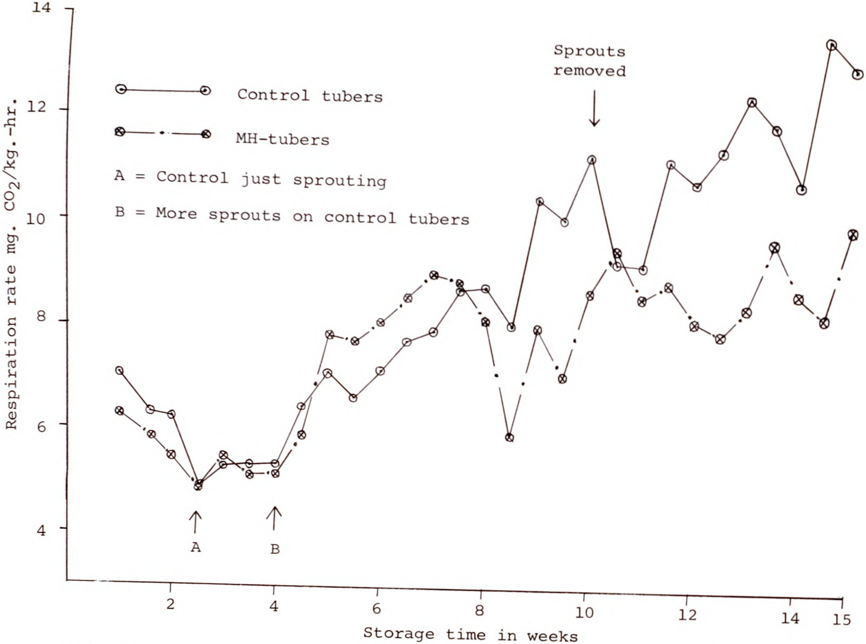


Fig. 9b. The effect of MH-30 on the respiration rate of Russet Rural tubers stored at 70° F. and 70% relative humidity for 15 weeks.

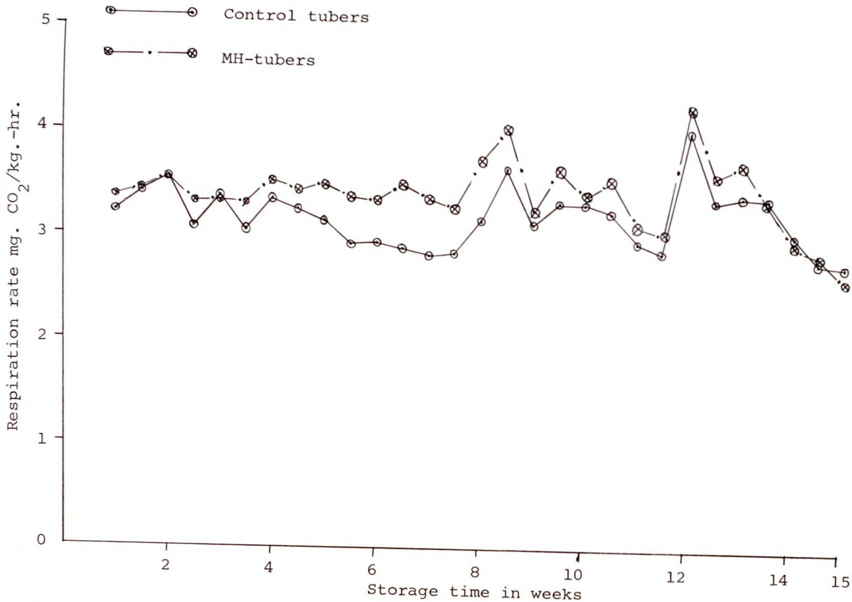


Fig. 10a. The effect of MH-30 on the respiration rate of Kennebec tubers stored at 41° F. and 90-95% relative humidity for 15 weeks.

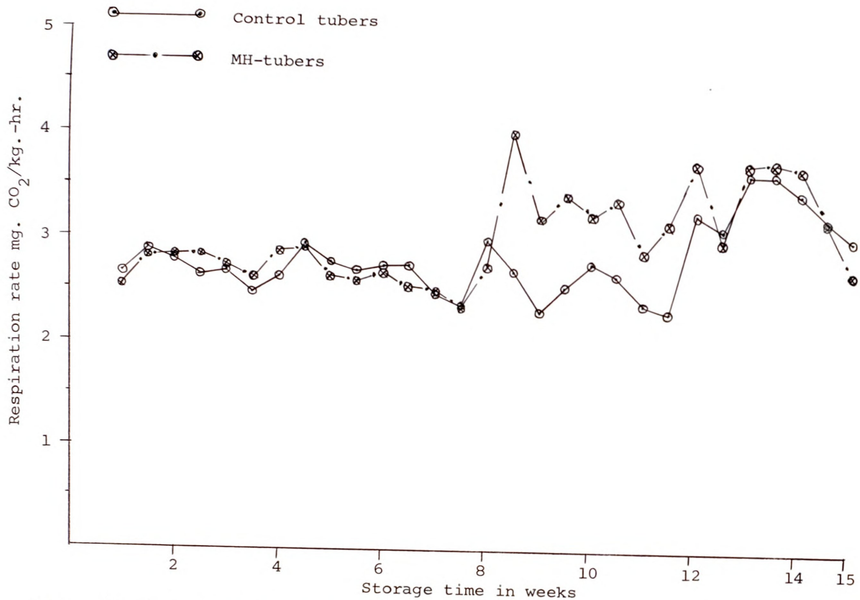


Fig. 10b. The effect of MH-30 on the respiration rate of Russet Rural tubers stored at 41° F. and 90-95% relative humidity for 15 weeks.

tubers and control tubers at the same temperature were similar until the control tubers began to sprout excessively. After the sprouts were removed, the respiration rates of both control and MH-tubers again became identical, until new sprouts showed up on control tubers.

At 41° F., where there were no sprouts, the respiration rates of MH-tubers and control tubers were similar.

Records of weight loss during the respiration experiment were kept. The results are shown in Tables 5, 6 and 7.

Table 5. Evaporation and respiration losses from tubers stored at 41° F. and 90-95% relative humidity for 15 weeks in respiration pails expressed in grams per kilogram initial fresh weight, after various periods of storage.

VARIETIES AND TREATMENT	WEEKS IN STORAGE			
	4	8	12	15
	g/kg	g/kg	g/kg	g/kg
Kennebec control	3.4	8.0	12.9	16.4
" MH-30	3.2	7.9	13.2	16.6
Russet Rural control	3.2	8.0	13.1	16.7
" " MH-30	3.0	7.7	12.9	16.6

Table 6. Evaporation and respiration losses from tubers stored at 70° F. and 70% relative humidity for 15 weeks in respiration pails expressed in grams per kilogram initial fresh weight, after various periods of storage.

VARIETIES AND TREATMENT	WEEKS IN STORAGE							
	2	4	6	8	10	12	13	15
	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
Kennebec:								
control	10.3	20.8	33.9	45.7	58.6	75.3	83.9	103.8
MH-30	13.3	24.3	36.8	48.0	59.8	72.2	80.8	100.5
Russet Rural:								
Control	11.9	23.2	38.5	51.6	65.7	90.0	96.6	117.4
MH-30	12.2	23.2	38.2	51.7	65.2	83.4	92.0	110.3

Table 7. The weight of sprouts from tubers stored for 15 weeks in respiration pails expressed in grams per kilogram initial fresh weight, after various periods of storage.

STORAGE		Varieties and treatment	1st 10 weeks	Next 5 weeks	To-tal
Temperature °F.	% Relative humidity				
			g/kg	g/kg	g/kg
41	90-95	Kennebec control	0.0	0.0*	0.0*
		" MH-30	0.0	0.0	0.0
		Russet Rural control	0.0	0.0	0.0
		" " MH-30	0.0	0.0	0.0
70	70	Kennebec control	14.8	34.4	49.2
		" MH-30	6.4	3.3	9.7
		Russet Rural control	5.9	16.2	22.1
		" " MH-30	0.6	1.6	2.2

* Tiny sprouts.

The following equation was used to convert the CO_2 production of the tubers to grams starch per kilogram fresh material:

$$C_6(H_{10}O_5)n + (6O_2)_n \longrightarrow (6CO_2)_n + (6H_2O)_n$$

$$162 \text{ grams} \longrightarrow 264 \text{ grams}$$

Table 8 shows the pattern of weight loss by the tubers during the respiration experiment. At 41° F., water evaporation and respiration accounted for all losses since no sprouts developed.

Tuber Size and Respiration Rate

An experiment was conducted between February 15 and February 22, 1962, to determine the effect of size of potato tubers on the rate of respiration. The tubers were sorted into small (less than 3 1/2 inch diameter) and large (3 1/2 inch minimum diameter) sizes and each tuber was numbered for its identity. The respiration data obtained are shown in Table 9.

The respiration rates of the small and large tubers were similar except in Russet Rural MH-tubers where the large

Table 8. Components of weight lost by tubers during the 15 weeks of storage in respiration pails expressed in grams per kilogram initial fresh weight and expressed as percent of total weight loss.

STORAGE			WEIGHT LOSS						
Temp. °F.	% Relative humidity	Varieties and treatment	Total	Sprout	Water**	Respiration*	Sprout	Water	Respiration
			g/kg	g/kg	g/kg	g/kg	%	%	%
41°	90-95	Kennebec control	16.4	0.0	11.5	4.9	0.0	70.1	29.9
		" MH-30	16.6	0.0	11.4	5.2	0.0	68.7	31.3
		Russet Rural control	16.7	0.0	12.4	4.3	0.0	74.3	25.7
		" " MH-30	16.6	0.0	12.0	4.6	0.0	72.3	27.7
70	70	Kennebec control	153.0	49.2	91.3	12.5	32.2	59.6	8.2
		" MH-30	110.2	9.7	90.0	10.5	8.8	81.7	9.5
		Russet Rural control	139.5	22.1	104.0	13.4	15.8	74.6	9.6
		" " MH-30	112.5	2.2	98.7	11.6	2.0	87.7	10.3

* Calculated from CO_2 production and expressed as starch loss. ** By difference.

Table 9. The effect of tuber size on the rate of respiration of potato tubers stored at 70° F. and 70% relative humidity.

Varieties and treatment	AVERAGE RESPIRATION RATE IN MG. CO_2/KG.-HR.					
	2-15-62		2-19-62		2-22-62	
	Small tubers	Large tubers	Small tubers	Large tubers	Small tubers	Large tubers
Kennebec:						
Control	14.41	14.68	12.18	12.12	14.34	14.33
MH-30	9.77	8.94	8.04	7.15	7.92	8.59
Russet Rural						
Control	11.61	12.25	10.67	11.00	13.00	14.29
MH-30	3.53	11.01	7.42	10.07	8.74	7.84

tubers respired faster than the small ones on the 15th and 19th of February 1962.

Condition of the Tubers

At the end of 15 weeks of the respiration experiment, the tuber samples were photographed (see Figs. 11a and 11b and 12a and 12b). Tubers stored at 41° F. were fresh and firm. The MH tubers had no sprouts, but the control tubers, especially the Kennebecs, had tiny visible sprouts. Tubers

Fig. 11a. The condition of Kennebec tubers stored at 41° F. and 90-95% relative humidity at the end of 15 weeks. Photographed on 2-27-62.

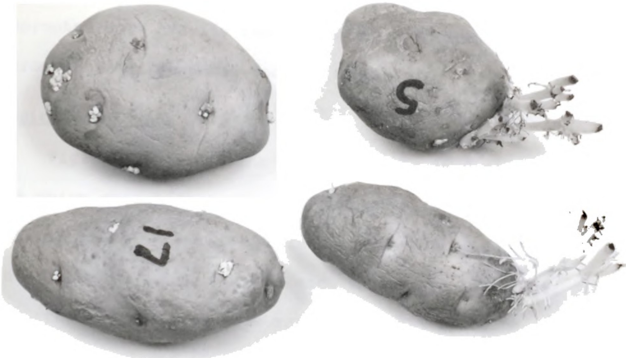
Fig. 11b. The condition of Russet Rural tubers stored at 41° F. and 90-95% relative humidity at the end of 15 weeks. Photographed on 2-27-62.

MH-tubers | Control tubers

MH-tubers | Control tubers

Fig. 12a. The condition of Kennebec tubers stored at 70° F. and 70% relative humidity at the end of 15 weeks. Photographed on 2-27-62.

Fig. 12b. The condition of Russet Rural tubers stored at 70° F. and 70% relative humidity at the end of 15 weeks. Photographed on 2-27-62.



MH-tubers

Control tubers

MH-tubers

Control tubers

at 70° F. were wrinkled and flabby. The control tubers sprouted more heavily than MH tubers. Sprouting was most pronounced on Kennebec control tubers.

Apical Dominance

Fig. 13 confirmed the results of the 1960-61 experiments in which apical dominance was destroyed in MH tubers. Careful examinations of the MH-tubers when they sprouted revealed that:

a) the apical dominance of each sprout was also lost, since the lateral buds grew rather than the apical bud;

b) the basal end sprout was the most vigorous, and

c) the vigor of the sprouts produced decreased progressively from the basal end to the apical end of the tuber.

Cooking Quality

Potato chips and boiled potatoes were evaluated.

Potato chips:

The potato chips produced were scored using the proposed color reference standard obtained from the Potato Chip Institute International of Cleveland, Ohio (18). The averages of 2 scores from 2 replications are presented in Table 10. The scores were judged on a scale from 1 to 10. The evaluation of the scores is as follows:

MH-tubers Control tubers

Fig. 13. Potato tubers photographed at the end of 3 months in storage at 70° F. and 70 ± 2% relative humidity to illustrate the loss of apical dominance by MH-tubers.

1 - 4	=	Very good
5	=	Good
6 - 7	=	Fair
8 - 10	=	Poor

Acceptable chips have scores of 1 to 5; 1 to 4 being the most desirable. The results (see Table 10) indicated that MH did not improve the color of the potato chips from MH tubers over the color of chips from control tubers stored at 41° or 70° F. Acceptable chips were produced only from potatoes stored at 70° F.

Conditioning:

Potato chips were made at the beginning of conditioning at 70° F. and at 2, 3 and 4 weeks later using 2 tuber samples. Table 11 shows the average score from 2 replications. The color reference standard (18) was used to evaluate the quality of the potato chips. MH was effective in bringing the potato chips from MH tubers to a desirable color a week earlier than those from the control tubers.

At the end of the conditioning period, Russet Rural MH tubers made chips scored at 5.5. This score was an average of 4 scores of 4, 4, 6 and 8. This incidentally confirms the views of people in the potato chip industry that Russet Rural tubers do not always condition.

Table 10. Evaluation of potato chips made from potato tubers from treated and untreated plants during the storage period.

STORAGE		Varieties and treatment	CHIP COLOR SCORE AT THE END OF			
Temperature °F.	% Relative humidity		1 month	2 months	3 months	5 months
41°	85-90	Kennebec control	7.5	10.0	10.0	9.5
		" MH-30	7.5	10.0	9.0	9.0
		Russet Rural control	7.5	9.0	9.5	9.5
		" " MH-30	7.0	9.0	9.5	10.0
70	70 ± 2	Kennebec control	4.5	3.5	3.0	
		" MH-30	3.5	3.0	3.0	
		Russet Rural control	5.0	4.0	3.0	
		" " MH-30	7.0	3.0	3.5	

Table 11. Potato chip color score* during conditioning at 70° F. and 70% relative humidity of tubers previously kept at 41° F. and 90-95% relative humidity for 15 weeks.

Varieties and treatment	Initial	AFTER 2 weeks	3 weeks	4 weeks
Kennebec control	10.0	9.5	8.0	4.5
" MH-30	10.0	8.0	4.0	3.0
Russet Rural control	9.5	8.0	7.5	5.0
" " MH-30	9.0	8.0	3.5	5.5**

* Average of 4 scores.
** Average of 4, 4, 6 and 8.

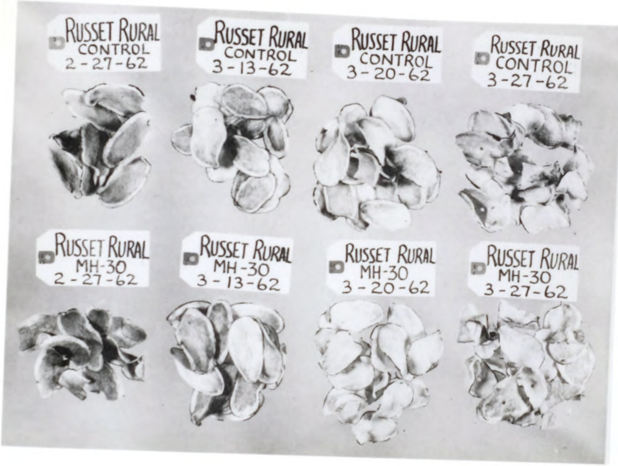
The potato chips produced were photographed in series at the end of the experiment to show the change in color of the chips during conditioning. The photographs are shown in Figs. 14 and 15.

The condition of the tubers and weight losses by them are shown in Figs. 16 and 17 and Tables 12 and 13.

Respiration measurements were made during conditioning. The respiration data are presented in Figs. 18a and 18b.

Fig. 14. Potato chips from Russet Rural tubers made at the beginning of conditioning and at 2, 3 and 4 weeks later to show the trend in chip color change.

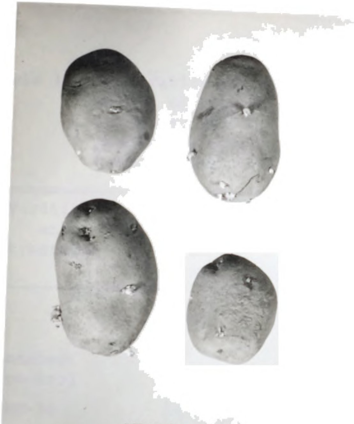
Fig. 15. Potato chips from Kennebec tubers made at the beginning of conditioning and at 2, 3 and 4 weeks later to show the trend in chip color change.


RUSSET RURAL
CONTROL
2-27-62
RUSSET RURAL
CONTROL
3-13-62
RUSSET RURAL
CONTROL
3-20-62
RUSSET RURAL
CONTROL
3-27-62
RUSSET RURAL
MH-30
2-27-62
RUSSET RURAL
MH-30
3-13-62
RUSSET RURAL
MH-30
3-20-62
RUSSET RURAL
MH-30
3-27-62

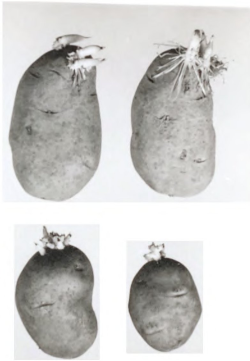

KENNEBEC
CONTROL
2-27-62
KENNEBEC
CONTROL
3-13-62
KENNEBEC
CONTROL
3-20-62
KENNEBEC
CONTROL
3-27-62
KENNEBEC
MH-30
2-27-62
KENNEBEC
MH-30
3-13-62
KENNEBEC
MH-30
3-20-62
KENNEBEC
MH-30
3-27-62

Fig. 16. The condition of Kennebec MH-tubers and control tubers at the end of conditioning at 70° F. and 70% relative humidity.

Fig. 17. The condition of Russet Rural MH-tubers and control tubers at the end of conditioning at 70° F. and 70% relative humidity.



MH-tubers



Control tubers

MH-tubers

Control tubers

Table 12. Evaporation and respiration losses from tubers and weight of sprouts produced during the conditioning period at 70° F. and 70% relative humidity of tubers previously stored at 41° F. and 90-95% relative humidity for 15 weeks.

Varities and treatment	TUBER WEIGHT LOSS IN 2 weeks	3 weeks	4 weeks	Sprout weight	Total weight loss
	g/kg	g/kg	g/kg	g/kg	g/kg
Kennebec:					
control	14.8	22.6	30.1	9.5	39.6
MH-30	14.8	22.3	29.0	3.2	32.2
Russet Rural:					
control	14.8	22.7	29.7	6.9	26.6
MH-30	16.1	24.4	31.6	1.0	32.6

Table 13. Components of weight loss during the conditioning period at 70° F. and 70% relative humidity of tubers previously held at 41° F. and 90-95% relative humidity for 15 weeks.

Varieties and treatment	WEIGHT LOSS To-tal	Sprout	Wa-ter**	Respi-ration*	Sprout	Wa-ter	Respi-ration
	g/kg	g/kg	g/kg	g/kg	%	%	%
Kennebec:							
control	39.6	9.5	25.8	4.3	24.0	65.1	10.9
MH-30	32.2	3.2	24.8	4.2	9.9	77.0	13.1
Russet Rural:							
control	36.6	6.9	25.5	4.2	18.9	69.7	11.4
MH-30	32.6	1.0	27.7	3.9	3.1	85.0	11.9

*Calculated from CO_2 production and expressed as starch loss.
**By difference.

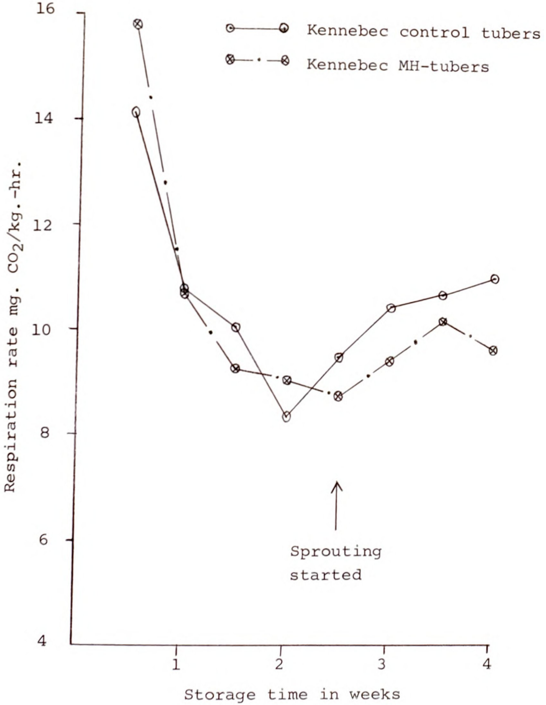


Fig. 18a. The effect of MH-30 on the respiration rate of Kennebec tubers during 4 weeks of conditioning at 70° F., following storage at 41° F. for 15 weeks.

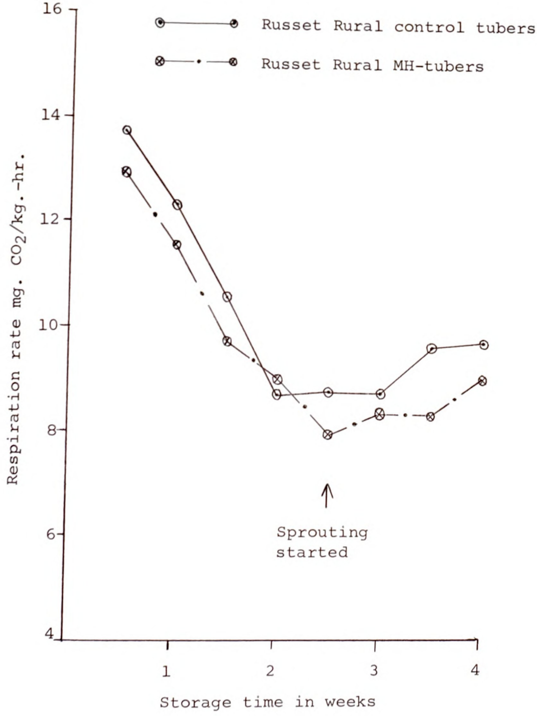


Fig. 18b. The effect of MH-30 on the respiration rate of Russet Rural tubers during 4 weeks of conditioning at 70° F., following storage at 41° F. for 15 weeks.

High and similar initial respiration rates were recorded for both MH-tubers and control tubers. As conditioning continued, the respiration rates of the tubers declined sharply but began to rise again after 2 1/2 weeks by which time the tubers had started to sprout.

The results of the sugar analyses made at the beginning and end of conditioning are shown in Table 14. The results indicate that tubers had to have less than 0.05% total sugar in order to make acceptable chips.

Boiled potato:

Potato tubers boiled for 25 minutes were scored for color, flavor and texture (see Table 15). Scores of 1 to 10 were assigned for each of the cooking quality items evaluated.

For color evaluation a whitish tuber flesh was most desirable and 10 points were awarded for that. The more yellow the color, the less the number of points scored. As for the flavor, a tasteless, i.e., flat potato scored 10 points. The score of tubers with taste decreased the sharper the taste. For texture, a crumbly dry tuber scored 10 points. Water logged sticky moist potatoes scored very low.

Table 14. The relationship between the amount of total sugar expressed as percent of fresh weight of tuber and potato chip color score at the beginning and end of conditioning at 70° F., and 70% relative humidity of tubers previously stored at 41° F. and 90-95% relative humidity for 15 weeks.

Varieties and treatment	START (2-27-62)			END (3-27-62)		
	Total sugar	Average total sugar	Chip color score	Total sugar	Average total sugar	Chip color score
	%	%		%	%	
Kennebec control	0.510	0.605	10.0	0.051	0.065	3.0
	0.700		10.0	0.078		6.0
Kennebec MH-30	0.834	0.701	10.0	0.071	0.054	3.0
	0.568		10.0	0.036		3.0
Russet Rural control	0.510	0.539	10.0	0.069	0.055	6.0
	0.467		9.0	0.041		4.0
Russet Rural MH-30	0.618	0.609	10.0	0.046	0.084	4.0
	0.600		8.0	0.122		7.0

Table 15. Color, flavor and texture scores of boiled potato tubers made at monthly intervals from tubers stored at 41° and 70° F. for 5 and 3 months respectively.

STORAGE		Varieties and treatment	SCORE AT THE END OF											
Temp. °F.	% Relative humidity		1 month			2 months			3 months			5 months		
			C	F	T	C	F	T	C	F	T	C	F	T
41°	85-90	Kennebec:												
		control	8.5	8.0	6.0	7.0	8.5	8.0	7.0	7.0	8.0	8.0	8.0	7.0
		MH-30	7.0	9.5	8.5	9.0	9.3	8.0	8.0	10.0	6.0	7.5	9.5	10.0
		Russet Rural:												
		control	9.0	8.0	7.5	8.3	8.3	7.3	8.0	10.0	10.0	7.0	8.5	10.0
		MH-30	7.5	7.5	9.0	7.5	7.5	9.0	8.0	10.0	10.0	7.0	9.5	10.0
70°	70 ± 2	Kennebec:												
		control	10.0	9.0	8.0	7.5	7.8	7.5	9.0	8.5	7.5			
		MH-30	8.0	9.0	8.5	9.5	9.3	7.3	9.0	7.5	8.0			
		Russet Rural:												
		control	7.5	7.0	7.5	7.5	7.8	8.5	8.5	7.0	6.5			
		MH-30	8.5	7.5	8.0	6.3	9.0	9.5	9.0	9.0	7.5			

C = Color F = Flavor T = Texture

A good comparative study of the boiled potato tubers could not be made owing to the arbitrary nature of the method of evaluation. In fact, each group of 8 samples was evaluated independent of the next group. Despite the weakness of this test, MH tubers had better flavor and texture than the control tubers.

Anatomical Studies

Slides of the longitudinal sections of MH tubers and control tubers did not show any anatomical differences, especially as regards cell differentiation and the thickness of the cork layer.

Dry Matter Losses

Summary tables of dry matter losses from potato tubers and the dry matter showing up in sprouts are presented in Tables 16, 17 and 18. NFE and crude protein accounted for most of the losses.

MH-tubers lost less dry matter than the control tubers stored at 41° , 60° or 70° F. Also, use of MH reduced crude protein loss in MH-tubers as storage continued.

During conditioning, loss of dry matter due to respiration by the tubers in 4 weeks at 70° F. was as great as the

Table 16. Dry matter losses from tubers and sprouts from the end of the third month to the end of the sixth month in storage at 41° F. ± 2° and 60° F. in the 1960-61 experiments.

	Total organic matter by end of 3rd month [initial]	DRY MATTER LOSS FROM TUBERS						DRY MATTER LOSS IN SPROUTS			
		N.F.E.		Crude protein		Total organic matter		Crude protein		Total organic matter	
			As % initial N. F. E.		As % initial crude protein		As % initial tl. organic matter		As % initial CP in tuber		As % initial organic matter
41°F. ± 2°	g/kg	g/kg	%	g/kg	%	g/kg	%	g/kg	%	g/kg	%
Kennebec											
control	177.50	11.45	7.5	+0.63	+3.1	11.09	6.2	-*	-*	2.69	1.5
MH-30	177.83	7.07	4.6	+0.46	+2.3	6.82	3.8	-*	-*	1.13	0.6
Russet Rural											
control	181.50	12.30	7.7	+0.77	+4.5	12.14	6.7	-*	-*	5.83	3.2
MH-30	176.03	8.10	5.3	+0.69	+3.9	8.05	4.6	-*	-*	0.03	0.0
60° F.											
Kennebec											
control	169.41	33.84	23.2	4.09	21.1	38.17	22.5	3.68	19.0	19.74	11.7
MH-30	156.69	8.42	6.3	+1.23	+6.3	8.06	5.1	-*	-*	1.19	0.8
Russet Rural											
control	181.50	36.21	22.6	2.10	13.0	38.76	21.4	2.92	18.0	17.68	9.7
MH-30	175.98	9.22	6.0	+1.80	+10.4	7.84	4.5	-*	-*	0.76	0.4

*Sprout sample too small for chemical analyses.

+ Gain, not loss.

Table 17. Dry matter losses from tubers in respiration and from sprouts in 15 weeks at 41° F. and 90-95% relative humidity and 70° F. and 70% relative humidity expressed in grams per kilogram initial fresh weight and as percent of total dry matter loss.

	DRY MATTER IN SPROUTS		DRY MATTER IN RESPIRATION*		Total dry matter loss
		As % of total dry matter loss		As % of total dry matter loss	
41° F.	g/kg	%	g/kg	%	g/kg
Kennebec control	0.0	0.0	4.9	100	4.9
" MH-30	0.0	0.0	5.2	100	5.2
Russet Rural control	0.0	0.0	4.3	100	4.3
" " MH-30	0.0	0.0	4.6	100	4.6
70° F.					
Kennebec control	8.4	40.2	12.5	59.8	20.9
" MH-30	1.6	13.2	10.5	86.8	12.1
Russet Rural control	6.0	30.9	13.4	69.1	19.4
" " MH-30	0.7	5.7	11.6	94.3	12.3

* Computed from CO_2 production.

Table 18. Dry matter loss from tubers during conditioning at 70° F. and 70% relative humidity expressed in grams per kilogram initial fresh weight and as percent of total dry matter loss.

	DRY MATTER LOSS						
	IN RESPIRATION*				IN SPROUTS		TOTAL
	At the end of 3 weeks		At the end of 4 weeks				
	g/kg	%	g/kg	%	g/kg	%	g/kg
Kennebec control	3.23	56.3	4.34	75.6	1.40	24.4	5.74
" MH-30	3.22	67.9	4.23	89.2	0.51	10.8	4.74
Russet Rural control	3.20	60.4	4.18	78.9	1.12	21.1	5.30
" " MH-30	3.04	74.1	3.92	95.6	0.18	4.4	4.10

* Computed from CO_2 production.

loss of dry matter in 15 weeks at 41° F. MH-tubers lost less dry matter through sprout growth than the control tubers which sprouted more, but both MH-tubers and control tubers lost identical amounts of dry matter in respiration.

DISCUSSION

Sprout Growth

Treatment with maleic hydrazide reduced sprout growth markedly, and at the same time eliminated or even reversed apical dominance. Since sprouting was associated with removal of protein from the tubers, it is suggested that MH interferes with the mobility of the protein. Since apical dominance is commonly associated with auxin concentration, it may be inferred that MH treatment led to auxin redistribution.

Respiration

In all cases with either MH-tubers or control tubers, the rate of respiration tended to decrease as the duration of storage was prolonged whether sugar contents of the tubers were increasing or decreasing. Whenever sprouts appeared, however, this downward trend was interrupted, and as sprouts became abundant, respiration rate was greatly increased. All or most of the differences in respiration of tubers, regardless of variety, may be attributed to differences in the occurrence of sprouts. Similarly, differences in respiration of MH tubers and control tubers were closely related to sprout growth.

The high initial respiration rates recorded for both MH-tubers and control tubers when transfered from 41° to 70° F. agree with the findings of Appleman and Smith (5). Since the respiration rate of the tubers was low at 41° F. compared with the high initial respiration rate when the same tubers were transfered to 70° F., and since the sugar content of the tubers was the same, this proves that there is no direct correlation between sugar content and respiration rate of the tubers. Therefore, the high initial respiration rates observed at 70° F. could only be due to the change in temperature (5).

The decline in the respiration rate of these tubers that followed the initial rise was probably due to the reconversion of about 4/5 of the accumulated sugar to starch (3). This decreased concentration of available sugars in the tubers was insufficient to support the high rate of respiration at 70° F. The increased respiration rate when sprouts appeared was due to the translocation of carbohydrate from the tuber into the sprouts in order to supply adequate amounts of energy for the metabolic processes of the developing sprout tissue (70). Sprout tissues being very young compared with those of the tubers, respire much faster (70).

Cells of potato tubers are packed closely together (45). This limits ready access of air and may account in part for their relatively low rate of respiration (39). These factors combined should explain why the size of tubers did not affect their respiration rate.

Losses in Weight

Losses in weight, either as water or as dry matter, were reduced either by low temperature storage or by the use of maleic hydrazide, alone or in combination. However, although maleic hydrazide greatly reduced sprouting, even at 60° or 70° F., the losses of water at the higher temperatures resulted in shriveled and unsaleable potatoes. Dry matter losses in the period from 3 to 6 months storage, however, present quite a different contrast between MH-tubers and control tubers. Whereas control tubers of both varieties lost about 22% of their total dry matter in 3-6 months, MH tubers lost only 5%. Not only were losses in sprouts greatly reduced, but respiratory loss was decreased by the MH treatment. Protein losses in sprouts amounted to about 19% of the total protein in the control tubers, while the MH tubers showed no loss. Since potato protein is highly nutritious (34) this saving of protein could add to

the food value of such potatoes.

In the limited trial, MH-tubers conditioned a week earlier than the control tubers. This would have prevented the loss of 25% of the total dry matter lost in 4 weeks during the conditioning period (see Table 18). Since in potato chip manufacture the greater the dry matter the better the chips (45), the use of MH for conditioning of potato tubers may be recommended.

The quantity of dry matter remaining in the tubers, after storage at 70° F. was greatly affected by MH treatment as indicated above. In the case of conditioning at 70° F. after storage at 41° F., differences in loss of dry matter after 4 weeks of conditioning were relatively small, but still less in MH-tubers than in the control tubers. The slightly higher loss of dry matter by control tubers is attributable to the larger sprouts of the control tubers.

Water loss from Russet Rural tubers was greater than in their Kennebec counterparts at both temperatures. Since Russet Rural tubers were in general much smaller than Kennebec tubers, and since water evaporation from a material depends among other things on the surface area to volume ratio of the material (66), it is expected that the Russet

Rural tubers with the larger surface area to volume ratio than Kennebec tubers should have lost more water.

The ratio of weight losses of water to dry matter in respiration was about 3:1 at 41° F. and 9:1 at 70° F. A ratio of 10:1 at the warmer temperature was reported by Hensen (41). The bulk of the weight loss was through water evaporation.

Color of Potato Chips

As shown in Table 14, there is a correlation between the amount of total sugar in tubers and the color of chips made from them. Hence, tubers stored at 41° F. made poor chips owing to sugar accumulation (67, 73), while those stored at 70° F. produced acceptable chips, because the high respiration rate at that temperature not only prevented sugar accumulation, but also depleted the sugar content of the tubers.

Similarly, the faster respiration rate of the tubers, and the reconversion of most of the sugars in the tubers to starch during the conditioning period at 70° F. (3), explain why acceptable chips were produced from conditioned tubers.

Treatment with MH may have accelerated conditioning slightly, but in either case, low content of total sugars was necessary to produce good chips.

SUMMARY AND CONCLUSIONS

Kennebec and Russet Rural potato vines were sprayed in the field 10-12 days after full bloom with 1 gallon MH-30 in 100 gallons of water per acre. Potato tubers were harvested and stored at 41° F., 60° F., and 70° F. at high relative humidity (about 70-90%) for periods up to 5 or 6 months, or until sprouting became excessive.

Weight losses due to the different storage environments were computed.

Chemical analyses were made of tubers harvested in 1960 to determine the variations in their chemical constituents during the storage period.

Respiration measurements of tubers were made every 3 1/2 days during storage at 41° F., and 70° F. Similar measurements were made during conditioning of tubers previously stored at 41° F.

Cooking quality was evaluated with potato chips and boiled potatoes. Sugar was determined in tuber samples collected at the beginning and end of the conditioning period. Anatomical studies were also made on the tubers at the end of the storage period.

MH inhibited sprout growth of both varieties and destroyed their apical dominance.

Yield and specific gravity of tubers were unaffected by MH treatment.

The key effect of MH was the prolonging of the rest period and especially the inhibition of sprout growth. Fresh weight losses from MH-tubers and control tubers were identical as long as the sprout growth of control tubers was small. MH-tubers, however, lost less dry matter than control tubers.

Weight loss from tubers was a result of water evaporation, losses of protein and carbohydrate due to sprout growth and losses due to respiration. Water loss contributed the highest percentage of weight loss.

MH-tubers stored at 60° F. lost less hydrolyzable carbohydrate than the control tubers--5% versus 22% respectively, and had no loss in crude protein while the control tubers lost 20-25% of their crude protein.

The respiration rates of MH-tubers and control tubers were identical as long as the control tubers did not sprout.

There was no direct correlation between the sugar content and the respiration rate of the tubers.

MH-tubers did not make better potato chips than the control tubers when stored at 41° and 70° F. In limited trials, MH-tubers, however, conditioned a week faster than the control tubers. Tubers made acceptable chips only if their total sugar content was 0.05% or less.

Boiled MH-tubers had better flavor and texture than boiled control tubers.

High weight losses at 60° and 70° F. indicate that MH should be used as an accessory to regulation of temperature and relative humidity in order to keep losses at a minimum.

LITERATURE CITED

1. Alexander, L. M., Schopmeyer, G. E. and Anderson, R. B. Potato storage and quality of french fries. Amer. Potato Jour. 26: 439-445, 1949.

2. Anderson, R. L. and Houseman, E. E. Table of orthogonal polynomial values extended to N = 104. Iowa State College Research Bull. 297, April 1942.

3. Appleman, C. O. Changes in potatoes during storage. Md. Agr. Exp. Sta., Bull. 167:327-334, 1912.

4. _______. Potato sprouts as an index of seed value. Md. Agr. Exp. Sta., Bull. 265, 1924.

5. _______ and Smith, C. L. Effect of previous cold storage on the respiration of vegetables at higher temperatures. Jour. Agr. Res. Vol. 53, No. 8: 557-580, 1936.

6. Association of Official Agricultural Chemists. Official Methods of Analysis. 9th edition, 1960.

7. Andus, L. J. Plant Growth Substances. University Press, Aberdeen, Great Britain, 1959.

8. Barnard, E. E. and Warden, R. L. The effects of various herbicides on weed control, stands and yields of Netted Gem potatoes. North Central Weed Control Conference, p. 145, 1950.

9. Beach, R. G. and Leopold, A. C. The use of maleic hydrazide to break apical dominance of *Chrysanthemum morifolium*. Am. Soc. for Hort. Sci. 61: 543-549, 1933.

10. Bennett, R. B. *et al*. Topping flue-cured tobacco and sucker control. Mimeo sheet, 9 pp., 1956 (North Carolina State College).

11. Buchholtz, K. P. Dalapon and maleic hydrazide for control of quackgrass. Proc. North Central Weed Control Conference, pp. 62-63, December 1954.

12. Burton, W. G. The Potato. Chapman and Hall, Ltd., London, 1948.

13. Carder, A. C. The selective control of wild oats in cereal crops by use of maleic hydrazide. North Central Weed Control Conference, p. 50, 1954.

14. Carroll, R. B. Analyses of diethanolamine in cigarettes and potato tubers treated with MH-30. Unpublished report, Apr. 1957, Consulting Chemist, Greenwich, Conn.

15. Cibes, H. <u>et al</u>. Influence of preharvest sprays with maleic hydrazide on the sprouting of potatoes. Jour. of Agriculture of the Univ. of Puerto Rico 39: 92-99, 1955.

16. Ciferri, R. The prevension of sprouting of potato tubers and onion bulbs by maleic hydrazide. 1st Bot. Univ. Lab. crittogam., Pavia, Atti 10: 155-159, 1953; Chem. Abst. 48: 2971.

17. Claypool, L. L. and Keefer, R. M. A colorimeter method for CO_2 determination in respiration studies. Proc. Am. Soc. for Hort. Sci. 40: 177-186, 1942.

18. Coughlin, F. J. Quality control in potato chip manufacturing. Proposed color reference standard. A talk presented at the production and technical division meeting, National Potato Chip Inst., Jan. 25, 1954.

19. Crafts, A. S. <u>et al</u>. Comparative studies on herbicide transport. Research Report Western Weed Control Conference, p. 97, March, 1957.

20. Darlington, C. D. and McLeish, John. Action of maleic hydrazide on the cell. Nature 167: 407-408, 1951.

21. Davies, M. E. Effect of relative humidity on a gram sample of maleic hydrazide as the diethanolamine salt. Unpublished report, May 1957. Naugatuck Chemical Division of United States Rubber Company, Bethany, Conn.

22. DeFrance, J. A. and Hart, S. W. The effect of maleic hydrazide on the growth of lawn turf grasses. Paper presented Northwestern Section Am. Soc. for Hort. Sci., Cambridge, Mass., Jan. 1954.

23. Denisen, E. L. Response of Kennebec potatoes to maleic hydrazide. Proc. Am. Soc. for Hort. Sci., 62: 411-421, 1953.

24. Denny, F. E. The use of methyl ester of α-naphthalene acetic acid for inhibiting sprouting of potato tubers, and an estimate of the amount of chemical retained by tubers. Contrib. Boyce Thompson Inst. 12: 387-403, 1942.

25. Denny, F. E. et al. Effect of the vapor of the methyl ester of α-naphthalene acetic acid on the sprouting and the sugar content of potato tubers. Contrib. Boyce Thompson Inst. 12: 253-268, 1942.

26. Denny, F. E. and Thornton, N. C. Factors for color in the production of potato chips. Contrib. Boyce. Thompson Inst. 11: 291-303, 1940.

27. ________. The third year's results on storage of potato tubers in relation to sugar content and color of potato chips. Contrib. Boyce Thompson Inst. 12: 405-430, 1942.

28. Dewey, D. H. and Wittwer, S. H. Chemical control of top growth of prepacked radishes. Proc. Am. Soc. for Hort. Sci. 66: 322-330, 1955.

29. Eaks, I. L., Pratt, H. K., with additions by Clerx, W. A. and Dewey, D. H. Adaptation of the Claypool-Keefer CO_2 method in vegetable crops laboratory. Personal communication with Dewey, D. H., Mich. State Univ.

30. Elmer, O. H. Growth inhibition of potato sprouts by the volatile products of apples. Sci. 75: 193, 1932.

31. Esau, Katherine. Anatomic effects of barley yellow-dwarf virus and maleic hydrazide on certain Gramineae. Hilgardia (in press) manuscript 70 pages with 46 references.

32. Findlen, H. Effect of several chemicals on sprouting of stored table-stock potatoes. Am. Potato Jour. 32: 159-167, 1955.

33. Fischnich, O. et al. Application of maleic hydrazide to some cultivated plants. Angew. Botanik 28: 88-113, 1954.

34. Fischnich, O. and Heilinger, F. The chemical constituents of the potato; formation, utilization, preservation. Land ban forschung. 9 (1959) 1: 15-16, 1959.

35. Franklin, E. W. and Thompson, N. R. Some effects of maleic hydrazide on stored potatoes. Am. Potato Jour., 30: 289-295, 1953.

36. Greulach, Victor A. Notes on the starch metabolism of plants treated with maleic hydrazide. Bot. Gaz. 114: 480-481, 1953.

37. __________. Recent work on maleic hydrazide as a plant growth inhibitor. Elisha Mitchell Sci. Soc. Jour. 70: 134-135, 1954.

38. _________ and Haesloop, John G. Some effects of maleic hydrazide on internode elongation, cell enlargement, and stem anatomy. Am. Jour. of Bot. 41: 44-50, 1954.

39. Hardenburg, R. E. How to ventilate packaged produce. Pre-Pack-Age, Vol. 7, No. 6, pp. 14-17, Feb. 1954.

40. Haskins, F. A. and Chapman, H. W. Effects of irradiation, maleic hydrazide, temperature and age on enzyme activity in seedlings of corn, Zea mays L. Physiol. Plant. 9: 356-363, 1956.

41. Hensen, J. C. Weight losses through evaporation. Eur. Potato Jour. Vol. 3, No. 3 (Sept.), 1960.

42. Highlands, M. E., Licciardello, J. J. and Cunningham, C. E. Reducing sugar content of Maine-grown potatoes treated with maleic hydrazide. Am. Potato Jour. 29: 225-227, 1952.

43. Hillyer, I. G. Effect of growth substances on flowering of cucurbitaceous plants. Ph.D. thesis, 102 pp. 1956.

44. Isenberg, Francis M. R. The effect of maleic hydrazide on plants. Abstract of Ph.D. thesis, University Microfilms, Ann Arbor, Mich., pp. 407-409, 1954.

45. Isleib, D. R. Personal communication. Michigan State University.

46. Isleib, D. R. and Thompson, N. R. Potato handling equipment for use in experimental work. Am. Potato Jour. 34: 70-71, 1957.

47. Kennedy, E. J. and Smith, Ora. Response of the potato to field application of maleic hydrazide. Am. Potato Jour. 28: 701-712, 1951.

48. ________. Response of seven varieties of potatoes to voliar applications of maleic hydrazide. Proc. Am. Soc. Hort. Sci. 61: 395-403, 1953.

49. Klein, W. H. and Leopold, A. C. Maleic hydrazide and its effects on plant development. Abstract paper presented Am. Soc. of Plant Physiologists, p. 4. Columbus, Sept. 11, 1950.

50. Linder, Paul J. Absorption of some new herbicides by plants. Proc. of Northeastern Weed Control Conference, pp. 7-12, 1951.

51. Marshall, E. R. and Smith, O. Maleic hydrazide as a sprout inhibitor for potatoes. Bot. Gaz. 112: 329-330, 1951.

52. McIlrath, Wayne J. The use of maleic hydrazide for the production of male sterility in grain sorghum. Paper presented Am. Soc. of Plant Physiologists, Madison, Wisconsin, Sept. 8, 1953.

53. Miller, E. V. et al. Effect of maleic hydrazide on growth and reproduction of the sandbur. Bot. Gaz. 117: 76-78, 1955.

54. Naylor, A. W. Investigations in the chemical control of flowering. Report of Fifth Hybrid Corn Industry Research Conference, Chicago, pp. 18-21, Nov. 1950.

55. ________ and Davis, E. A. Respiration response of root tips to maleic hydrazide. Bull. Torrey Bot. Club 78: 73-79, 1951.

56. Paterson, D. R. Some effects of foliar sprays of maleic hydrazide on the post-harvest physiology of potatoes, onions and certain root crops. Ph.D. thesis, Dept. of Horticulture, Michigan State Univ., 90 pp., 1952.

57. Petersen, E. L. and Naylor, A. W. Some metabolic changes in tobacco stem tips accompanying maleic hydrazide treatment and the appearance of frenching symptoms. Physiol. Plant. 6: 816-828, 1953.

58. Rao, S. N. Certain physiological and morphological responses in potatoes and onions induced by maleic hydrazide. Ph.D. thesis, Dept. of Horticulture, Michigan State Univ., 85 pp., 1954.

59. Rao, S. N. and Wittwer, S. H. Some morphological studies of maleic hydrazide induced dormancy in onions and potatoes. Paper presented Am. Soc. for Hort. Sci. meeting, Ithaca, N. Y., Sept. 1952.

60. Salunkhe, D. K. The influence of certain environmental factors on the production and quality of potatoes for the potato chip industry. Ph.D. thesis, Dept. of Farm Crops, Michigan State Univ., 146 pp., 1953.

61. ________ and Wittwer, S. H. The influence of preharvest foliar spray of maleic hydrazide on the specific gravity of Irish cobbler potatoes and the quality of their chips. MHIS No. 8, Naugatuck Chemical Div., United States Rubber Company, Bethany, Conn.

62. Sawyer, R. L. and Dallyn, S. L. Timing maleic hydrazide sprays to stage of plant development. Am. Potato Jour. 35: 620-625, 1958.

63. Schoene, D. L. and Hoffman, O. L. Maleic hydrazide, a unique growth regulant. Sci. 109: 588-590, 1949.

64. Silva, S. and Vicente, J. Some effects of folial applications of maleic hydrazide on guinea grass. Agron. Jour. 48: 275-276, 1956.

65. Smith, A. E. et al. Absorption studies of maleic hydrazide by plants. Bethany Information Sheet No. 88, Nov. 1, 1955.

66. Smock, R. M. and Neubert, A. M. Apples and Apple Products. Interscience Publishers, Inc., New York, pp. 95-101, 1950.

67. Sweetman, M. D. The relation of storage temperature of potatoes to their culinary quality. Am. Potato Jour. 8: 174-176, 1931.

68. Talburt, W. F. and Smith, Ora. Potato Processing. The Avi Publishing Co., Inc., Westport, Conn.

69. Thompson, N. R. Personal communication. Michigan State Univ.

70. Thompson, H. C. and Kelly, W. C. Vegetable Crops. McGraw-Hill Book Company, Inc., 5th Edition, 1957.

71. Treadway, R. H. et al. Effects of storage on starch and sugar contents of Maine potatoes. Am. Potato Jour. 26: 33-44, 1949.

72. USDA Crop Reports, 1953-57.

73. Wright, R. C. et al. The cooking quality, palatability and carbohydrate composition of potatoes as influenced by storage temperature. USDA Tech. Bull. 507, Feb. 1936.

74. Wittwer, S. H. and Hansen, C. M. The reduction of storage losses in sugar beets by preharvest foliage sprays of maleic hydrazide. Agron. Jour. 43: 340-341, 1951.

75. Zukel, J. W. A literature summary on maleic hydrazide. MHIS, No. 8, Naugatuck Chemical Div., United States Rubber Company, Bethany, Conn.

76. ________. Progress report on use of maleic hydrazide for grass inhibition on highway areas. Paper presented Highway Research Board, National Academy of Sciences, Washington, D.C., Jan. 1952.

ROOM USE ONLY