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The Effect of Isopropyl N (3-Chlorophenyl) Carbamate Upon Certain Physiological and Biochemical Changes of Irish Potatoes During Storage.

Robert Narcis Falgout

Louisiana State University and Agricultural & Mechanical College

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THE EFFECT OF ISOPROPYL N (3-CHLOROPHENYL) CARBAMATE UPON CERTAIN PHYSIOLOGICAL AND BIOCHEMICAL CHANGES OF IRISH POTATOES DURING STORAGE

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in

The Department of Horticulture

by

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B.S., Louisiana State University, 1961
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ABSTRACT

Two varieties of Irish potatoes, La Chipper and Red LaSoda, were used to determine the effect of isopropyl N-(3-chlorophenyl) carbamate (CIPC) upon certain physiological and biochemical changes in the tubers during storage at two temperatures, 60°F and room temperature (75°F). Included in the study was the effect of the chemical on sprouting, shrinkage, dry matter, reducing, non-reducing and total sugar, and starch contents, respiration rate and cooking quality of the tubers. The CIPC treatment consisted of dipping the tubers into a one percent water emulsion of CIPC for one minute.

A preliminary test was conducted to determine the best method of treatment. The three methods used were: (1) only the wooden storage crates or burlap bags were treated and the untreated tubers were stored in them, (2) the tubers were treated and then stored in the untreated containers, and (3) finally both the container and tubers were treated together and stored. All of these samples were stored at 60°F.

Preliminary results indicated that any of the three methods of treatments were satisfactory in controlling sprouts, although the experiment was terminated prematurely because of excessive decay of the tubers.

In other tests CIPC was shown to be a very effective sprout inhibitor at either storage temperature (60°F. or room temperature). Complete sprout inhibition was obtained throughout all of the various tests by using a one percent water emulsion of CIPC. Treated potatoes stored at 60°F. remained sound and sprout-free for one year. All tubers, treated
and control, stored at room temperature had to be discarded no later than five months of storage. Because of excessive sprouting after four months of storage at 60°F., the control tubers lost a considerable amount of total weight. The controls lost progressively more weight after about four months. The treated tubers lost no more than six percent of their total weight after one year, whereas the controls lost as much as 40-50 percent in some cases. There appeared to be no effect of the chemical on percent of dry matter in the tubers. The controls even though they sprouted profusely and lost much more total weight, generally contained about the same percentage of dry matter as did the treated tubers throughout the storage period. Large variations occurred within a twenty-tuber sample each month in regard to dry matter and shrinkage percentages. On one sample date, the tubers varied as much as ten percent in dry matter content. There was as much as eleven percent difference in the shrinkage rate from one tuber to another on the same sample date. This result led to the conclusion that twenty tubers were not enough to be considered a representative sample for accurate shrinkage and dry matter measurements.

When the effect of tuber treatment with CIPC on certain carbohydrates was studied, few differences between the treated and control tubers were noted. These differences were irregular and inconsistent.

There was also no apparent effect of CIPC treatment on the respiration rate of stored potatoes. Differences recorded were small and inconsistent.

In regard to cooking quality, CIPC treated tubers were equal to or superior to the cooked products of the control tubers, especially where flavor was considered. In some cases the chip color of treated tubers was darker, but this may have been caused by a slightly higher reducing
sugar content due to a lack of sprout growth in these potatoes.

Correlations, especially in La Chipper tubers, showed that CIPC apparently did not alter the metabolic processes studied. These results were less conclusive when correlations of these processes were made with Red LaSoda tubers.
INTRODUCTION

The Irish potato is the most important vegetable crop, ranking fourth only to wheat, rice and corn, in general food crops (107). Thus, it is only natural that storage problems concerning it have received a great deal of attention at the hands of investigators. The most important purpose of potato storage is to maintain tubers in their most edible and salable condition and to provide a uniform flow of tubers to the processing plant throughout the year. Good storage should prevent excessive loss of moisture and general shrinkage, development of decay and excessive sprouting of tubers. It should also prevent large accumulation of sugars and other constituents which result in dark-colored processed products (99).

After harvest, potatoes usually undergo a rest period of several months, the specific length of time varying with variety, during which there is little or no sprout growth regardless of environmental conditions. Following the termination of the rest period, sprout growth occurs at temperatures of 40°F. or above. When tubers are stored below 40°F. very little, if any, sprout growth occurs. However, reducing sugars and sucrose accumulate in tubers in excessively high quantities at temperatures below 40 to 50°F. while starch content decreases (99). High reducing sugar content of tubers in conjunction with certain nitrogenous components is thought to be the cause of the undesirable dark brown color of potato chips and French fries and the browning of dehydrated potatoes during shipment or storage (99). It is important to have available some method of storing potatoes at 50 to 60°F. with little or no sprout growth, no
reduction in specific gravity of tubers, no accumulation of sugars, and a minimum loss of weight.

Chemical inhibitors for the control of Irish potato sprouting in storage have been available for commercial application since around 1947. From the time Elmer (38) discovered in 1932 that a gas given off by apples in storage would reduce sprouting of tubers, they have held an interesting potential. However, major emphasis on chemical inhibitors in research programs was not given until about 1945. Since that time they have been a part of the research programs of almost all of the major potato producing areas of the world (99).

There are several reasons which caused an increased interest in chemical inhibitors. During World War II, there was a great need for some means other than refrigeration which would keep potatoes free of sprouts while in transit to many areas of the world. Another reason for this increased interest is the fact that potato processing industries using deep fat frying are utilizing more of the total production each year. These processors would prefer to have their product stored at 50°F. or higher, because tubers processed in this manner produce an undesirable color when stored at lower temperatures. Also, potato processors who realize that they will need a given volume of tubers during their operating season would like to be able to purchase as large a portion of the raw product as possible at periods of peak supply when prices are lower. In order to keep these potatoes relatively sprout free for the maximum time desired, some method other than temperature alone has to be used.

Another factor for consideration is cost of storing potatoes. Stor-
age of tubers at 40°F. is quite expensive because of the type of chamber and refrigeration equipment needed. Growers who could not afford this type of storage would have to sell on the open market earlier. This would tend to flood the market and bring the prices down (99).

Chemical inhibitors are only one of several factors in a good sprout control program. Temperature, maturity and length of rest period are among the major factors affecting storage and should be utilized properly in a good sprout inhibition program (92, 99).

Temperature manipulation is undoubtedly the most important factor, because it not only affects sprouting but also influences storage decay, respiration rate, and moisture loss. Sprout growth is very slow at temperatures of 38 to 40°F., even when rest is broken. As the holding temperature is raised above 40°F., the rate of sprouting, respiration, moisture loss and development of storage rots increase. Sprouting and respiration may be decreased by the use of chemical inhibitors, but if the temperature is not controlled, serious storage losses may be incurred from the effects of moisture loss and storage rots (99, 104).

Processors dealing with fried products frequently have color control problems when storage temperatures are lower than 50°F. Some varieties will not recondition from storage temperatures under 50°F., but varieties that do recondition require a longer period if the storage temperature has been below 50°F. To get the best cooking quality and longest storage life, the temperature should be maintained as low as possible, taking into consideration color control. In this regard, chemical inhibitors may be used as accessories to temperature manipulation (99).

Since the time Elmer (38) found that the volatile gases of apples reduced potato sprouting many different chemicals have been tested and
now several chemical inhibitors have been used commercially in the United States. However, much research on this problem has been conducted in other potato producing countries. There are inhibitors which have promising aspects and have been used in research programs for several years, although they have not received governmental clearance or commercial acceptance as yet.

In preliminary tests Jones (58) among others has found that potatoes treated with one percent isopropyl N (3-chlorophenyl) carbamate (CIPC) and stored at 60°F. ± 2 showed no signs of sprouting and kept very well for periods up to 12 months. Based on these studies, it appeared appropriate to investigate the effect of this chemical on certain phases of tuber metabolism and also on certain culinary aspects of two varieties of Louisiana-grown Irish potatoes, LaChipper and Red LaSoda.
REVIEW OF LITERATURE

The commercially accepted potato sprout inhibitors and those which have appeared most promising in research programs include the methyl-ester of alpha napthaleneacetic acid (MENA), tetrachloronitrobenzene (TCNB), maleic hydrazide (MH), isopropyl N (3-chlorophenyl) carbamate (CIPC), various alcohols, and irradiation with radioactive isotopes.

Methyl-Ester of Alpha Napthaleneacetic Acid (MENA)

MENA was the first chemical inhibitor used commercially to any extent in the United States. Approximately 500,000 bushels were dust treated with this material on Long Island as early as 1947, according to Smith and Scudder (94). It has also been tested commercially in several foreign countries (99).

The early success of MENA applied as a dust to potatoes in storage was short-lived. Serious storage losses were encountered which were explained by the concurrent work of Ellison and Cunningham (37) and Cunningham (25). Fusarium dry rot organisms entered the tubers easily because MENA inhibited the formation of wound periderm (99). Once the treated tubers were bruised, there was no further protection against decay organisms.

Several methods have been tried with varying degrees of success in applying the sprout inhibitor. The vapor method devised by Guthrie (47) consisted essentially of soaking strips of filter paper in an acetone solution of MENA, allowing the acetone to evaporate, and then mixing the tubers with the filter paper and placing them in closed containers. Storage of tubers in small paper bags impregnated with the auxin was also
highly effective. In applying this method to bulk storage treatment, Denny (30) experimented with storage in wooden boxes or bins, and found that, although MENA impregnated paper strips mixed thoroughly with the tubers gave complete sprout inhibition; the mere covering or lining of the boxes or bins with the paper induced dormancy only in its immediate vicinity, showing that an even distribution of vapor through the whole volume of the stored tubers was necessary for effective control. Denny (31), Smith (93), and Marth and Shultz (65) used impregnated paper and dusts with satisfactory results. Confetti was found to be most effective over paper strips as a carrier.

Talc has also been tested as a carrier of the auxin, and this can be easily and uniformly distributed throughout a large bulk of tubers. The only objection to this method is that the white dust covering the tubers, as a result of this talc treatment, tends to detract from their market value (99).

The Dutch workers, Stuivenberg and Veldstra (6), used a spray treatment with a two percent solution of MENA in 95 percent alcohol, covered as quickly as possible after tuber treatment, to prevent loss of auxin by evaporation. This treatment was highly effective in sprout control, although it gave a higher percentage of decayed tubers than the untreated controls. This result was attributed to the moist condition of the potato caused by spraying. Other workers (9) have dipped tubers in dilute aqueous solutions and dried them at 70 to 135°F. for 20 minutes, with highly satisfactory results.

Ellison and Smith (35) obtained some sprout inhibition by foliar application. Findlen (41) showed that MENA would control potato sprouting in market channels by application in the washing water or wax emulsion.
Sawyer and Dallyn (80) found that in storages with forced air ventilation the material could be vaporized by hot plate into the storage ducts with effective results. It was pointed out that when applying auxin, care should be taken not to bruise the tubers, as the auxin in high enough concentrations prevents wound periderm formation.

**Tetrachloronitrobenzene (TCNB)**

Tetrachloronitrobenzene has found some commercial acceptance in many European countries, Australia and the United States. In the United States its principal region of acceptance has been Long Island which frequently encounters sprouting problems in storage, and in Maine by potato processors (99).

The sprout inhibiting properties of TCNB were noted first when it was used as a fungicide (39). Emilsson (39) reported that TCNB has a fungicidal effect on some of the potato storage rot organisms. Cunningham (25) produced some evidence that TCNB will delay and inhibit tuber wound cork formation which ordinarily prevents infection and growth of Fusarium dry rot. There are several reports which indicate that TCNB is a relatively weak sprout inhibitor. Ellison (36) found a considerable amount of tuber sprouting around the edges of treated bins. Poor results have been obtained when there was free ventilation of air from the storage. Sawyer (78) found that the use of some ventilation with the TCNB treatment was desirable to control the storage temperature. Tubers removed from the vapors of TCNB for several weeks lost all traces of sprout inhibition and produced a normal crop when used as seed, according to Brown and Reavill (12).

The main disadvantage of this material, according to Talburt and
Smith (99), is the relatively weak sprout inhibition obtained at a relatively high cost. They also claim that the dust may cause some discoloration of the tubers.

**Maleic Hydrazide (MH)**

Of the chemical sprout inhibitors, maleic hydrazide has been tested more thoroughly and received a wider range of commercial acceptance than any other material in the United States. The greatest use of this chemical has been with potato processors who store potatoes long enough to require the use of an inhibitor (99).

The importance of time of application was demonstrated by Kennedy and Smith (59, 60). Foliar sprays applied early in the season caused increased tuber set and yield reduction. Applying the material before the vines reached an advanced stage of maturity, so that some of the material would be translocated to the tubers, was of major importance in obtaining effective sprout control. Salunkhe (77), Patterson (69), Highlands et. al. (53), Franklin and Thompson (43), Kennedy and Smith (59, 60) Wilkerson and Coke (111), Bishop and Schweers (8), Tomake et. al. (105), and Hosking (55) all found that satisfactory sprout control could be obtained from maleic hydrazide sprays applied several weeks before harvest. Denison (28) found that a blossom-fall application of MH gave less detrimental effects to tubers than earlier sprays. Sawyer and Dallyn (81) also found a blossom-fall application most satisfactory.

Applied at a concentration of 2,500 parts per million as a drenching spray to the potato foliage in the northern states, maleic hydrazide has not caused any reduction in yields of tubers and has prevented sprouting of the potatoes for long periods in storage (28, 55, 81, 99).
However, Jones and Miller (58) found that applying this chemical in the same manner to potatoes in Louisiana has resulted in decreased yields. This reduction was clearly shown where the chemical was applied four weeks before harvest or earlier. During subsequent storage at 60°F, there was no sprouting to any extent up to about four months, at which time the untreated potatoes had sprouted profusely. After this period, small rudimentary sprouts appeared on the treated tubers and persisted throughout the storage period of 12 months. They also found that during the latter part of this period the treated potatoes showed a high degree of shrinkage, apparently much less than the untreated potatoes; however, as pointed out by Talburt (99), one of the main disadvantages of this material is the time of application. Since the only method of application is a foliate spray, growers must apply the material long before there is any actual need for a sprout inhibitor. Also, proper timing of application is essential. Improper timing may cause a reduction of yield (99).

Alcohols

Several of the alcohols have given good sprout inhibition with potatoes (14, 17, 99). Vapors of amyl or nonyl alcohols have been used commercially on a small scale in England. These materials have received no governmental clearance as yet for use in the United States (99).

Most of the work with alcohols was done by Burton (14) who found that sprouting of potatoes could be controlled with a concentration of about one mg. of amyl or nonyl alcohol per liter of air. Ventilation for a two-week period with the alcohol vapors was alternated with a two-week period without the vapors for as long as sprout inhibition was desired. Burton (17) found that the rate of ventilation should be
from 3.5 to 5.3 cu. ft. of air per minute per 2,200 lbs. of tubers.

Alcohol concentration in the air was obtained by determining the rate of air flow and adjusting the drip of alcohol on a small hot plate at the air intake ventilator. Sawyer (80) obtained sprout inhibition with several alcohols and observed lenticel pitting of the tubers whenever the concentration of the alcohol in storage became too high.

**Irradiation**

Gamma irradiation is a very effective potato sprout inhibitor. As yet, however, it has not received governmental clearance for commercial use in the United States. Sparrow and Christenson (96) observed that certain irradiation dosages gave excellent sprout control for as long as 15 months in tubers stored at 40°F. Brownell et. al. (13) found irradiation from 15,000 to 200,000 REP inhibited periderm formation completely. Sawyer (79) and Berger (5) found that irradiation increased the incidence of black spot and storage rot.

As explained by previous workers (5, 13, 79, 96) in order to use the sprout inhibiting qualities of irradiation, it is essential to use the minimum dosages necessary for sprout control to avoid detrimental effects on the darkening reactions and storage rots caused by too high dosages.

**Isopropyl N (3-chlorophenyl) Carbamate (CIPC)**

CIPC is the most effective chemical yet found in the sprout inhibition field. Inhibition tends to be complete with no sprouts developing under ideal application and storage conditions (99).

Marth and Schultz (65) found that CIPC controlled potato sprouting for four months at a temperature of 70°F. when applied as a dust.
Rhodes et. al. (75) showed that CIPC applied in a one percent mixture with an inert dust carrier at the rate of 2.68 gm. per kg. of tubers gave complete sprout inhibition. A water solution dip was also very effective. Heinze et. al. (50) obtained very good sprout control with a 0.5 percent dip. Rhodes et. al. (75) found that IPC was more effective than MENA. Marth and Shultz (65), Heiligman et. al. (48), and Jones and Miller (58), Sawyer and Dallyn (79, 80) applied CIPC as a gas to stored potatoes at one fourth and one half gram per bushel and obtained good results. Sprout inhibition was very good. Hendel (52) found that air circulation was very important for even distribution of CIPC applied as a gas.

Jones and Miller (58) published their findings on the effect of CIPC on potato sprouting after 5 years of study. They reported that CIPC was a more effective sprout inhibitor than maleic hydrazide. They found in 1957 that tubers dipped in a one percent CIPC solution showed no sprouting while those treated with granular CIPC sprouted moderately. In 1960 they showed that sprouting could be controlled by treating only the tuber containers and storing them at 60°F. Regular commercial burlap sacks and Kraft brown paper bags were used as the storage containers. After 10 months of storage at 60°F, the tubers in the treated bags showed no signs of sprouting while those in untreated bags had sprouted profusely and were badly decayed.

Hendel (52), Audia et. al. (5), and Reeve and Forrester (73) found that CIPC inhibits potato wound periderm formation, similar to MENA. Reeve et. al. (74) found that both tuber wound periderm and sprouting were completely inhibited in freshly-harvested, cut potatoes treated by evaporation of CIPC at 10 and 100 ppm and then incubated at 70 to 75°F.
and 88 percent relative humidity. At one ppm CIPC sprouting at room temperature was only slightly retarded. Wound periderm was completely inhibited in the central tissues and markedly retarded in the cortex of the tubers.

Audia et. al. (5) also found that CIPC inhibits suberin development but to a much lesser extent than wound periderm development. Scott et. al. (89) showed that CIPC caused an apparent inhibition of mitosis and enlargement of cells near the root apex in squash and cucumber. Hendel (52) found that wound healing was greatly retarded by an application of CIPC to freshly cut surfaces which caused a loss of sap and blackening of the surfaces. In this study, air velocity was important in storage for uniform distribution of the chemical. He also found that CIPC had a fungicidal effect on tuber dry rot organisms. Sawyer (80) found that CIPC applied to well-cured potatoes in storage did not increase the amount of dry rot; however, the application to freshly-harvested or poorly-cured potatoes in storage did result in increased dry rot. It was pointed out that an increase in rotting of treated tubers could be expected if tubers were handled and bruised. Once the protective barrier of the periderm was broken, rot organisms had an easy avenue to the tuber and since CIPC, a mitotic poison, prevented new periderm formation, it has been suggested by the researchers using CIPC that a minimum of handling, if any, be used after the tubers have been treated.

Stored potatoes basically undergo three different phases which influence their physiology according to Toko (104). These periods were classified as the curing period, the resting period, and the sprouting period. The curing period begins when tubers are placed in storage
and includes that time when the storage atmosphere is maintained at levels of temperature and relative humidity which are conducive to wound healing or curing. The resting period is the remainder of the time that potatoes are dormant, and the sprouting period begins when rest has been broken and sprout growth occurs.

Curing Period

Toko (104) pointed out that there is a great deal of metabolic activity in potato tissues during the curing period of about one to three weeks, brought about by the stage of tuber maturity and by the change in the environment. The most important of these activities is the wound healing. This includes first, suberization, and then wound periderm formation. Effective wound healing or curing does not occur in potatoes at temperatures below 55°F., and takes place slowly and incompletely if the relative humidity is below 75 percent (104).

If the temperature and relative humidity of the atmosphere are maintained at levels which permit rapid wound healing, the total water lost during the curing period will be reduced (104). Potatoes incur their greatest shrinkage losses at this time from loss of water from the tubers to the surrounding air. Water is transpired through the lenticels and through the partly-formed periderm. In addition, water evaporates from the torn cells of injured and unhealed surfaces of the tubers. Potatoes usually lose from two to four percent of their original weight during the first month of storage, almost one half of what they would be expected to lose during five to seven subsequent months of storage (104).

Toko (104) also explained that as the injured surfaces of the
tubers heal, water loss from these areas diminish until it is no
greater than losses from other uninjured areas. Also, tubers whose
wound healing process is rapid lose considerably less weight during
the remainder of the storage period than do those in which wound heal-
ing has been slow or incomplete (104).

It was further stated (104) that rapid wound healing has another
benefit which is probably more important than the reduction of weight
loss. It seals the areas through which various rot-producing organisms
can enter the tuber and will thus reduce the amount of deterioration
in subsequent storage. Most tuber-rotting organisms are unable to
penetrate sound tubers, but inoculation and infection may occur at
any time after the skin of the tuber has been broken. The potential
infection of stored potatoes is therefore directly related to the number
and severity of the injuries. The amount of decay which develops is
inversely related to the rate at which these injuries heal. The rate
of wound healing is probably more important in reducing tuber decay
than is the extent of suberin and periderm formation, according to
Toko (104). He reported that under optimum curing conditions it will
take about four days for wound-healing to effectively reduce soft
rot infection.

Evidently (104) respiration of potato tubers is at its highest
rate immediately after harvest. Total dry matter decreases when
starches and sugars are used up during respiration; however, the percent
dry matter decrease or increase depends on the ratio of solids lost
through respiration to shrinkage due to water loss (104).

The respiration rate tends to increase as temperature increases,
and the wounding of tuber tissues during harvesting and handling also
results in temporarily increasing the respiration rate (104). Respiration rates are greater in immature tubers than in mature ones and greater in bruised and skinned tubers than in sound ones (104).

Resting and Holding Period

It was emphasized by Toko (104) that temperatures in storage areas should be lowered rapidly after the curing period. The time of cooling to the desired storage temperature depends on the efficiency of ventilation and cooling methods, outside air temperature and size of tuber lots stored. This temperature reduction primarily achieves two effects: (1) the rates of transpiration and respiration are reduced and (2) the activity of storage-rot organisms is retarded or actually stopped (104).

The amount of water lost from tubers is, however, related to the relative humidity, and is influenced by temperature as shown by Toko (104). As the relative humidity of the air decreases, the absorptive property of the air is increased, and greater water loss from potatoes occurs. At high temperatures, even with high relative humidity, water loss may increase slightly because of high respiration rates (99).

Shrinkage losses of potatoes increase with the length of storage (92, 99, 104). Loss of water from the tubers amounted to about 0.3 to 0.5 percent per month during the rest period when tubers were held at 40°F and 85 - 90 percent relative humidity (104).

During the resting and holding period, the main chemical changes that take place in the tuber evidently are a reversible conversion of starch to sugars and the utilization of sugars through respiration (99, 104). At about 50 - 60°F, the starch-sugar conversion is nearly
equal to the reverse reaction (99, 104).

It has been known for many years that the sugar content in potatoes increases when they are stored at comparatively low temperatures, as shown by Appleman (1). He mentioned three processes that occurred in potatoes during storage: (1) respiration in which sugar is utilized, (2) the conversion of starch to sugar by amylolytic enzymes, and (3) the conversion of sugar to starch by starch synthesizing enzymes. As sugars increase at low temperatures starch decreases, and at high temperature sugars decrease as a result of increased respiration and starch synthesis (1).

Apparently, the amount of sugars formed during low temperature storage depends on variety, maturity, and pre-storage conditions as well as temperature (99). The extent of sugar loss which occurred on exposure of potatoes to high temperatures, also varied with variety and maturity as reported by Talburt and Smith (99). A large increase in total sugars, primarily reducing sugar, occurred in potatoes stored at 34 and 36°F. At temperatures of 38 and 42°F, the increase in sugar was less, and at 50 and 60°F. a slight reduction occurred (99). Treadway et al. (106) found most of the reducing sugars in tubers stored at 60°F. present in the sprouts. Wright et al. (112) found that the dividing line between relatively high and low sugar content occurred between storage temperatures of 40 and 50°F. The sugar content of potatoes stored at 50 and 60°F. for some time was about the same as that present when the potatoes were first placed at these temperatures (112).

It was explained by Smith (92) and Talburt and Smith (99) that potatoes which have become sweet through storage at low temperature
may in most instances be reconditioned by storage for a week or more at temperatures of about 60°F. or above. Under these conditions the high sugar content may be lowered as a portion of the sugar is reconverted to starch and some of the remainder is utilized through respiratory processes proceeding at a more rapid rate than the starch is being changed to sugars (92, 99).

As for the influence of storage temperature on processing quality, it has been shown that potatoes stored at temperatures under 50°F. usually produce dark colored chips (99). French fries and dehydrated potatoes are somewhat less susceptible to browning than are potato chips, but they often darken excessively if the storage temperature is below about 45°F. as shown by Talburt and Smith (99). Sweetman (98) found that chips made from tubers stored between 32 and 37°F. were darker than those made from potatoes stored at temperatures between 40 and 55°F. Color of potato chips was most desirable when made from tubers stored at 60 to 70°F. and the brown color of chips became more intensified as storage temperatures decreased to 40, 36, and 32°F. in studies by Peacock et. al. and Wright et. al. (70, 112).

During storage at low temperatures reducing sugars accumulated in potatoes more rapidly than sucrose, according to Schwimmer et. al. (87). With Chippewa, Kinnebec, Katahdin and Russet Burbank tubers the ratio of glucose to fructose was approximately one at low storage temperatures, and it increased to above two at higher temperatures. White Rose tubers tend to accumulate fructose (99).

It was pointed out by Arreguin et. al. (3) that sucrose, fructose and glucose comprise the major sugars of the potato. He found that, of the principal ones, fructose is most responsive to changes in storage
temperature. Tubers stored at low temperatures were high in fructose and fructose-6-phosphate, whereas those stored at high temperatures were high in glucose and glucose-6-phosphate (3).

Starch - The starch content of potatoes usually decreases with a lowering of storage temperature through the process of starch conversion to sugars by amylolytic enzymes. Starch may increase in potatoes by conversion of sugars to starch at higher temperatures. In experiments by Treadway et. al. (106), a great deal of starch was lost in potatoes at storage temperatures of 34, 36 and 38°F. Those in cold storage for two to three months contained only about 70 percent of their original starch, and at higher temperatures the change from the original was less. After seven to 37 weeks of low temperature storage and two weeks at room temperature, the starch percent increased approaching the value at harvest.

The total carbohydrate content of potatoes expressed on the dry weight basis changed little in storage at 34 to 60°F. according to Talburt et. al. and Treadway et. al. (99, 106). In other studies (87) White Rose tubers stored at 40°F. decreased in starch content but showed practically no change at 50 and 70°F. In Russet Burbank tubers, however, starch remained almost constant except for a decrease after 18 weeks of storage at 40°F. and an increase at 70°F.

The change of starch to sugar at low temperatures and the subsequent partial resynthesis of starch from sugars at high temperatures may change the growth structure of starch granules sufficiently to alter the properties of the paste. This is likely to affect the quality of the starch and subsequently the texture of the cooked potato as demonstrated by
Talburt et. al. (99). Nutting and Whittenberger (68) found, however, that although potatoes lost 30 percent of their starch while in storage, this change did not alter the granule structure or the starch molecules within it sufficiently to change the swelling capacity of the granules. It also did not change the stability of the swollen granules toward dissolving, mechanical breakage, or loss in volume by diffusion into the pasting medium. Paste viscosity of starch was not affected by storage of potatoes for periods up to nine months at temperatures of 34, 42, and 50°F. (68). Toko (104) explained that storage at relative humidities of 85 to 90 percent will not, in general affect the specific gravity, whereas storage at humidities of about 60 percent may cause an increase in the proportion of total solids because of the greater loss of moisture. He (104) further stated that the specific gravity of potatoes stored at 40°F. and 85 percent relative humidity will show little change whereas at 50°F. under the same humidity, specific gravity may increase. Since transpiration losses increase with the length of storage, the proportion of dry matter may become higher as time in storage increases (104).

The temperature and relative humidity of the storage chamber may have an effect on change in specific gravity of the tubers. Chippewa, Green Mountain, Katahdin, Russet Burbank, and Triumph potatoes stored at a relative humidity of 83 to 84 percent increased in specific gravity at both 40 and 55°F. storage in experiments by Heinze et. al. (49). At 90 percent relative humidity the specific gravity of the tubers remained practically unchanged in storage up to six and one-half months at 40 and 50°F. Specific gravity of potatoes increased with length of time in storage, indicating an increase in percentage of
solids in the tubers in a study by Terman et. al. (100). This was a result of greater loss of water by evaporation than loss of solids by respiration. According to Whittenberger (109) factors such as sprout formation, storage at high temperatures (75°F.) or low temperatures (35°F.) tend to decrease the amount of starch per cell, while other factors such as dormacy or storage at 50°F. retards the decrease in starch and help retain the original texture.

As explained by Talburt (99) the factors influencing tuber weight loss are: (1) stage of maturity of the potatoes at the time of harvest, (2) injury during harvesting and storage, (3) storage temperature and relative humidity during a short time after harvest, (4) temperature, relative humidity and amount of ventilation during storage, and (5) length of storage. Smith (92) found that potatoes harvested immature lost 9.89 percent in weight during seven months of storage, whereas potatoes harvested when mature lost only 6.97 percent during the same period. Potatoes handled carefully during harvesting and storage lost only 6.78 percent during seven months of storage, while those harvested in the normal manner lost 10.08 percent. Potatoes which were cured for eight to twelve days immediately after harvest under warm, moist conditions lost 7.54 percent of their weight, and those which were not cured showed a weight loss of 9.33 percent during seven months of storage. At the end of one month of storage, mature harvested potatoes had lost 4.66 percent in weight, and 8.91 percent at the end of seven months (92, 104).

Respiration - The respiration rate of potatoes is strongly influenced by storage temperature. Hopkins (54) has shown that the minimum rate
of respiration of potato tubers occurs at a temperature of 37.4°F. and that the rate of respiration of tubers stored at 32°F. is greater than that of tubers stored at 40°F.

The rate of respiration may be closely linked with physiological shrinkage during storage. Smith (91, 92) found that immature tubers and freshly-harvested ones have higher rates of respiration than mature tubers or those that have been harvested for some time. Potatoes which were carefully handled to avoid bruising during harvest and storage respired at a lower rate than those which were handled less carefully. Lutman (63) found a large increase in the respiratory rate of potatoes on the second or third day after wounding, followed by a gradual return to the normal rate. Some of this apparent increase in rate of respiration, however, might have been due to facilitating the escape of carbon dioxide by injury to the periderm of the potato, in view of the fact that carbon dioxide builds up to a rather high concentration in the tissues of the normal tuber as shown by Magness (64) and Smith (91). Because of this accumulation of carbon dioxide in tuber tissues, rates of respiration may appear to be different in potatoes in closed containers compared with those with continuous removal of exhaled gas as pointed out by Denny (33, 34).

Smith (91) showed that dormant potatoes stored under conditions that increased respiration had lower oxygen content in their tissues than those with lower respiration rates. Burton (15) found that there was no marked change in oxygen content of tubers during storage.

When potatoes are transferred from lower to higher temperatures there is an increase in respiratory activity, usually of short duration, according to Kimbrough (61) and Smith (92). Appleman and Smith (2)
report that the sugars which accumulate at low temperatures are not responsible for the initial high respiration rate when placed at higher temperatures. In a study by Smith (92) respiratory activity of potatoes in storage rapidly decreased with time. Six weeks after harvest potatoes in 40°F. storage had a low respiration rate and maintained this rate while they were dormant. As sprout growth began and especially with an increase in storage temperature, respiratory activity increased (92). Evidently loss of weight of potatoes in storage due to respiration is very small as compared to the loss in weight caused by evaporation of water as Smith (92) found that in common storage during a seven month period shrinkage, as a result of respiration was only 0.51 percent whereas shrinkage due to water loss was 5.71 percent.

The rate of uptake of oxygen by tubers of late varieties was found to be greater than that by early varieties by Talburt and Smith (99), and individual tubers of the same variety showed considerable variation in respiratory activity.

Sprouting Period

When the tubers begin sprout growth, the respiration rate increases because of increased metabolic activity in the tissues (104). The tubers lose some weight through the process of respiration, but the weight of a tuber will decrease as sprout growth progresses primarily because both solids and water move from the tubers to serve as food for the new growth occurring in the sprouts (104). Loss in weight is accelerated in proportion to the rate of sprout growth as shown by Toko (104).
The effect of sprout inhibitors on carbohydrate content, specific gravity and metabolism.

Although much research has been done with sprout inhibitors, a search through the literature reveals that very little has been done on metabolic processes affected by those inhibitors other than sprout inhibition.

Highlands et al. (53), Kennedy and Smith (60), and Gooding and Hubbard (45) have shown that spraying maleic hydrazide solution on plants in the field had no influence on the reducing sugar content of the tubers during subsequent storage. At the end of six months of storage at 40°F, treated potatoes of the Katahdin and Kennebec varieties showed no difference in reducing sugar content as compared with untreated tubers (53). The reducing sugar content of seven varieties of potatoes stored at 50°F showed no differences between maleic hydrazide treated and untreated potatoes (60). Gooding and Hubbard (45) found that treatment of potatoes with TCNB had no effect on their reducing sugar or sucrose content during subsequent low temperature storage. However, Salunkhe et al. (77) reported that maleic hydrazide treated potatoes were lower in reducing sugars during storage than untreated ones.

Sereno et al. (90) found no significant difference in reducing sugars of gamma irradiated and untreated Katahdin tubers during the first six months of storage at 40, 50, and 60°F. During the second six month period, however, irradiated tubers had higher reducing sugar content during the first six months, whereas the irradiated tubers were higher than the untreated ones during the second six month period of storage. Irradiating Russet Burbank potatoes after they had been stored for five months at 40°F resulted in a three fold increase in
sucrose in 16 days while glucose and fructose showed much smaller increases in a study by Schwimmer et. al. (88). He also found that at 70°F. the levels of sucrose and glucose in irradiated tubers increased above those of the controls, reaching a maximum in four days and then declining. There was no effect of irradiation on fructose loss.

Sereno et. al. (90) found little significant difference in the starch content of irradiated and untreated Katahdin potatoes regardless of the storage temperature. Brownell et. al. (14) found that the respiration rate of potatoes which received dosages of five, fifteen, and twenty-five kilo-REP of gamma irradiation decreased about 30 percent the first day following the treatment. The second day it increased to 60 percent above that of the untreated tubers. This was followed by a decline until during the thirteenth week of storage when the irradiated tubers respired about five percent less than the untreated ones. Irradiation of Sebago and Pontiac tubers with 5,000 - 15,000 REP caused less change in respiration than higher dosages in experiments by Gustafson et. al. (46). Salunkhe et. al. (77) reported that tubers from maleic hydrazide treated vines had a greatly reduced rate of respiration during storage. Craft et. al. (24) reported that the oxygen uptake of small potato tubers dipped in a 0.5 percent solution of CIPC was not significantly different from that of untreated tubers during the four days after treatment. The oxygen uptake of potato discs incubated in a dilute suspension of CIPC was not significantly different from that of control samples.

Salunkhe and Wittwer (77) obtained beneficial effects on specific gravity and color of potato chips from the use of maleic hydrazide,
but other workers have not obtained these results (43, 55, 69, 99).

In general, no adverse or detrimental effects on potato processing quality have been encountered with any of the sprout inhibitors according to Talburt and Smith (99).

In the United States, CIPC has a permanent residue tolerance established at 50 ppm in both the raw and processed potato (104).
MATERIALS AND METHODS

An experiment was begun in February, 1963 on fall-grown potatoes to study the effect of CIPC on sprouting and shrinkage of the tubers during storage. Determinations were made of weight loss, percent dry matter, sugars, and starch contents. This experiment was also designed to study the effect of treatment of different storage containers and/or the tubers with CIPC, using two varieties, LaChipper and Red LaSoda. The treatment consisted of (1) control, (2) slatted wooden crates treated only, (3) potatoes treated only, and (4) crates and potatoes treated together, using both varieties. A similar procedure was then followed, utilizing commercial burlap type bags instead of crates as the storage container. Each treatment was replicated three times, and each container held 50 pounds of potatoes at the beginning of the test.

The treatments consisted of dipping the tubers or container or both for one minute into a one percent water solution of CIPC in an emulsifiable form.

After air drying, the treated material was placed in a storage room where the temperature was controlled at 60°F ± 2, with no control over relative humidity.

Each container with its potatoes was weighed at monthly intervals to determine weight loss. Representative samples were also taken of dry matter, sugar and starch determinations. Immediately afterwards the remainder of each storage samples was reweighed.

**Dry Matter** - Before this phase of the work could be done, the duration for which the samples should remain in the oven until all of
the moisture had been removed had to be determined. For this standardization procedure, five pounds of potatoes were ground in a power-driven meat grinder through a 4.5 mm. sieve and then thoroughly mixed with an electrical Sunbeam mixmaster.

Approximately ten grams were then weighed into numbered tin cans, using an analytical balance calibrated in ten thousandths of a gram and then dried at 80°C. for 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20 hours. After cooling in a desiccat, the duplicate samples were weighed to determine moisture loss. Figure 1 shows the Standard Curve derived from the resulting information. A period of twelve hours was selected as sufficient time to drive out all of the moisture from a 10 gram sample.

This procedure was used in determining the percent dry matter in the succeeding experiment.

In the Spring of 1963, additional shrinkage tests were begun with determinations being based on an individual tuber basis instead of group weights. This was designed as an attempt to control the tuber decay factor which interfered with collection of reliable data from the previous tests. The potatoes were harvested and washed in the Spring, LaChipper on May 16, 1963, and Red LaSoda two weeks later. After washing, twenty medium-sized potatoes were selected and the dry matter percentage was determined. An additional 20 tubers were selected, numbered, and weighed, and then cured along with the rest of the potatoes. After two weeks of curing at about 75 - 80°F. and 85 percent relative humidity, the twenty previously weighed tubers were weighed again, and the percent dry matter was established. This procedure was followed in order to determine the
Figure 1. The Water Loss by 10 Grams of Macerated Potato Tissue With Time at 80°C.
amount of shrinkage during the curing period.

After curing, the tubers were selected, treated, weighed and numbered, and placed in their respective storage rooms.

The selections were made for medium-size tubers as free as possible from defects, blemishes, cuts and bruises. A total of 1,500 tubers per variety were chosen and separated into four lots. These lots consisted of the treated and untreated ones stored at 60°F, and the treated and untreated ones held in common storage room temperature. A sample of 20 tubers was taken every month thereafter for 12 months, or until they decayed or sprouted and shrank so badly that they had to be discarded.

The percent dry matter and shrinkage were determined from the 20 tuber samples. The treatment of those tubers to be treated consisted of a one percent water solution of CIPC in the emulsifiable form. Upon measuring the solution after treatment, calculations showed that one crate with 100 potatoes absorbed 5.23 grams of CIPC. Both the crate and potatoes were immersed in the solution for about one minute. This method had proven satisfactory in preliminary tests and in earlier experiments by Jones (58). The samples were air dried and then numbered with an indelible pencil. This method of identification proved quite satisfactory for the numbers were clearly legible almost a year later. The numbered potatoes were then weighed on a Mettler electrical balance to the nearest hundredth of a gram.

From this group of tubers, percent shrinkage and dry matter were determined during subsequent storage.

During the following year the same procedure was followed. In addition to shrinkage and dry matter content, sugar and starch determinations were made from this same group of tubers. The respiration rate was
also determined, but the tubers for this experiment came from the same lot as those used in the cooking tests.

**Dry Matter** - Since these analyses were run on an individual tuber basis, it was evident that the methods used in the previous tests were unsatisfactory. Therefore, another method was devised for sampling, utilizing a number 8 cork borer. A cylindrical plug of tuber tissue about 27 mm. long and 15 mm. in diameter was taken from each tuber with the cork borer. This plug weighed approximately five grams. A total of 20 plugs, one from each tuber, was taken, each constituting a replication.

In an attempt to control the possible variation among tubers, only two large potatoes were used for the standardization procedure determination of the proper drying time at 80°C. A plug from each tuber represented a duplicate of each sample. A sufficient number of plugs were extracted from each tuber so as to dry samples for 12, 15, 18, 21, 24, 27, 30, 33, 36, and 39 hours. These samples were also cooled in a desicator, weighed, and the moisture loss was computed. Figure 2 shows the results of these determinations. It was decided that 24 hours was a satisfactory drying time.

From this dry matter and shrinkage data, it was intended to show the effect of CIPC on shrinkage and dry matter content of the tubers at the two storage temperatures, 60°F. and room temperature.

**Cooking Tests** - For these tests, a different lot of tubers were selected, treated, and handled in the same manner as those used for the shrinkage tests, with the exception of numbering and weighing them. Cooking quality was determined twice during the storage period, first when small sprouts were noticed on the untreated samples, and second
Figure 2. The Water Loss by Potato Tissue Sampled as 5-Gram Plugs With Time at 80°C.
when these samples were sprouting profusely. The table quality of the potatoes was evaluated by a panel of three judges previously selected for uniformity in judging cooking quality. Some of the tubers were boiled, and others were chipped. The boiled tubers were immersed for 30 minutes in boiling water, with each treatment sample being cooked separately.

The tubers to be chipped were sliced 1/32 of an inch and fried in a deep fat fryer using cotton seed oil. One hundred gram samples were fried in the oil at 320°F. for three minutes, drained, and stored in plastic bags until used in the taste test (the same or following day).

The boiled tubers were rated for color, flavor, and texture, and the chipped ones were evaluated for color, flavor, and crispness. The judges evaluated these samples by the paired comparison method developed by Bradley and Terry (10, 11, 101) each pair being replicated four times.

During the following year the same procedure was followed with the exception that another cooking date was added - this being when the untreated tubers were sprouting moderately.

**Respiration** - Ten potatoes from each treatment were selected at random at monthly intervals of storage. Each sample was then subdivided into two parts with five tubers each. A plug of tissue was taken with a number 4 cork borer from each tuber. From this plug, a small section was cut just under the epidermis. Five of these sections, each coming from a different tuber, weighing approximately 0.5 grams total weight were then weighed on a Mettler-electrical balance graduated in ten thousandths of a gram. The respiration rate of these samples from each of the tests was measured for two hours at 15 minute intervals using the Warburg respirometer.
Carbohydrate Analysis - Samples were taken from each treatment lot in duplicate from carbohydrate analysis. These analyses consisted of reducing sugar, non-reducing sugar, total sugar, and starch determinations. Samples were taken at harvest, after curing, and at monthly intervals of storage for the 1963 container tests, and at harvest, after curing, and at monthly intervals for the 1964-65 shrinkage tests. Additional samples were taken from the tubers used in the cooking quality study, at the same time samples were taken for the cooking tests.

For each analytical sample, 20 medium-size tubers were used. One quarter of each tuber was ground in a power-driven meat grinder equipped with a 4.5 mm. sieve. After thoroughly mixing the ground pulp, a 20 gram sample was weighed into a 250 ml. Erlenmeyer flask. Duplicate samples were taken of the ground pulp.

The weighed samples were covered with 80 ml. of 95 percent ethyl alcohol and then boiled 10 minutes to inactivate enzymes which might have been functioning to alter some of the sugar fractions. The flasks were then cooled, numbered, stoppered, and stored at 35°F. until analysis of the samples could be run.

A standard curve of glucose concentration was established in Figure 3. In plotting the curve, two ml. samples of sugar solution ranging in concentration from 0.1 to 1.7 mg. of glucose were related to the amount of light that passed through the samples. In developing these curves, a Beckman model B. spectrophotometer with a 410 mp. filter and a sensitivity value of two was used. The same instrument was likewise used in making the carbohydrate determinations of the tuber samples.

In the separation of carbohydrates, the samples preserved in 95 percent alcohol were filtered into 250 ml. volumetric flasks, the residue
Figure 3. Standard Glucose Curve Showing the Percent Transmission of Light at Various Concentrations of Glucose.
being washed with 80 percent ethyl alcohol. This filtrate was used for the determination of sugars.

The alcohol-insoluble residue left on the filter paper was dried by spreading the filter paper on paper towels. This residue was used for the determination of starch.

a). Reducing Sugar: The filtrates were placed on a hot plate to evaporate the alcohol. As they were evaporating, 50 ml. of distilled water were added gradually to the beakers to prevent their drying out. After evaporation of the alcohol, the filtrate was cooled to room temperature, clarified with two ml. of neutral lead acetate, five ml. of 20 percent disodium phosphate and approximately one-half teaspoon of charcoal, and filtered into 100 ml. volumetric flasks. The filtrate was diluted to volume, and two ml. of the diluted sample was taken and the reducing sugar analysis was completed according to the procedures of Forsee and Morell (42, 67).

b). Total Sugar: For the determination of total sugars, the same procedure was followed as that for reducing sugar with the exception that three drops of a one percent invertase solution was added to the diluted two ml. sample. The test tube containing the sugar and invertase solution was then allowed to stand for two hours at room temperature for hydrolysis of sucrose before the sugar determination was made.

c). Non-reducing Sugar: This component was determined by subtracting the quantity of reducing sugar originally present from the quantity of total sugar present after hydrolysis.

d). Starch: The alcohol-insoluble residue was washed into a 250 ml. Erlenmeyer flask. A volume of 10 ml. of 6N HCL was added to the flask which was held on a hot plate for hydrolysis of the starch for
three hours. The flask was then cooled, neutralized with 6N NaOH, clarified with two ml. neutral lead acetate and five ml. disodium phosphate, and filtered into a 500 ml. Volumetric flask. After bringing the solution up to volume, 10 ml. of this solution was diluted to 100 ml. and the amount of glucose present was determined as described above for reducing sugar. The percent glucose thus obtained was multiplied by 0.90 to determine the percent of starch as described in A.O.A.C. (4).
EXPERIMENTAL RESULTS

Storage Container Experiment.

The potatoes for the storage container experiment in 1963 were harvested from Idlewild Experiment Station, Clinton, Louisiana on November 27, 1962. One February 16, 1963, when very small sprouts were first noted on the tubers, this experiment was begun. The treatments consisted of (1) control, (2) slatted wooden crates treated only, (3) potatoes treated only and (4) crates and potatoes both treated together, using two varieties, La Chipper and Red LaSoda. A similar procedure was then followed, utilizing commercial burlap bags instead of crates as the storage container. Each treatment was replicated three times and each container contained fifty pounds of potatoes at the beginning of the test.

The treatment consisted of dipping the tubers or container or both for one minute into a one percent water solution of CIPC (emulsifiable concentrate) and then allowing them to air dry. Each container with its tubers were then weighed and placed in a storage chamber where the temperature was controlled at 60°F. ± 2. The treated samples were stacked together, and the controls were placed at the far end of the room.

At monthly intervals the tubers were removed from the chamber, weighed and 10-tuber samples were taken. The remaining tubers and their containers were reweighed and placed back into storage. The 10-tuber samples were used to determine the percent dry matter and also the content of certain carbohydrates which included reducing sugar, non-reducing sugar, total sugar, and starch.

It was difficult to obtain accurate shrinkage information because
of the tuber decay factor. Any weight loss due to decay had to be calculated as shrinkage because the tubers were weighed as a group.

The results of this experiment showed that a one percent CIPC treatment was sufficient to completely inhibit sprout growth up to 5 months after treatment. The tubers were treated 2.5 months after harvest. No sprouts were observed in any of the treated lots in either variety, whereas the checks sprouted profusely, as shown in plates I-IV. Although sprouting was completely inhibited, the experiment had to be terminated prematurely because of decay in the treated tubers. They were stored in the hallway of a large storage section of the Horticulture building and were subject to undue bruising because of the movement of other experimental materials through the hall.

Although there were appreciable differences between the control and the treated samples in regard to sprouting, the difference in shrinkage was not so great, as shown in Table I. In most cases the controls lost more weight per month than the treated samples; however, there appeared to be no real differences among the different types of treatment. There was an obvious difference in weight loss between tubers stored in crates and those stored in bags. Both varieties when stored in bags lost more weight after the first month of storage than did those stored in crates. There also appeared to be more weight loss in each treatment during the month of June, four months after treatment, than any other time. There was also an indication that tubers stored in crates lost less total weight than those stored in bags.

The results of the dry matter determinations are shown in Table II. There appeared to be no differences due to treatment. Only during the first two months of storage was there indicated a consistent difference
Plate I. The Effect of CIPC Applied by Different Methods on Sprouting of Red LaSoda Potatoes Stored in Crates for Three Months at 60°F.
Left to Right: Both Treated, Tubers Treated, Crates Treated, and Control
Plate II. The Effect of CIPC Applied by Different Methods on Sprouting of Red LaSoda Potatoes Stored in Bags for Three Months at 60°F. Left to Right: Both Treated, Tubers Treated, Bags Treated, and Control.
Plate III. The Effect of CIPC Applied by Different Methods on Sprouting of La Chipper Potatoes Stored in Crates for Three Months at 60°F.
Left to Right: Both Treated, Tubers Treated, Crates Treated, and Control.
Plate IV. The Effect of CIPC Applied by Different Methods on Sprouting of La Chipper Potatoes Stored in Bags for Three Months at 60°F. Left to Right: Both Treated, Tubers Treated, Bags Treated, and Control.
Table I. The Effect of CIPC Applied by Different Methods\(^1\) on Weight Loss of Two Varieties of Potatoes During Storage at 60°F.

<table>
<thead>
<tr>
<th>Variety and Container</th>
<th>March</th>
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<th>June</th>
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<th>August(^3)</th>
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<td>20</td>
<td>17</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Tubers Treated</td>
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<td>10</td>
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<td>9.8</td>
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<td>23.5</td>
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<td>-</td>
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\(^1\) Treatments consisted of a one minute dip in a one percent water solution of CIPC.

\(^2\) Values expressed as an average of 3 replications.

\(^3\) Missing data represent samples discarded because of excessive decay.
Table II. The Effect of CIPC Applied by Different Methods\(^1\) on the Dry Matter Content\(^2\) of Two Varieties of Potatoes During Storage at 60°F.

<table>
<thead>
<tr>
<th>Variety and Container</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
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<tr>
<td><strong>RED LASODA</strong></td>
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</tr>
<tr>
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<tr>
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<td>20.0</td>
<td>22.7</td>
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<tr>
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<td>21.8</td>
<td>-</td>
<td>-</td>
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</tr>
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<td>22.2</td>
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<td>21.6</td>
<td>22.2</td>
<td>-</td>
<td>22.4</td>
</tr>
</tbody>
</table>

1. Treatments consist of a one minute dip in a one percent water solution of CIPC.
2. Values are expressed as percent and represent an average of 3 replications.
3. Missing data represent samples discarded because of excessive decay.
between the control and the other treatments. The control appeared to have a slightly higher percentage of dry matter. There appeared to be very little difference as far as the storage container was concerned, although those tubers stored in crates had just a little lower percentage of dry matter.

Figures 4-11 show the results of the various carbohydrate analyses of the different treated lots. These include determinations of reducing sugar, non-reducing sugar, total sugar, and starch contents of the tubers. Figures 4 and 5 show the results of the effect of CIPC applied in different ways on percent reducing sugars. With the exception of La Chipper stored in crates (Figure 4) there was not a great deal of difference among treatments. This pattern was similar throughout the storage period. Although the actual concentrations of reducing sugar varied between varieties, the reactions of the varieties to treatment were similar. The results shown in Figure 4, where La Chipper was stored in crates, indicate that there might have been real differences among treatment effects, especially during the third, fourth, and fifth months of storage. These wide differences occurring in the middle of the storage period were not present, however, during the last month of storage.

Figures 6 and 7 show the effect of CIPC applied in different ways on percent non-reducing sugar in the tubers. No great differences were noted among the treatments of Red LaSoda stored in either crates or bags. As in the case of reducing sugars, however, La Chipper reacted differently to storage container. The four treatments in which La Chipper was stored in bags showed no great differences, as shown in Figure 7. In Figure 6 it may be noted that larger differences occurred when La Chipper was stored in crates indicating that there might have been a real difference.
Figure 4. The Effect of CIPC Applied by Different Methods on the Reducing Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
Figure 5. The Effect of CIPC Applied by Different Methods on the Reducing Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
Figure 6. The Effect of CIPC Applied by Different Methods on the Non-Reducing Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
Figure 7. The Effect of CIPC Applied by Different Methods on the Non-Reducing Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
among treatments. It should be remembered here, however, that these values were determined by subtracting the percent reducing sugar from the percent total sugars. Any large differences in percent reducing sugar would appear again in percent non-reducing sugars, provided there were no great differences among treatments when tested for total sugars.

The two varieties reacted differently in regard to percent non-reducing sugar. Red LaSoda showed a sharp increase after curing and then a very sharp decline from 0.3 percent to 0.05 percent after the first month of storage. Then for the next four months slight fluctuations were noted at around 0.05 percent. Following that, slight increases were noted after six months. La Chipper also showed an increase after curing which was not as great as that of Red LaSoda. The value rose from 0.025 percent to 0.1 percent during curing and then a gradual uneven increase throughout the storage period.

Figures 8 and 9 show the results of percent total sugar determinations. No great differences were observed among treatments within any of the four tests. The varieties performed similarly in different containers, although the percent total sugar did not drop as low after three months when Red LaSoda was stored in crates (Figure 9) as it did in samples of this variety stored in bags (Figure 8).

As in the previous sugar determinations, the two varieties reacted differently when tested for percent total sugars. The total sugars in Red LaSoda remained high after one month of storage and declined to remain low for the next three months. The content increased again toward the end of the storage period. The total sugars in La Chipper, on the other hand, increased during curing and also after one month of storage. A sharp decrease was noted after two months of storage, followed by
Figure 8. The Effect of CIPC Applied by Different Methods on the Total Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
Figure 9. The Effect of CIPC Applied by Different Methods on the Total Sugar Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
increases through the fifth month. The results of the starch determinations are shown in Figures 10 and 11. As in most of the other sugar determinations, no consistent differences were noted among the different treatments in each test. Any increase or decrease in one sample usually was accompanied by the same response by the other three treatments. Slight differences were recorded when different storage containers were used for each variety. There was more of a decrease in starch content after the first two months of storage when Red LaSoda tubers were stored in bags than when they were stored in crates (Figure 11). The percent starch of La Chipper tubers stored in bags showed a great decline after the second month of storage than did those stored in crates (Figure 11).

The varieties reacted similarly in storage in regard to percent starch. There was a general slight decrease after two months of storage, followed by a slight increase and then a gradual decrease for the remainder of the storage period.

Sprouting and Shrinkage Tests.

The potatoes used in these three experiments were handled in a manner similar to that in the previous study. La Chipper was harvested from the Ben Hur Horticulture farm at Baton Rouge on May 15, 1963 and on May 28, 1964. Red LaSoda was harvested from Idlewild Experiment Station, Clinton, Louisiana on May 29, 1963 and on June 2, 1964. Both the Red LaSoda and La Chipper tubers that were used for the 1964-65 supplemental 60°F storage test were harvested at Idlewild on December 3, 1964. After washing, twenty medium-sized potatoes were selected, and the dry matter percentage was determined. An additional twenty tubers were selected, numbered, weighed, and then cured along with the remainder of the experimental potatoes. After two weeks of curing at about 75-80°F.
Figure 10. The Effect of CIPC Applied by Different Methods on the Starch Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
Figure 11. The Effect of CIPC Applied by Different Methods on the Starch Content of Two Varieties of Potatoes During Storage at 60°F. (Expressed as an average of duplicate samples).
and 85 percent relative humidity, the twenty previously-weighed tubers were weighed again, and then the percent dry matter was determined.

After curing, the tubers were selected, treated, numbered, weighed, and placed in their respective storage rooms.

The shrinkage rate was determined on an individual tuber basis in these experiments rather than on a group basis. This was designed as an attempt to eliminate the problem caused by tuber decay which interfered with the collection of reliable data from the previous test.

In 1963 the tubers were selected, treated, weighed, and then numbered. In 1964 for the last two tests, the one percent CIPC treatment was the last operation before storage in order to avoid as much handling as possible of the treated tubers. The tubers that were treated and stored at room temperature in 1963 had to be discarded rather early because of excessive decay. The extra handling after treatment might have had some effect on the extent of this decay.

A total of four storage rooms were used for these experiments: two at room temperature, 75°F. ± 5, and two controlled at 60°F. ± 2. Two separate rooms were needed at each temperature so that the control samples and treated tubers could be kept in separate rooms in order to prevent any drift of the chemical from the treated tubers to the controls.

The 1963 and 1964 tests with Spring-grown potatoes were conducted using both varieties and four treatments of each. These consisted of a dip for one minute in a one percent water solution of CIPC and a control stored at 60°F. and treated tubers and a control stored at room temperature.

Twenty-tuber samples were taken from each of the treated lots and weighed to determine the amount of shrinkage at monthly intervals. These
tubers had been previously weighed and numbered immediately after curing. After weighing, five gram plugs were extracted from each tuber, and dry matter determinations were made.

In 1964, the same determinations were made. In addition, the remaining portion of the tubers on each sampling date were ground up, and duplicate samples were taken for the carbohydrate analyses described earlier in the Materials and Methods.

The respiration rate was also determined in 1964 but not with the same twenty tubers. Another lot of potatoes were handled in the same way as those used for the shrinkage measurements, except that it was unnecessary to number and weigh them at the outset. Along with the respiration studies, the cooking quality of treated and control samples was determined, also with this second group of tubers.

On June 18, 1964 a malfunction of the air-conditioning equipment caused the temperature to drop to 28°F. for 12 hours in the storage room where the control samples were stored at 60°F. Since it was not known what effect this sudden change in the storage temperature might have here on the metabolism of the tubers, a supplementary 60°F. storage test was begun. Only that portion of the previous spring experiment in which tubers were stored at 60°F. was repeated. The tubers were handled in a similar manner as in the two preceding tests, and determinations were the same as those made for the 1964 Spring experiments at 60°F.

Similar to the results of previous tests, a one percent solution of CIPC was highly effective in controlling sprouting of the tubers during storage. Sprouting was completely inhibited for a period of one year after harvest for two consecutive years in samples stored at 60°F. Plates V-X show the progressive stages of sprouting of the control and
Plate V. The Effect of CIPC on Sprouting of Red LaSoda Potatoes Stored for Four Months at 60°F. Top to Bottom: Treated with One Percent CIPC and Control.
Plate VI. The Effect of CIPC on Sprouting of La Chipper Potatoes Stored for Four Months at 60°F. Top to Bottom: Treated with One Percent CIPC and Control.
Plate VII. The Effect of CIPC on Sprouting of Red LaSoda Potatoes Stored for Eight Months at 60°F. Left to Right: Control and Treated with One Percent CIPC.
Plate VIII. The Effect of CIPC on Sprouting of La Chipper Potatoes Stored for Eight Months at 60°F. Left to Right: Control and Treated with One Percent CIPC.
Plate IX. The Effect of CIPC on Sprouting of Red LaSoda Potatoes Stored for Twelve Months at 60°F. Left to Right: Control and Treated with One Percent CIPC.
Plate X. The Effect of CIPC on Sprouting of La Chipper Potatoes Stored for Twelve Months at 60°F. Left to Right: Control and Treated with One Percent CIPC.
the inhibition of sprouting of the treated samples stored at 60°F. The results of the experiments at room temperature also show complete control of sprouting in the treated sample as shown in Plate XI. However, it was found that after two years of study that storage at room temperature was not suitable for Irish potatoes. In fact, at the time the photographs mentioned above were taken, the Red LaSoda tubers had already been discarded because of excessive decay. In 1963, that portion of the experiment had to be discarded after only four months of storage due to excessive decay. In 1964, the tubers stored at room temperature lasted only five months in storage. La Chipper tubers lasted from one to two months longer at room temperature than did Red LaSoda.

The results of the general shrinkage tests conducted at 60°F. are shown in Figures 12-14. Only small differences were observed between the treated samples and the controls until after four and one half to five months of storage. Then the differences began to increase. The treated samples showed only slight weight losses at any time and at the end of 10 months of storage had lost about five to six percent of their original weight. The controls, on the other hand, lost much weight during the second part of the storage period. At the end of 10 months of storage at 60°F. the control samples had lost from 35 to 50 percent of their original weight. It was interesting that the varieties differed in the percent total loss lost during curing as well as from one year to another.

A similar pattern was followed when the tubers were stored at room temperature, as shown in Figure 15. After four and one-half to five months, noticeable differences in shrinkage rates were shown by the tubers that were still sound.
Plate XI. The Effect of CIPC on Sprouting of La Chipper Potatoes Stored for Four Months at Room Temperature. Top to Bottom: Treated with One Percent CIPC and Control.
Figure 12. The Loss in Weight by Spring-Grown Red LaSoda Potatoes During Storage at 60°F. as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
Figure 13. The Loss in Weight by Spring-Grown La Chipper Potatoes During Storage at 60°F. as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
Figure 14. The Loss in Weight by Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of 20 individual tuber samples).
Figure 15. The Loss in Weight by Two Varieties of Spring-Grown Potatoes During Storage at Room Temperature as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
The percent dry matter was determined with the same tubers used for the shrinkage tests described above. Five gram plugs taken from each of the twenty tubers were dried at 80°F. for 24 hours, as was described in detail in the Materials and Methods.

The results of the dry matter determinations of tubers stored at 60°F. are shown in Figures 16-18. Generally, there was not a great difference between the treated samples and the controls at any time during the storage period. In some cases there were obvious differences, but they were not consistent. In 1963, Red LaSoda tubers showed a large difference between the treated tubers and the controls after eight months (Figure 16). The control samples contained almost 17 percent dry matter while the treated lot showed only 15 percent. During the following month no differences occurred, but for the last month a substantial difference was noted. The controls contained over three percent more dry matter than treated samples. In 1964, there was no difference after eight months, but the ninth and tenth month determinations showed a difference of about one percent, and at this time the treated tubers contained more dry matter. During the second, third, and fourth month of storage, the controls contained one percent more dry matter than the treated tubers. In 1963, after one month of storage the control samples were one percent higher, but after the following month the controls were one percent lower. The differences between the control and treated tubers of Red LaSoda in dry matter were not so obvious in the supplementary 60°F. test (Figure 18). Only after the second month was there a noticeable difference when the treated tubers showed more than a one percent increase over the control.
Figure 16. The Dry Matter Content of Spring-Grown Red LaSoda Potatoes During Storage at 60°F. as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
Figure 17. The Dry Matter Content of Spring-Grown La Chipper Potatoes During Storage at 60°F. as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
Figure 18. The Dry Matter Content of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC -- 1964-65. (Expressed as averages of 20 individual tuber samples).
The differences due to treatment using La Chipper tubers were also very inconsistent, as shown in Figures 17 and 18. In 1963, during the first three months of storage the control was lower than the treated tubers. During the fourth month no differences were noted, and then from the fifth month on, the control contained more dry matter than the treated samples. However, in the 1964 Spring test and the supplementary 60°F. test, no large differences were noted at any time during the storage period.

The results of the test at room temperature are shown in Figure 19. Inconsistencies were noted again. There were no large differences between the treatments and the control in the tubers of the Red LaSoda variety. Fluctuations occurred in 1964. Potatoes of the La Chipper variety showed more differences between the treatment than did Red LaSoda.

It was intended that from these dry matter and total loss determinations, a more accurate measurement of shrinkage could be obtained by calculating the amount of water and the amount of solids lost. After preliminary calculations, however, it was found that this was impossible because of fluctuations of dry matter percentages. Apparently, twenty tubers were not a large enough number to constitute a representative sample. Dry matter percentages varied considerably among individual tubers, as shown in Table III. These variations were found in both treated and untreated samples. The five sampling dates for each variety represent the entire storage period.

There was also a wide range among the individual tubers within a twenty tuber sample when shrinkage was determined, as shown in Table IV. This was true in treated and control tubers. Again, the five sampling dates for each variety cover the entire storage period.
Figure 19. The Dry Matter Content of Two Varieties of Spring-Grown Potatoes During Storage at Room Temperature as Affected by Treatment with CIPC. (Expressed as averages of 20 individual tuber samples).
Table III. The Dry Matter Content of Individual Tubers of Two Varieties of Potatoes During Storage at 60°F.

<table>
<thead>
<tr>
<th></th>
<th>RED LASODA</th>
<th></th>
<th>LA CHIPPER</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>17.81</td>
<td>17.48</td>
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</table>

* Control
** Treated with one percent CIPC
Table IV. The Loss in Weight by Individual Tubers of Two Varieties of Potatoes During Storage at 60°F.

<table>
<thead>
<tr>
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<tr>
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<td>2.99</td>
</tr>
<tr>
<td>3.18</td>
<td>3.11</td>
</tr>
</tbody>
</table>

| 1.35               | 2.44              | 5.71              | 4.42              | 21.28              | 3.16              | 4.06              | 8.77              | 15.54             | 6.33              |

* Control
** Treated with one percent CIPC
Carbohydrate Determinations.

The carbohydrate determinations consisted of percent of reducing, non-reducing and total sugar, and starch. Immediately after determining shrinkage and dry matter content of the twenty tuber samples each month, approximately one-fourth of each tuber was ground in a power-driven meat grinder. After thoroughly mixing the group tissue, duplicate twenty-gram samples were weighed into a 250 ml. Erlenmeyer flask. After adding 80 ml. of 95 percent ethyl alcohol, the samples were boiled for five minutes to inactivate any enzymes which might alter those carbohydrates measured in later analyses. The samples were then cooled and stored at 35°F., to be analyzed at a later date.

The exact procedure used in determining those particular carbohydrate contents was discussed in detail in the Materials and Methods. The results were obtained as percent light transmission and converted to percent sugars or starch.

Samples were taken at harvest and after curing as well as at monthly intervals of storage. Since the potatoes were treated after curing, only one determination of each carbohydrate per variety was made at harvest and after curing.

The results of the effect of CIPC application on sugar and starch contents of potatoes stored at 60°F. are shown in the succeeding figures. Figures 20 and 21 show the results of the reducing sugar determinations. It is difficult to recognize any consistent effect of the chemical on the reducing sugar content of the tubers. The data from the supplemental 60°F. storage test shown in Figure 21 show smaller differences among treatments than the large 1964 Spring test (Figure 20). Red LaSoda tubers show large differences between the treated samples and the
Figure 20. The Reducing Sugar Content of Two Varieties of Spring-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
Figure 21. The Reducing Sugar Content of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC -- 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
control (Figure 20). During the third, fourth, and fifth month, the controls show a higher percentage of reducing sugar; however, during the next two months a higher value is shown in the treated tubers. After the next month smaller but opposite differences are noted, and during the last two months the treated samples exhibited a higher content of reducing sugar. Results for La Chipper presented in the same figure show the same kind of fluctuations; however the differences are not quite as large.

The results of the effects of CIPC application on non-reducing sugars in potatoes stored at 60°F. are shown in Figures 22 and 23. No large differences were observed during the first half of storage, although some fluctuations were observed during the first half of storage, although some fluctuations were noted. With Red LaSoda large differences were noted only after nine and ten months of storage, in which case the control showed a higher content of non-reducing sugars. In results with La Chipper, also shown in Figure 22, larger differences occurred after six, seven, and eight months, at which time the treated samples were higher in non-reducing sugars. The results from the ninth and tenth month samples show that the differences fluctuated. After nine months, the control was higher, and after ten months the treated samples were higher with regards to non-reducing sugar.

The results from the supplemental 60°F. test show that, as with the case of reducing sugars, only small differences in non-reducing sugar were noted between the treated lots and the control (Figure 23). However, Red LaSoda tubers showed some differences after one and two months of storage. Large differences between years were noted. Red LaSoda tubers gained in non-reducing sugar during curing of the Spring
Figure 22. The Non-Reducing Sugar Content of Two Varieties of Spring-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
Figure 23. The Non-Reducing Sugar Content of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
crop while those harvested in the fall decreased during this period. There was a sharp increase after three months of storage of the fall crop while non-reducing sugars in the Spring crop decreased during this time. The levels in La Chipper potatoes from the two crops were similar at the beginning, but after two months of storage a decrease was noted for the Spring crop while the fall crop showed marked increases.

The results of the total sugar determinations are shown in Figures 24 and 25. Red LaSoda tubers showed a pattern similar to that for their content of reducing sugars. During the third, fourth, and fifth months of storage, the control showed a higher level of total sugars (Figure 24). Then for the next two months the treated tubers were higher. During the last two months there apparently were no differences between the control and treated tubers. Although the results with La Chipper tubers presented in Figure 24 look somewhat similar, large differences occurred between treatments after six months of storage. Large differences also occurred after seven months of storage; however, the differences were in the opposite direction. The treated potatoes showed a higher total sugar content than the control at six months and a smaller amount at seven months. It appears that the La Chipper control samples were one month later than the treated lots in accumulation of total sugars.

Red LaSoda in the supplementary 60°F. storage experiment showed a fairly consistent pattern of differences in total sugar content (Figure 25). Through five months of storage the control samples showed a higher percentage of total sugars than did the treated ones. The differences each month were not as large as those in some of the other tests, however.

La Chipper potatoes on the other hand showed a typical inconsistent
Figure 24. The Total Sugar Content of Two Varieties of Spring-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
Figure 25. The Total Sugar Content of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
pattern (Figure 25). There were no large differences due to treatment and fluctuations occurred each month.

A similar effect due to season of growth was noted for total sugar content, as in the case of non-reducing sugars. It may be noted in Figure 24 that Spring-grown Red LaSoda tubers showed a decrease in total sugars up to five months, whereas the fall crop used for the supplementary 60°F. test showed this same decrease at five months, but there was a sharp increase at three months followed by a sharp decline at four months (Figure 25). La Chipper potatoes in the Spring showed a slight increase in total sugar after one month and then a gradual decrease after five months of storage (Figure 24). The fall-grown tubers, however, exhibited a large accumulation of total sugars after three months of storage at 60°F. (Figure 25).

The results of the starch determinations in these tubers are shown in Figures 26 and 27. These results, like the sugar determinations, indicate no general pattern as to the effect of CIPC on the percent of starch in the tubers. Treated tubers of the Red LaSoda variety show a higher amount of starch than the control during the second, third, and fourth months of storage and again after the sixth month (Figure 26). Then, after eight months, the control samples increased to a value above the treated samples. There appears to be no difference after nine months, and then the untreated tubers again indicated an increase over the treated potatoes.

The results for La Chipper tubers presented in the same figure also show marked inconsistencies. Although there were noticeable differences between the control and treated potatoes, the differences did not persist in the same direction for long periods. For example, the control
Figure 26. The Starch Content of Two Varieties of Spring-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC -- 1964-65. (Expressed as average of duplicate samples taken from a 20-tuber composite).
Figure 27. The Starch Content of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
tubers were higher in starch after the second, seventh, and tenth months of storage. Conversely, the treated potatoes show a marked increase over the controls during the third, fourth, fifth and sixth months. Differences were smaller after the eighth and ninth months of storage.

The results of the supplementary 60°F. test are shown in Figure 27. The effects of CIPC application were opposite on the two varieties with regard to starch content. After five months of storage, Red LaSoda potatoes treated with CIPC and stored at 60°F. showed a higher content of starch than the control while La Chipper, on the other hand, showed that during the last three months of storage the control samples had a higher percentage.

The results of the effect of CIPC application on the sugar and starch contents of tubers stored at room temperature are shown in Figures 28 and 29. This portion of the experiment had to be terminated after four and five months of storage because of excessive decay of both control and treated tubers. Figure 28 shows that in the case of the three sugars in Red LaSoda potatoes, the control samples show either equal or higher percentages than those of the treated lots. The differences were fairly consistent. Although the three sugars showed this consistency, the starch contents showed larger differences, but the effect changed. After two months of storage, the control had a considerably higher percentage of starch than did the treated tubers. However, the results for the last two months show the opposite effect.

The results of the effect of CIPC application on the sugar and starch contents of La Chipper tubers stored at room temperature are shown in Figure 29. The results for reducing sugars show that small differences occurred, but they were inconsistent and fluctuated widely.
Figure 28. The Sugar and Starch Contents of Spring-Grown Red LaSoda Potatoes During Storage at Room Temperature as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
Figure 29. The Sugar and Starch Contents of Spring-Grown La Chipper Potatoes During Storage at Room Temperature as Affected by Treatment with CIPC -- 1964-65. (Expressed as averages of duplicate samples taken from a 20-tuber composite).
In the content of non-reducing sugars, the differences between treatments were slight except after five months when the treated tubers showed a much lower percentage. The results of the total sugar determinations were somewhat similar. During the last two months large differences were noted, in that the control had more total sugar than did the treated tubers. It appears that the control was about one month later in its accumulation or decrease in sugar content. There appears to be a similar situation with regards to starch content. Larger differences occurred after the third and fourth months of storage when the control was higher. However, there appeared to be no differences in starch content after five months.

It may be noted here that the results of the sugar and starch determinations in both Red LaSoda and La Chipper tubers showed similar responses to that of the supplementary 60°F. storage test. The effect of treatment on each carbohydrate level was similar, and in some cases the results were almost identical.

Respiration Study.

For these tests, a different lot of tubers were selected, treated, and handled in the same manner as those used for the shrinkage tests, except that they were not numbered or weighed. With samples from this group of potatoes, the respiration rate was measured at monthly intervals, and also the cooking quality of treated and untreated lots was evaluated.

For the respiration studies, ten potatoes from each of the treatment lots were selected at random. Each sample was then subdivided into two parts with five tubers each. A plug of tissue was taken with a
number four cork borer from each tuber. From this plug, a small section was made immediately beneath the epidermis. Five of these different sections, weighing approximately 0.1 gram each were then weighed on a Mettler electrical balance graduated in ten thousandths of a gram. The five sections of tissue were placed in manometer flasks containing two ml. of a phosphate buffer solution to maintain the pH at 6.5. The middle section of the flasks contained 0.2 ml. of KOH on a small section of filter paper. The KOH absorbed the carbon dioxide given off by the respiring tissue. The uptake of oxygen was measured by measuring the change in the manometers. Brodie's solution was used as the fluid in the manometer and 250 was used as the reference point. The respiration rate of these samples was measured for two hours at 15 minute intervals using the Warburg respirometer. The values obtained were converted to microliters of oxygen used per hour per gram of tissue.

The results of these determinations are shown in Figures 30 - 32. There appeared to be no substantial differences between the respiration rates of the treated tubers and the control in Red LaSoda tubers until about the seventh month (Figure 30). Small differences occurred earlier but they fluctuated somewhat. During the seventh, eighth, and ninth months, the control showed marked increases; however, after 10 months there appeared to be no difference in the rates of samples stored at 60°F.

La Chipper tubers on the other hand, showed some differences after two months. The control absorbed some 20 microliters more of oxygen than the treated tubers. Smaller differences occurred throughout the storage period but fluctuated somewhat. For example, after four months more oxygen was absorbed by the treated tubers, while after the sixth
Figure 30. The Respiration Rate of Two Varieties of Spring-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicates of 5-tuber composites.)
Figure 31. The Respiration Rate of Two Varieties of Fall-Grown Potatoes During Storage at 60°F. as Affected by Treatment with CIPC -- 1964-65. (Expressed as averages of duplicates of 5-tuber composites).
Figure 32. The Respiration Rate of Two Varieties of Spring-Grown Potatoes During Storage at Room Temperature as Affected by Treatment with CIPC — 1964-65. (Expressed as averages of duplicates of 5-tuber composites).
through the ninth months the controls respired more rapidly. Then, after ten months, the treated tubers showed a higher respiration rate.

Figure 31 shows the effect of CIPC on the respiration rates of the samples in the supplementary 60°F. test. Neither Red LaSoda nor La Chipper tubers showed any sizeable differences between the treated samples and their controls. Generally, the two varieties performed similarly in respiration rate. It may be noted, however, that the small differences which occurred between treatments were just the opposite in varietal response. Tubers treated with CIPC showed a higher respiration rate among Red LaSoda tubers at the end of the storage period, whereas, the treated lots of the La Chipper variety showed a lower respiration rate.

Figure 32 shows the results of the respiration rate determinations in potatoes stored at room temperature. Treated Red LaSoda potatoes exhibited a higher respiration rate than did the control for the first three months of storage and then declined during the next month below the control.

Treated La Chipper tubers as shown in the same figure, showed a slightly higher respiration rate during the first two months of storage. Only small differences were observed for the next two months, but during the last month, sizeable differences occurred; the untreated tubers having a higher respiration rate.

No consistent difference was found between varieties in respiration rate.
Cooking Quality Studies.

The potatoes for these tests were taken from a different lot of treated and untreated tubers each month during 1963-64, as was the case for the respiration studies. Cooking quality was determined twice during the storage period, first when small sprouts were noticed on the untreated samples, and second when these samples were sprouting profusely. The table quality of the potatoes was evaluated by a panel of three judges previously selected for uniformity in judging the characters in potatoes considered important in determining cooking quality. The procedure used in cooking the tubers is described in the Materials and Methods.

During the following year, the same procedure was followed, with the exception that another cooking date was added, this being when the untreated tubers were sprouting moderately.

The first two cooking tests were carried out successfully. However, at the proposed time for the third sampling date, the control samples had sprouted and shrunken so severely that they were impossible to prepare for quality measurements. Since the treated samples were apparently still in good condition, it was decided to determine whether reconditioning them would improve their cooking quality. Accordingly, approximately one-half of the treated tubers were placed in storage at a temperature of 85°F ± 5 and held there for two and one-half weeks. The same method of paired comparison was used, and in this case, instead of the treated lot being compared to a control, the reconditioned treated tubers were compared with those held continuously at 60°F. The paired samples were replicated four times.

Each pair was judged separately. The superior member of each pair was indicated and assigned a value of one point. When neither member
was better than the other, a value of one-half point was given to each
member. Thus, a consistently superior member of a pair, if judged so by
the three judges, could receive a total of 12 points. Final results were
determined by adding the points of the three panelists and the four obser-
vations of the treated tubers versus the controls.

The results of the table quality studies are shown in Tables V, VI,
and VII. In the absence of appropriate statistical procedure, it was
difficult to determine how large a difference constitutes a true difference
in treatment effects. Therefore, in presenting these results, the termin-
ology of "large" or "small" differences was used. Small differences were
interpreted as that of a magnitude which is questionable for true difference.

The results after four months of storage in 1963, as given in Tables
V and VI, show the treated tubers to be rated as equal to or better than
the controls in all treatments for all characters affecting quality except
one. When La Chipper tubers that had been stored at 60°F. were boiled,
the control samples received a higher rating for color than the treated
ones. Plates XII-XVII show the appearance of the cooked samples used in
this experiment.

The results of the cooking tests when La Chipper and Red LaSoda
tubers were stored at 60°F. for 12 months in 1963-64 are also shown in
Table V. The judges gave both the Red LaSoda and La Chipper control chips
better ratings for color than the treated potatoes. In all other cases,
the judges rated the treated tubers as equal to or better than the
controls.

The results of the cooking tests for the following year, using tubers
in storage for four months, were somewhat different from those of the
preceeding year, as shown in Table VI and VII. Varietal effects were also
Table V. The Cooking Quality\(^1\) of Two Varieties of Potatoes After Four and Twelve Months of Storage at 60°F. as Affected by Treatment with CIPC -- 1963-64.

<table>
<thead>
<tr>
<th></th>
<th>4 MONTHS AFTER HARVEST</th>
<th>12 MONTHS AFTER HARVEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LA CHIPPER Treated</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CHIPPED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>4.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Flavor</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Crispness</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>BOILED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Flavor</td>
<td>10.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Texture</td>
<td>9.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

\(^1\) Expressed as the sum of 4 paired observations by 3 judges.
Table VI. The Cooking Quality\textsuperscript{1} of Two Varieties of Potatoes After Four Months of Storage at Room Temperature as Affected by Treatment with CIPC -- 1963 and 1964.

\begin{tabular}{|c|c|c|c|c|}
\hline
 & \textbf{1963 LA CHIPPER} & & \textbf{1964 LA CHIPPER} & \textbf{RED LASODA} \\
 & Treated & Control & Treated & Control & Treated & Control \\
\hline
Color & 6.0 & 6.0 & 1.0 & 11.0 & 11.1 & 1.0 \\
Flavor & 7.0 & 5.0 & 5.5 & 6.5 & 9.5 & 2.5 \\
Crispness & 4.5 & 7.5 & 10.5 & 1.5 & 9.5 & 2.5 \\
\hline
Color & 7.0 & 5.0 & 4.0 & 8.0 & 7.0 & 5.0 \\
Flavor & 8.0 & 4.0 & 4.0 & 8.0 & 7.0 & 5.0 \\
Texture & 7.5 & 4.5 & 5.0 & 7.0 & 7.0 & 5.0 \\
\hline
\end{tabular}

\textsuperscript{1} Expressed as the sum of 4 paired observations by 3 judges.
Table VII. The Table Quality\(^1\) of Two Varieties of Potatoes After Four, Seven, and Twelve Months of Storage at 60° F., as Affected by Treatment with CIPC — 1964-65.

<table>
<thead>
<tr>
<th></th>
<th>4 MONTHS AFTER HARVEST</th>
<th>7 MONTHS AFTER HARVEST</th>
<th>12 MONTHS AFTER HARVEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LA CHIPPER</td>
<td>RED LASODA</td>
<td>LA CHIPPER</td>
</tr>
<tr>
<td></td>
<td>Treated Control</td>
<td>Treated Control</td>
<td>Treated Control</td>
</tr>
<tr>
<td><strong>CHIPPED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>11.0  1.0</td>
<td>4.5  7.5</td>
<td>0.0  12.0</td>
</tr>
<tr>
<td>Flavor</td>
<td>2.0  10.0</td>
<td>7.0  5.0</td>
<td>1.0  11.0</td>
</tr>
<tr>
<td>Crispness</td>
<td>2.0  10.0</td>
<td>9.0  3.0</td>
<td>3.0  9.0</td>
</tr>
<tr>
<td><strong>BOILED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>4.0(^1)  8.0</td>
<td>7.0  5.0</td>
<td>4.5  7.5</td>
</tr>
<tr>
<td>Flavor</td>
<td>8.0  4.0</td>
<td>7.5  4.5</td>
<td>4.0  8.0</td>
</tr>
<tr>
<td>Texture</td>
<td>6.5  5.5</td>
<td>6.5  5.5</td>
<td>4.5  7.5</td>
</tr>
</tbody>
</table>

\(^1\) Expressed as the sum of 4 paired observations by 3 judges.
\(^2\) Held continuously at 60° F. until chipped.
\(^3\) Held for 2.5 weeks at 75° F. before chipping (reconditioned).
Plate XII. The Effect of CIPC on Chip Color of Red LaSoda Potatoes Stored for Four Months at 60°F.
A. Treated with One Percent CIPC
B. Control
Plate XIII. The Effect of CIPC on Boiled Red LaSoda Potatoes Stored for Four Months at 60°F.
Left to Right: Control and Treated with One Percent CIPC.
Plate XIV. The Effect of CIPC on Chip Color of La Chipper Potatoes Stored for Four Months at 60°F. Left to Right: Treated with One Percent CIPC and Control.
Plate XV. The Effect of CIPC on Boiled La Chipper Potatoes Stored for Four Months at 60°F.
A. Control
B. Treated with One Percent CIPC
Plate XVI. The Effect of CIPC on Chip Color of La Chipper Potatoes Stored for Four Months at Room Temperature. 
A. Treated with One Percent CIPC
B. Control
Plate XVII. The Effect of CIPC on Boiled La Chipper Potatoes Stored for Four Months at Room Temperature.
A. Treated with One Percent CIPC
B. Control
noted here, as well as those for temperature. For example, when the tubers that were held at room temperature were chipped, the treated Red LaSoda tubers were given a better color rating than the control, whereas La Chipper control samples rated higher than the corresponding treated tubers.

Red LaSoda tubers acted similarly at both temperatures with regard to the effects of CIPC, in which case the treated potatoes were equal to or better than the control. The only variation noted within this variety was in the case of the tubers treated and stored at room temperature. They made much lighter-colored chips than the control as shown in Table VI. The opposite effects were noted where the potatoes were stored at 60°F., however, but the differences here were not as great.

The effects of the chemical on La Chipper potatoes were not quite so consistent. When these tubers were stored at room temperature, the control showed equal or superior ratings in all cases, with the exception of the crispness factor of the chips. The color of chips from treated tubers stored at 60°F. received a much higher rating than its corresponding control. The flavor and texture of the boiled tubers were equal to or better than the control also. In all other cases the controls received a much higher rating than the treated samples.

The results of the cooking tests after seven months of storage at 60°F. are also shown in Table VII. When La Chipper potatoes were processed and tested, the judges gave the control samples higher ratings in all cases in both chipped and boiled tubers.

Red LaSoda control chips were also superior to the treated lots; however, when the potatoes were boiled and rated the treated tubers received the higher ratings.

The results of the reconditioning experiment are shown in the same
The reconditioned tubers when chipped were superior to those held at 60°F. in both color and flavor in both varieties. There was some variation when the chips were rated for crispness. La Chipper tubers when reconditioned and chipped were rated lower than its control while the reconditioned Red LaSoda tubers rated slightly higher than those not reconditioned. Plates XVIII and XIX also show the appearance of the chips from the reconditioning experiment.

The relationship of chip color to sugar content of the tubers as affected by CIPC treatment is shown in Tables VIII, IX and X.

There appeared to be an inverse relationship between percent reducing sugar and chip color; that is, the lighter the chip color as indicated by a higher rating, the lower the amount of reducing sugar, as shown in Tables VIII and IX. However, this relationship did not hold true in the case of Red LaSoda tubers stored at 60°F. in 1963. At four months, chips from treated tubers received a better color rating, yet a sugar analysis revealed that those tubers contained a slightly higher percentage of reducing sugar as shown in Table VIII.

A positive relationship appeared between chip color and percent non-reducing sugar. Again one exception was noted. An analysis showed that the control contained more non-reducing sugar than treated samples when La Chipper tubers were stored at room temperature. No difference was noted in chip color in these samples (Table IX).

No relationship was apparent between chip color and percent total sugar, also starch content of the tubers and chip color appeared to show no close association. Tables IX and X show that the relationship of chip color to the sugar and starch contents of the tubers after four months of storage does not agree with the results of the 1963 tests.
Plate XVIII. The Effect of Reconditioning on Chip Color of CIPC Treated La Chipper Potatoes after Storage at 60°F for Twelve Months.
1. Held continuously at 60°F.
3. Reconditioned at 75°F. for 2.5 Weeks after Storage
Plate XIX. The Effect of Reconditioning on Chip Color of CIPC Treated Red LaSoda Potatoes After Storage at 60°F. for Twelve Months.

2. Held continuously at 60°F.

4. Reconditioned at 75°F. for 2.5 Weeks after Storage
Table VIII. The Relationship of Chip Color\(^1\) to the Sugar\(^2\) and Starch\(^3\) Contents of Two Varieties of Potatoes After Storage for Four and Twelve Months at 60°F. as Affected by Treatment with CIPC — 1963-64.

<table>
<thead>
<tr>
<th></th>
<th>4 MONTHS AFTER HARVEST</th>
<th>12 MONTHS AFTER HARVEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LA CHIPPER</td>
<td>RED LASODA</td>
</tr>
<tr>
<td></td>
<td>Treated</td>
<td>Control</td>
</tr>
<tr>
<td>Color Rating</td>
<td>4.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Percent Reducing Sugar</td>
<td>.037</td>
<td>.025</td>
</tr>
<tr>
<td>Percent Non-Reducing Sugar</td>
<td>.013</td>
<td>.035</td>
</tr>
<tr>
<td>Percent Total Sugar</td>
<td>.050</td>
<td>.060</td>
</tr>
<tr>
<td>Percent Starch</td>
<td>10.85</td>
<td>9.45</td>
</tr>
</tbody>
</table>

1 Expressed as the sum of 4 paired observations by 3 judges.
2 Expressed as the average of duplicate samples taken from a 20 tuber composite.
Table IX. The Relationship of Chip Color$^1$ to the Sugar$^2$ and Starch$^2$ Contents of Two Varieties of Potatoes After Four Months of Storage at Room Temperature as Affected by Treatment with CIPC -- 1963 and 1964.

<table>
<thead>
<tr>
<th></th>
<th>1963 LA CHIPPER</th>
<th></th>
<th>1963 LA CHIPPER</th>
<th>1964 RED LASODA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Control</td>
<td>Treated</td>
<td>Control</td>
<td>Treated</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rating</td>
<td>6.0</td>
<td>6.0</td>
<td></td>
<td>1.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing</td>
<td>.025</td>
<td>.025</td>
<td></td>
<td>.070</td>
<td>.110</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing</td>
<td>.010</td>
<td>.069</td>
<td></td>
<td>.240</td>
<td>.270</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>.035</td>
<td>.094</td>
<td></td>
<td>.310</td>
<td>.380</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>9.75</td>
<td>12.40</td>
<td></td>
<td>4.50</td>
<td>13.5</td>
</tr>
</tbody>
</table>

$^1$ Expressed as the sum of 4 paired observations by 3 judges.

$^2$ Expressed as the average of duplicate samples taken from a 20 tuber composite.
Table X. The Relationship of Chip Color$^1$ to the Sugar$^2$ and Starch$^2$ Contents of Two Varieties of Potatoes After Storage for Four, Seven, and Twelve Months at 60°F. as Affected by Treatment with CIPC — 1964-65.

<table>
<thead>
<tr>
<th></th>
<th>4 MONTHS AFTER HARVEST</th>
<th>7 MONTHS AFTER HARVEST</th>
<th>12 MONTHS AFTER HARVEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LA CHIPPER</td>
<td>RED LASODA</td>
<td>LA CHIPPER</td>
</tr>
<tr>
<td></td>
<td>Treated Control</td>
<td>Treated Control</td>
<td>Treated Control</td>
</tr>
<tr>
<td>Color Rating</td>
<td>11.0</td>
<td>1.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Percent Reducing Sugar</td>
<td>0.037</td>
<td>0.050</td>
<td>0.117</td>
</tr>
<tr>
<td>Percent Non-Reduction Sugar</td>
<td>0.048</td>
<td>0.035</td>
<td>0.015</td>
</tr>
<tr>
<td>Percent Total Sugar</td>
<td>0.085</td>
<td>0.085</td>
<td>0.132</td>
</tr>
<tr>
<td>Percent Starch</td>
<td>12.7</td>
<td>7.7</td>
<td>9.70</td>
</tr>
</tbody>
</table>

$^1$ Expressed as the sum of 4 paired observations by 3 judges.

$^2$ Expressed as the average of duplicate samples taken from a 20 tuber composite.

$^3$ Held continuously at 60°F. until chipped.

$^4$ Held for 2.5 weeks at 75°F. before chipping (reconditioned).
The results of the color ratings are not consistent either. Only when La Chipper samples were stored at 60°F for four months did the inverse relationship between chip color and percent reducing sugar hold true. At seven months, the La Chipper control received a higher chip color rating but contained more reducing sugar. The Red LaSoda control, however, also was rated higher in chip color but had less reducing sugar. After 12 months of storage, both varieties when reconditioned made better chips and contained lower reducing sugar in the tubers. The association of chip color and non-reducing sugar again appeared to show a positive nature except in two cases, once when Red LaSoda was stored at room temperature for four months, and second when La Chipper was stored for seven months at 60°F. as shown in Table X.

Also, as in 1963, there appeared to be no relationship between chip color and the level of total sugar or starch in the tubers.

Table XI shows the correlation coefficients and the nature of the relationship of various characteristics of the tubers held at 60°F. during the 1964-65 season.

All possible comparisons were made within each variety and within each treatment. The results presented in the table show only the significant correlations or those that approached significance.

Only one association was common to all four treatments, and that being the reducing sugar and total sugar relationship. This correlation was significant in all cases. Most of the other correlations were peculiar to the treatments, while others were common only to varieties.

When the effects of the chemical on each variety were studied, La Chipper tubers showed less effect than did Red LaSoda. The four correlations which were statistically significant when La Chipper potatoes were
Table XI. The Relationship of Various Characteristics of CIPC Treated and Untreated Tubers of Two Varieties of Potatoes During Storage at 60°F. — 1964-65.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>LA CHIPPER - Control</th>
<th>LA CHIPPER - Treated</th>
<th>RED LASODA - Control</th>
<th>RED LASODA - Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage and Reducing Sugar</td>
<td>+.874**</td>
<td>Shrinkage and Reducing Sugar</td>
<td>+.752*</td>
<td>Shrinkage and Dry Matter</td>
</tr>
<tr>
<td>Shrinkage and Total Sugar</td>
<td>+.751*</td>
<td>Shrinkage and Total Sugar</td>
<td>+.797**</td>
<td>Shrinkage and Respiration</td>
</tr>
<tr>
<td>Reducing Sugar and Total Sugar</td>
<td>+.898**</td>
<td>Reducing Sugar and Total Sugar</td>
<td>+.847**</td>
<td>Reducing Sugar and Total Sugar</td>
</tr>
<tr>
<td>Non-Reducing Sugar and Total Sugar</td>
<td>+.780**</td>
<td>Non-Reducing Sugar and Total Sugar</td>
<td>+.795**</td>
<td>Non-Reducing Sugar and Total Sugar</td>
</tr>
<tr>
<td>Shrinkage and Dry Matter</td>
<td>-.731*</td>
<td>Shrinkage and Non-Reducing Sugar</td>
<td>+.547</td>
<td>Starch and Respiration</td>
</tr>
<tr>
<td>Non-Reducing Sugar and Respiration</td>
<td>+.564</td>
<td>Dry Matter and Reducing Sugar</td>
<td>+.593</td>
<td></td>
</tr>
<tr>
<td>Dry Matter and Reducing Sugar</td>
<td>-.530</td>
<td>Dry Matter and Starch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Matter and Starch</td>
<td>+.502</td>
<td>Starch and Respiration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at .05 level.
** Significant at .01 level.
treated were also significant in the control tubers, indicating no change in the metabolic processes studied between the treated samples and the control. The similar correlations among the La Chipper tubers were principally concerned with sugars and shrinkage. As the rate of tuber shrinkage increased so did their content of the three sugars. The reducing and non-reducing sugars increases were also correlated with the total sugar accumulation.

Red LaSoda potatoes showed more effect and variations as a result of CIPC treatment than did La Chipper potatoes. Of the six correlations in the treated tubers, only three were similar to those of the control, indicating no differences in these processes between the control and treated tubers. There were, however, several more correlations which were significant or approached significance in the control of Red LaSoda, indicating closer relationships of the metabolic processes studied in this variety.

Both varietal controls showed more correlations among metabolic processes than did the treated tubers.

While correlations in the La Chipper variety were concerned with various sugars or shrinkage and sugars, Red LaSoda tubers showed a negative correlation between shrinkage and dry matter and positive correlations between shrinkage and respiration and also between reducing sugar and total sugar.

Most of the correlations that were similar in the treated and control tubers of both varieties were concerned with at least one of the sugars.
DISCUSSION

The storage container experiment was terminated prematurely because of excessive decay of the treated samples. All of the experimental material was stored in the hallway of the storage section of the Horticulture Building and was subject to undue bruising because of the movement of other experimental materials on carts through this hall. It was reported by previous workers (5, 52, 73, 74, 89) that CIPC inhibits potato wound periderm formation. Therefore, once the treated samples were bruised, CIPC apparently prevented any wound healing which normally would have occurred. After the protective barrier of the periderm was broken, decay organisms had an easy access to enter the tuber. This is offered as an explanation of the excessive decay of the treated potatoes in this test. The control tubers which were discarded a month before the treated ones were probably affected by this excessive bruising also, but decay and deterioration were expected because of the excessive sprouting and shrinkage. Whether this excessive bruising accelerated the rate of decay in the control tubers was uncertain.

Tubers from the succeeding shrinkage tests when treated and stored at 60°F. remained sound throughout the storage year. These tubers were kept in storage rooms rather than in the hallway, and handling and bruising were kept to a minimum. In fact, the tubers were not handled at all until they were removed for sampling. Very little tuber decay was observed in any of the samples.

However, the tubers stored at room temperature decayed rapidly after a relatively short time in storage. It is probable that since the
potatoes were numbered and weighed after they were dipped in the CIPC solution, this might have influenced the rate of decay in storage. This extra handling may have bruised them somewhat. However, in 1964, the CIPC dip was the last operation performed before storage in order to avoid this unnecessary handling of the tubers after treatment. The potatoes remained sound for only one month longer during this season, however. Apparently some other factor was affecting the longevity of the potatoes in storage, since Jones (58) did not experience decay rates of this magnitude in treated or control tubers held at this temperature in previous seasons.

CIPC was shown to be a very powerful sprout inhibitor in these experiments. These results are in accord with those of Jones (58), Smith (99), and others (48, 50, 85, 66, 75). No sprouts were observed at any time on treated samples at either storage temperature. Treated potatoes remained sound and sprout-free for one year when stored at 60°F., at which time the experiment was terminated.

The effect of treatment with CIPC on tuber shrinkage was well defined. Large differences were obtained by four months from the beginning of storage and later. The varieties responded similarly. The effect, however, was probably an indirect one. Sprouts from untreated tubers use large amounts of reserve material and water from the tuber, and consequently, increased shrinkage occurs. Treated potatoes, since they did not sprout, did not lose as much water and dry matter through this process, and therefore, less shrinkage resulted. Of course, it is recognized that the treated tubers themselves might have lost more water than the control during early storage, especially if periderm formation had not been completed at the time of treatment, or if the treated tubers were bruised during early storage. This does not appear to have happened in this case,
however.

The large differences began to occur after four months of storage at which time control tubers had begun sprouting for almost a month.

Generally speaking, the dry matter content of the tubers was not greatly affected by CIPC application. There were wide differences between treatments occasionally, but these occurred inconsistently and the differences seemed to level off within a short time. Only in the case of the La Chipper variety in 1963-64 (Figure 17) was the control consistently higher in dry matter content than the treated samples, and this difference occurred after five months.

Similar dry matter percentages in treated and control tubers would mean that, although the control lost more total weight, the ratio of water loss to solids loss was similar throughout the storage period for the two treatments. The rates of transpiration and respiration would have to be different, however, to account for such large differences in total weight loss between the two lots. Since the determination was based on percent, it was possible to note a lower amount of solids and water in the control and yet have similar percentages of dry matter in tubers with a great deal more of actual solids and water.

In the case where the dry matter content was higher, the ratio of solids to water loss was altered in favor of greater water loss.

It was intended that from these dry matter and total loss determinations based on twenty individual tubers a more accurate measurement of shrinkage could be obtained by calculating the amount of water and solids lost each month. Preliminary calculations showed that this was impossible, probably because of the fluctuations of dry matter percentages. This strongly indicated that 20 tubers was not a large enough number of
tubers to constitute a representative sample. Individual tubers varied as much as ten percent in dry matter among twenty tubers on one sample date (Table III).

Since sample size affected this phase of study, it is not impossible that too small a sample could have caused the many fluctuations and variations which occurred throughout this experiment.

It is difficult to discuss the results of the effect of tuber treatment with CIPC on certain carbohydrate levels during storage, because the results obtained were not very well defined or consistent. It has been reported (99) that the amount of sugars formed in potatoes during low temperature storage depends on variety, maturity, and pre-storage conditions as well as temperature. The extent of sugar loss which occurred on exposure of potatoes to high temperature also varied with variety and maturity (99). The results obtained in these experiments verify these conclusions. Differences and variations occurred between varieties and growing seasons, in that the same variety showed different contents of sugar and starch and its ability to accumulate or lose them from year to year.

It was reported by others (68, 87, 92, 99, 104, 106) that many varieties of potatoes accumulate reducing sugars during long periods of storage at 60°F. Evidently, non-reducing sugars tend to remain fairly constant while starch content generally decreases. This was the general trend of results obtained from these experiments. Reducing sugars had not accumulated, however, until after five months of storage. The treated tubers reacted similarly to those that were not treated, indicating no apparent effect of CIPC on reducing sugar content.

Non-reducing sugars were present in essentially the same concentrations
at the end of the storage period as they were at the beginning. There was, however, a large accumulation near the end of storage, but these accumulations decreased later. No explanation is offered for these results. Again, fluctuating differences were noted at monthly intervals, but no general or consistent differences or apparent effects of tuber treatment with CIPC on non-reducing sugar content was noted. Total sugars tended to accumulate in the samples during storage while starch content gradually decreased. Again, similar results as to the effect of CIPC were noted. Differences occurred infrequently and showed no consistent pattern throughout the storage period.

The results indicate no consistent effects of tuber treatment with CIPC on the levels of the carbohydrates studied. This could possibly be expected, since CIPC is a mitotic poison affecting only the meristematic areas (80). Evidently, it is not readily translocated from the stem and leaves of potatoes to the tuber as was maleic hydrazide (48, 58). Therefore any effect noted would be indirect through sprout inhibition, although no general effect of the chemical on levels of these carbohydrates was noted in these experiments. It is a possibility that different results might have been obtained showing a more positive effect of CIPC on sugar accumulation had another year's data been accumulated, especially during the latter part of the storage period when some effect might have been found as a result of growth suppression.

The results of respiration studies show that there were no differences in respiration rates between treated and untreated tubers. Red LaSoda tubers, however, showed some differences in respiration rates at 7, 8, and 9 months of storage; however, at ten months the respiration rate of the treated and untreated tubers was the same. It has been shown that
when potato tubers begin sprout growth, the respiration rate increases because of increased metabolic activity in the tissues (104). Yet indications from results obtained in respiration studies by the writer are that control samples which sprouted profusely showed no substantial difference in respiration rate from the treated tubers which were free of sprouts.

If there was no difference in dry matter percentages of treated and control samples, it appears that the respiration rate of the control would have to increase substantially over the treated tubers, since large differences occurred in shrinkage especially in the latter part of the storage period. Still, no such differences in respiration were found.

It may be recalled that the data shown in Figure 30 are expressed as averages of duplicates of only five-tuber composites and that a twenty-tuber sample used in dry matter determinations did not appear to be large enough to be representative.

Another factor to consider is the fact that the potatoes were stored at 60°F. Respiration rates were determined at 28°C. (82.5°F.). It is possible that any differences in respiration rates which might have been occurring at 60°F. would not persist at the higher temperature. In this regard Kimbrough (61) reported that when potatoes were transferred from lower to higher temperatures, there was an increase in respiratory activity, usually of short duration. This increased rate was greater than if the potatoes were stored constantly at the higher temperature.

Based on results obtained from these experiments, it appears that generally CIPC has little or no effect on the cooking quality of the tubers. This was not surprising since CIPC is not believed to be absorbed and translocated into the tuber to any great extent (48, 58). Any effect
would probably be an indirect one, stemming from the sprout inhibiting properties of the chemical. In the case of chip color, after 7 and 12 months of storage, the control usually rated higher than the treated tubers. This also may be the result of an indirect effect. Reducing sugar content was found to be lower in the chips receiving a higher color rating. Talburt and Smith (99) report that dark colored chips are caused by high reducing sugar content along with certain nitrogenous compounds in the tubers. Treated tubers had no sprouts to use up the reducing sugars, thus accumulating it and resulting in darker colored chips. The fact that CIPC treated tubers were equal to or superior to the cooked products of the control in regard to flavor indicates that CIPC causes no off-flavor in these products.

The results showing little effect of CIPC on certain metabolic processes in the tubers are accentuated when correlations were calculated on the various processes. La Chipper tubers when treated showed the same significant correlations in the control as those of the treated lots. This was a good indication of the insignificant effect of CIPC, since these processes were not altered by treatment.

It is difficult to understand the behavior of Red LaSoda tubers which were treated and untreated, as shown in Table X. Two of the three significant correlations were similar in the control. Red LaSoda control had more high correlations than the other variety at the same treatment. It is difficult to interpret the fact that there were less correlations among the treated samples than the control as direct effects of the chemical on the tubers, since all of the other experiments showed very little effects of CIPC on the biochemical and physiological changes that were studied.
SUMMARY

Two varieties of Irish potatoes, La Chipper and Red LaSoda, were used to determine the effect of treatment with the chemical, CIPC, upon certain physiological and biochemical changes in the tubers during storage at two temperatures, 60°F. and room temperature. These included the effect of CIPC on sprouting, shrinkage, dry matter content, reducing, non-reducing, total sugar and starch contents, respiration rates and cooking quality of the tubers. Treatments consisted of dipping the tubers into a one percent water solution of CIPC (emulsifiable form) for one minute. A preliminary test was conducted to determine the best method of treatment. The three methods studied were: (1) only the storage crates or bags were treated and untreated tubers were stored in them, (2) tubers were treated with CIPC solution and then stored into untreated containers, and (3) finally both the container and tubers were treated together and then stored. In this experiment all samples were stored at 60°F.

The results may be summarized as follows:

1. CIPC was shown to be a very effective sprout inhibitor at either storage temperature. Complete sprout inhibition was obtained throughout all of the various tests by using a one percent water solution of CIPC.

2. Preliminary results indicate that any of the three methods of treatment were satisfactory, although this experiment was terminated prematurely because of excessive decay of the treated tubers.

3. In other tests treated potatoes stored at 60°F. remained sprout-free and sound for one year. Neither treated potatoes nor the control
remained sound for long periods of storage at room temperature (75°F.). This was true for both years in both varieties.

4. There were great differences in the shrinkage rate between the treated and untreated samples. The differences were not evident for about four months of storage, after which the control progressively lost more weight. The treated tubers lost at most about six percent of their original weight after one year, whereas the control lost as much as 40-50 percent in some cases.

5. There appeared to be no effect of the chemical on dry matter percentage in the tubers. The control tubers, even though they sprouted profusely and lost much more total weight, generally contained about the same percentage of dry matter as did the treated tubers throughout the storage period.

6. Large variations occurred within a twenty-tuber sample each month in regard to dry matter and shrinkage percentages. On one sampling date, the tubers varied as much as 10 percent in dry matter. There was as much as 11 percent difference in shrinkage from one tuber to another on the same sampling date. This result led to the conclusion that twenty tubers was not a large enough number to be considered a representative sample for shrinkage and dry matter measurements.

7. There was no general effect of treatment with CIPC on reducing, non-reducing, total sugar, or starch content of the tubers. Differences were noted however, occurring irregularly and inconsistently.

8. There was also no apparent effect of CIPC on the respiration rate of stored tubers. Differences observed were small and inconsistent.

9. In regard to cooking quality, CIPC treated tubers were equal to or superior to the cooked products of control tubers in most cases.
On some sample dates the treated tubers made darker colored chips. This led to the conclusion that CIPC causes no off-flavor in cooked tubers, but may have adverse effects on color of chips.

10. Correlations, especially in La Chipper tubers, show that CIPC did not disturb the metabolic processes studied. These processes in treated and untreated Red LaSoda potatoes showed more differences, indicating that the effects of CIPC may show varietal interactions.
BIBLIOGRAPHY


Robert Narcis Falgout was born on June 22, 1939 in Houma, Louisiana. He attended Grand Caillou Elementary School and in June, 1957, he graduated from Terrebonne High School in Houma.

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EXAMINATION AND THESIS REPORT

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Major Field: Horticulture

Title of Thesis: The Effect of Isopropyl N(3-Chlorophenyl) Carbamate upon Certain Physiological and Biochemical Changes of Irish Potatoes During Storage.

Approved:

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