UNITED STATES DEPARTMENT OF AGRICULTURE
BIBLIOGRAPHICAL BULLETIN No. 11

Washington, D. C. Issued December 1949

HANDLING, STORAGE, TRANSPORTATION, AND UTILIZATION OF POTATOES

A digest of information on the subject published mostly from 1938 to 1948

By

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HANDLING, STORAGE, TRANSPORTATION, AND UTILIZATION OF POTATOES[1]

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By DEAN H. ROSE, *senior physiologist,* and HAROLD T. COOK, *senior pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration*

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[1] This digest is a report of a study made under the Research and Marketing Act of 1946. It is the first in a series intended to cover the biology and physical handling of important horticultural crops during the marketing period.

[2] For the sake of continuity a few references of earlier and later dates are cited.

INTRODUCTION

In tonnage produced, potatoes are the most important horticultural crop in the United States, outranking grapes, oranges, apples, peaches, sweetpotatoes, and pears. Figures that show the range in production of these crops are given in table 1 for 1937 and 1947. Potatoes are grown commercially in 47 States and are grown and shipped somewhere in the country every month in the year. (See Rion (*50*),[3] 1945.)

TABLE 1.—*Production of 7 major horticultural crops in 1937 and 1947*

[Figures compiled by Division of Fruit and Vegetable Statistics, U. S. Bureau of Agricultural Economics]

Crop	1937	1947
	Tons	*Tons*
Potatoes	9,547,680	11,532,000
Commercial apples	1,633,000	2,700,000
Oranges	2,776,000	4,327,000
Peaches	1,007,000	1,992,000
Sweetpotatoes	1,436,688	1,572,000
Pears	602,000	869,000
Grapes	2,402,000	3,094,000

Because of repeated surpluses and declining per capita consumption of potatoes, the potato industry in the United States is faced with a variety of problems that are in urgent need of solution. Among the most important are those of furnishing the highest quality potatoes to consumers and of disposing of the low-quality portion of the crop. These are problems primarily concerned with the postharvest handling of potatoes rather than with the growing of the crop. In view of this situation and because the field of work that has engaged most of the attention of investigators is that concerned with production rather than marketing problems the Potato Industry Advisory Committee appointed under the Research and Marketing Act of 1946 has made recommendations for research in the field of marketing and a number of new projects have been started. Undoubtedly others will follow either as a corollary to those already begun or to expand the field of investigation.

The following list of problems, inserted here to indicate the general type of work desired, was recommended by the committee for early attention.

1. Development of new objective tests for fresh stock that will indicate quality after cooking.
2. Storage tests to cover all possible methods of quality retention.
3. The relation of high starch content to cooking quality, particularly with chips.
4. The effect of fertilizers on culinary quality.
5. Investigation of all avenues that may lead to increased consumption.

[3] See p. 22.

6. Development of better methods of cooking and serving potatoes.
7. Additional work on nutritive values of potatoes, especially on food elements besides calories.
8. Dissemination of technical information to advertising and store personnel so that sale of potatoes can be promoted. (Popular versions of such information should also be made available.)
9. Study of the effect on potatoes of low temperatures in transit.
10. Studies on the prevention of shatter bruising and other mechanical injuries of potatoes during handling and shipping.
11. With new potatoes a comprehensive study to ascertain what modified icing services can be used satisfactorily with resulting saving in transportation charges.

In connection with this list of problems it is of interest to consider a chart showing the various ways in which potatoes are now utilized and the estimated quantities so used annually (fig. 1).

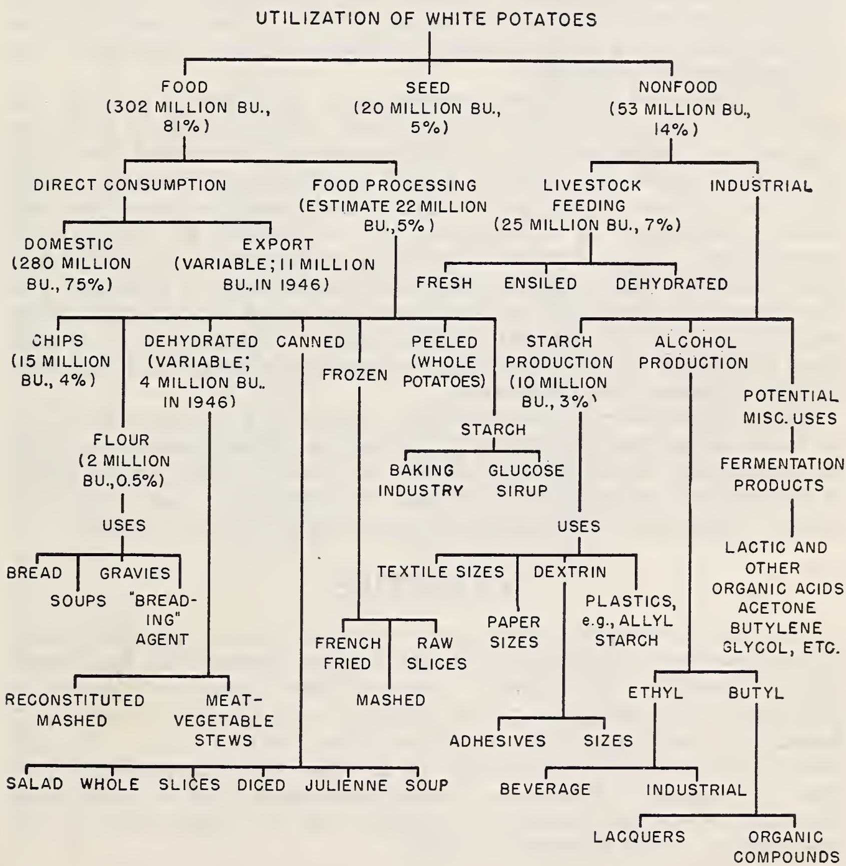

FIGURE 1.—Utilization of normal annual United States crop of potatoes (about 375 million bushels). When data were available the quantity of potatoes and percentage of total production going into each outlet are given. (Chart made by Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture.)

Several specific projects dealing with the general problems just listed have already been started by the United States Department of Agriculture and the State experiment stations. When this work was initiated it was realized that investigators would need to know what research had been done previously on the wide variety of problems of interest to the potato industry. Because the field of research in the program is foreign to that which has engaged most attention of potato investigators heretofore and many of these workers may not have ready access to the extensive library facilities available in the United States Department of Agriculture, the administrative advisors who supervise regional research projects conducted by the State experiment stations recommended that the Bureau of Plant Industry, Soils, and Agricultural Engineering be given the responsibility for preparing a digest of recent literature dealing with the physical handling of horticultural crops in the postharvest period. This resulted in the establishment of a project under the Research and Marketing Act for that specific purpose.

This digest of literature pertaining to potatoes is the first in the series contemplated in this project. In conformity with the requests of the committee of administrative advisors of the State experiment stations, it is purposely confined very largely to the physical and biological rather than the economic aspects that are usually presented in considering the marketing of agricultural commodities. It is further limited by excluding most of the material dealing with fundamental plant physiology of potatoes and the chemistry involved in the manufacture of starch and other industrial products derived from potatoes. To include all of this vast literature would involve an encyclopedic treatment not germane to present requirements.

The aim has been to deal with the subject in a practical way, but to make sure that governing physiological principles are applied as rigorously, so far as the writers are able, as they would be by a competent investigator at work on a problem that might be called without any condescension a problem in pure research.

VARIETIES

Varietal differences are more important during the production of potatoes and after they reach the market than during the operations covered by this digest. Some of them, however, have to be considered here because of their relation to methods of harvesting, handling,[4] cooking quality, transportation, and storage. For reference purposes it is desirable to list the more important commercial varieties of potatoes, the approximate time of year when they are ready for market or storage, and the States where they are grown. This is done in table 2.

[4] The term "handling" is used in this digest to denote the operations that begin with the digging of potatoes and end when they are placed in storage or in a railroad car or other conveyance for transportation to market.

TABLE 2.—*Principal commercial varieties of potatoes, approximate time of year when harvested, and States where grown, 1947* [1, 2]

Variety	Number of States where grown	States growing potatoes for indicated approximate time of harvest		
		Early	Intermediate	Late
Irish Cobbler	36	Arkansas, Delaware, Georgia, Louisiana, Maryland, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia.	Delaware, Georgia, Kansas, Kentucky, Maryland, Missouri, New Jersey, Oklahoma, Virginia.	Colorado, Connecticut, Illinois, Indiana, Iowa, Maine, Massachusetts, Minnesota, Nebraska, New Hampshire, New Mexico, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Utah, West Virginia, Wisconsin, Wyoming.
Triumph (Bliss Triumph)	25	Alabama, Arizona, Arkansas, Florida, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas.	Georgia, Kentucky, Oklahoma	Arizona, Arkansas, Colorado, Idaho, Minnesota, Nebraska, New Mexico, North Dakota, Oregon, South Dakota, Tennessee, Utah, Washington, Wisconsin, Wyoming.
Katahdin	23	Florida, Louisiana, Maryland, Mississippi, North Carolina, South Carolina.	Georgia, New Jersey	Colorado, Connecticut, Indiana, Maine, Maryland, Massachusetts, Minnesota, Nebraska, New Hampshire, New York, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Wisconsin.
Chippewa	21	Florida, Maryland, North Carolina, South Carolina.	Georgia, Kentucky	Connecticut, Idaho, Indiana, Iowa, Maine, Massachusetts, Michigan, Minnesota, New Jersey, New York, North Dakota, Oregon, Pennsylvania, Texas, Wisconsin.

See footnotes at end of table, p. 7.

TABLE 2.—*Principal commercial varieties of potatoes, approximate time of year when harvested, and States were grown, 1947* [1 2]—Continued

Variety	Number of States where grown	States growing potatoes for indicated approximate time of harvest		
		Early	Intermediate	Late
White Rose	17	Alabama, Arizona, California, Louisiana, North Carolina, South Carolina, Texas.	Arizona, California, Nevada	California, Colorado, Idaho' Minnesota, Nebraska, Nevada' Oregon, South Dakota, Washington, Wisconsin, Wyoming.
Green Mountain	15	Arkansas, North Carolina, South Carolina.	New Jersey, Virginia	Connecticut, Delaware, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New York, Rhode Island, Vermont.
Russet Rural	15		Kentucky, Maryland	Colorado, Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, New York, Ohio, Pennsylvania, Utah, West Virginia, Wisconsin.
Sebago	14	Alabama, Florida, Louisiana, South Carolina.	Georgia	Iowa, Maine, Minnesota, Nebraska, New York, North Dakota, Pennsylvania, South Dakota, Wisconsin.
Pontiac	13	Alabama, Florida, North Carolina, South Carolina.		Colorado, Iowa, Maine, Minnesota, New York, North Dakota, South Dakota, Wisconsin, Wyoming.
Russet Burbank (Netted Gem)	12		California	California, Colorado, Idaho, Minnesota, Montana, Nevada, North Dakota, Oregon, Utah, Washington, Wisconsin, Wyoming.
Sequoia	8	North Carolina		Maine, Minnesota, New York, North Carolina, North Dakota, Pennsylvania, Vermont, Wisconsin.

Early Ohio	8			Illinois, Indiana, Iowa, Minnesota, Nebraska, North Dakota, Ohio, South Dakota.
Red Warba	7	North Carolina		Colorado, Iowa, Minnesota, South Dakota, Wisconsin, Wyoming.
Warba	6	North Carolina		Maine, Minnesota, Nebraska, New York, North Dakota.
Calrose	4	California		Minnesota, Oregon, Washington.
Houma	4	Louisiana		Maine, New York, Vermont.
Rural New Yorker No. 2	4			Colorado, Minnesota, New York, Wisconsin.
Teton	4			Maine, Minnesota, New York, Pennsylvania.
Dakota Red	3		Delaware, Maryland, Virginia	
Earlaine	3	Florida, Louisiana	Maryland	
Menominee	3			Iowa, Michigan, Wisconsin.
Burbank	3			California, Oregon, Washington.
Erie	2			New York, Pennsylvania.
Mohawk	2			Maine, Minnesota.
Red McClure	2			Colorado, Wyoming.
Desota	1			Nebraska.
Ontario	1			New York.

[1] Table based on information from United States Department of Agriculture Agricultural Statistics for 1946 (*67*), Farmers' Bulletin 1904 (*28*), Farmers' Bulletin 1958 (*30*), and Circular 741 (*8*) and from members of the Fruit and Vegetable Branch, Production and Marketing Administration, and of the Potato Project, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering. (Italic numbers in parentheses refer to Literature Cited, p. 19.)

[2] Some States are listed in more than one group because they grow and harvest potatoes at more than one season of the year.

HARVESTING, HANDLING, AND MECHANICAL INJURY

DIGGING

Potatoes are harvested in many different ways, ranging from the use of a potato fork or a turnplow to large-scale operations with one- and two-row diggers and harvesters that dig, pick up, and bag the potatoes.

A survey in Maine reported by Schrumpf (*56*) [5] in 1947 showed that two-row tractor diggers were used on 40.0 percent of the farms, one-row tractor diggers on 37.5 percent, one-row horse-drawn engine diggers on 15 percent, and one-row digger combines on 7.5 percent. Operators of large farms used a higher percentage of two-row diggers than did operators of small farms.

All of these may cause injury to potatoes if carelessly used; so the choice of method to be employed should depend on which one causes least injury with the least attention or adjustment and still meets the grower's needs in convenience and economy of operation. Speed of operation—acres dug per day—is also important, but it should never be allowed to outweigh the importance of having the crop as a whole, just after digging, free of serious skinning, cracks, cuts, and bruises. Such injuries lower the value of potatoes for immediate sale by increasing the amount of culling necessary to meet grade specifications. They also increase shrinkage from loss in weight and render the potatoes susceptible to various rots in transit and in storage. (See p. 62 and p. 125.)

The amount of injury that occurs as the potatoes are being dug depends to a large extent on the condition of the soil, the type of digger, and the manner in which the digger is adjusted and operated. (See Hardenburg and Turner (*22*), 1940.)

Level-bed diggers that elevate the potatoes only a short distance above the soil, with minimum drop as they leave the digger, are growing in favor in some sections. (See Edmundson, Landis, and Schaal (*17*), 1945; Slosser (*61, 62*), Maine, 1945; and Werner (*69*), Nebraska, 1947.) They probably would be desirable in many others. The elevator type of digger now widely used is likely to cause more injury than a level-bed digger if it has an extension elevator onto which the potatoes fall from the front elevator. (See Beverly, Libby, and Wyman (*5*), Maine, 1946; and Donaldson, Bourne, and Boyd (*14*), Massachusetts, 1948.)

Metzger (*34*) in Colorado reported in 1938 that horse-drawn diggers injured more tubers than those with power take-off and that traction diggers with shaker at the rear injured more potatoes than horse-drawn diggers with gasoline engines to operate the elevators.

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[5] Italic numbers in parentheses refer to Literature Cited for Harvesting, Handling, and Mechanical Injury, p. 19.

A contour potato digger that is said to operate successfully on 18-percent slopes has been designed and built in Maine. (See Slosser (*60, 61, 62*), 1943 and 1945.)

All types may cause injury if the digger blade is run so shallow that it cuts some of the potatoes and if it does not raise enough soil to cushion the potatoes against bruising as they move along with the conveyor belt. (See Tussing (*66*), Ohio, 1939; Cordner (*10*), Oklahoma, 1943; Hibbard (*24*), Missouri, 1943; Odland and Moran (*41*), Rhode Island, 1943; McCollum, Linn, and Apple (*32*), Illinois, 1944; Beverly, Libby, and Wyman (*5*), Maine, 1946; and Donaldson, Bourne, and Boyd (*14*), Massachusetts, 1948.)

The diggers should have sufficient power to run the blade or shovel deep enough to avoid cutting the potatoes and to carry enough soil to cushion the potatoes against bruising. (See Ellis (*18*), Indiana, 1948; and Smith (*64*), New York, 1943.)

The speed at which the digger moves along the row should be slow enough to avoid violent agitation of the potatoes on the digger chains. In North Dakota Long (*31*) reported in 1944 that the least injury occurred at the rate of 220 to 240 feet per minute, or 5 to 6 minutes for a quarter mile of row. It is generally agreed that the speed should be reduced when the soil is dry and is easily shaken through the belts.

In addition to the forward speed of the digger, the speed of the digger chain and elevator apron should be regulated according to conditions. Smith (*64*) in 1943 stated that if the soil is dry or the tubers immature the digger chain should be run at a lower speed than if the opposite conditions exist. It was recommended by Prince and others (*45*) in New Hampshire in 1943 that the speed of the elevator apron should be the same as that of the forward movement of the digger. Eccentric agitators may be used for extra agitation to aid in separating the potatoes and earth when the soil is wet and sticky. (See Mimms and Woodbury (*36*), Idaho, 1939.) However, they inevitably cause some bruising and skinning and should be removed when they are not absolutely needed.

Adjustment of the apron tension to take up unnecessary slack and padding the shaker bar also will aid in reducing the amount of injury according to Hardenburg and Turner (*22*).

MECHANIZING THE HARVEST

Much interest has developed during recent years in mechanizing the harvesting of potatoes in order to reduce the amount of hand labor required and to speed up operations. Potato combines and machine pickers of various designs have been tried in California, Idaho, Maine, Montana, and North Dakota and in Great Britain. (See National Institute of Agricultural Engineering (*40*), 1944; Monson, Cockrum, and Allaway (*37*), 1944; Beresford (*2*), 1945; Kreiser (*27*), 1945; Beresford and Frost (*3*), 1946; Beverly, Libby, and Wyman (*5*), 1946; Schrumpf (*55*), 1946; Slosser (*63*), 1947; and West (*71*), 1947.)

The harvesters or combines are still in an experimental stage and will require considerable redesigning before they are suitable for general use. However, a considerable number have been developed for specific areas and are being used regularly. There is considerable variation in the different harvesters since many of them are home-designed and custom-made. In general they consist of a digger that digs and elevates the potatoes to a picking belt where they are separated mechanically and by hand picking from earth, weeds, vines, and stones. The potatoes are then bagged at the end of the picking belt or delivered by an elevator into a truck for bulk handling. (See Monson, Cockrum, and Allaway (*37*), 1944; Beresford (*2*), 1945; Kreiser (*27*), 1945; and Slosser (*63*), 1947.)

About 200 custom-built 2-row digger combines were used satisfactorily in Idaho in 1945 for field operations according to Beresford and Frost (*3*), but the handling of the potatoes when transferring them from the bulk trucks into the storage should be improved to avoid excessive injury.

The advantages and disadvantages of a mechanical potato harvester were listed in 1944 as follows by Shelton (*59*), an Ohio grower, after 1 year's experience:

Advantages:

1. Groups labor, making easy supervision.
2. Permits use of labor that is too young or too old to pick potatoes up from the ground.
3. Eliminates danger of sunscald (heat injury, p. 133).
4. In the evening or when caught with rain, all potatoes are in the bag.
5. No delay in the morning.

Disadvantages:

1. More danger of accidents.
2. Does not work well in wet weather because potatoes do not have time to dry before being bagged.
3. If potatoes are being stored, more dirt is put in than if potatoes are picked up by hand from the row.
4. One machine is not enough to harvest much acreage in a day.
5. There is likely to be discontent among people picking from the ground if there is another group working on a harvester, in the same field.

Logan (*29*), another Ohio grower, reported in 1944 that he had been using a potato harvester for 8 years. After using what he described as a rather crude machine for 6 years, he developed and built another that handled potatoes so well that they go into storage in good condition.

In Montana, Monson, Cockrum, and Allaway (*37*) reported in 1944 that the addition of a potato sacker to a power digger made it possible for a crew of 5 men to harvest a crop in about the same time as required by 12 men picking up in the usual way. In Idaho, Beresford (*2*) stated in 1945 that a single-row combine was capable of replacing 7 or 8 pickers and a 2-row machine replaced 10 to 12.

Bulk handling is used in a number of areas to reduce the number of bags and the amount of labor needed. The use of bulk handling in connection with the combines has already been mentioned. In Idaho (*1*) a dump cart with a box about $6 \times 6 \times 2$ feet and capable of holding 90 picker-basketfuls of potatoes has been used. It is mounted on two wheels and hinged at a point 1 foot back of the axle and 2 feet from the back edge of the box. On some of the Kern County, Calif., potato farms the filled bags are lined up in rows across the field as they are filled. Then trucks accompanied by elevator conveyors move down the rows, the sacks are conveyed to the truck-body height and dumped by hand on belts that carry the potatoes into the trucks. The trucks carry the bulk load to the washing and grading sheds where the hinged truck body is tilted so as to dump the potatoes directly into a washing vat.

A mechanical loader for sacked potatoes was described in 1946 from North Dakota by Promersberger, Russell, and Mallow (*46*). When this loader was used, more sacks per man-minute were loaded than when the loading was done by hand. Several commercially built sack loaders are also in use. Although no data are available on the relative amount of damage from mechanical and hand loading it appears that less damage would result from the former since there would be no occasion to heave the bags around.

The National Institute of Agricultural Engineering [of Great Britain] (*39*) published instructions for the care and maintenance of potato diggers, together with a number of detailed diagrams, all of which should be useful to users of such diggers.

Digging is facilitated if it is not done until the vines are dead or nearly so. An alternative method which is being increasingly used in certified-seed areas is to pull the vines and leave the tubers in the ground for at least 2 weeks for the natural maturing process during which the skin becomes toughened enough so that the tubers do not skin easily. (See Lombard, Brown, and Dykstra (*30*), 1948.) Other means of killing the tops are the use of chemical sprays or dusts, flame burners, and rotobeaters. (See Hoyman (*26*), 1948; Lombard, Brown, and Dykstra (*30*), 1948.) One of the English combines is equipped with a vine cutter consisting of a power-driven, knife-bladed rotor mounted just ahead of the digger blade (*71*). (See also Vine Killers, p. 31.)

In early-crop areas, chiefly in the South, potatoes are usually dug before the vines are dead and the potatoes fully matured. The prime object with the early crop is to harvest it as soon as possible, even though immature, and get it onto the market for the higher prices generally paid for new potatoes. Schroeder, Anderson, and Talbert (*53*) in 1938, Hibbard (*24*) in 1943, and Decker, Elmer, and Dean (*11*) in 1944 recommended harvesting the spring crop as soon as mature and before the ground gets hot.

CRACKING

In Nebraska, the Red River Valley of Minnesota and North Dakota, and to some extent in other States, potatoes of the Bliss Triumph variety often crack badly just at the time when they are turned out of the ground by the digger. They are also known to crack in the soil and when being removed from storage for shipment, weeks or even months after harvest. Tubers of the Red Warba, Kasota, and Early Ohio crack less readily than those of Bliss Triumph. Irish Cobbler, Chippewa, Mesaba, Katahdin, and Russet Rural tubers crack only under extreme conditions. Serious cracking was seen in Irish Cobblers of the 1948 crop in Maine. This trouble is caused by the excessive turgidity of the tubers, which makes them unable to withstand shock from any kind of handling without cracking. (See Werner (*68*, *69*), 1931 and 1947; Werner and Dutt (*70*), 1941.)

Cracking at digging time can be avoided or reduced by cutting the roots shortly before harvest. This greatly reduces the water available to the plants so that the tops wilt and the tubers absorb less water or may even lose some. Consequently, they become less turgid and crack much less readily. Most of the benefits to tubers from root cutting are accomplished within a day or two in sunny, windy weather. If the weather is cold, cloudy, or rainy or if the soil above the place where the roots were cut remains wet, root cutting may be of little value. (See Werner and Dutt (*70*), 1941; and Werner (*69*), 1947.)

Roots may be cut with any type of blade that will operate below the tubers. The blade can be attached to a tractor or a digger. Means should be provided for regulating the depth at which it cuts. Other methods of avoiding cracking that are sometimes used in Nebraska, and might be useful elsewhere, are the following: Earlier planting, no irrigation after early September, cultivating deeply or ridging rows late in the season, killing vines by spraying or by cutting them a week or more before harvest, delaying harvest a few days until tubers are less tender, and delaying digging for several hours on cold mornings when the air is much cooler than the soil. However, root cutting is the best and most practical method now known for altering the condition of the tubers so they can be handled with less danger of cracking at harvest (*69*).

FIELD HANDLING METHODS AFTER DIGGING

Late crop.—Late-crop potatoes are usually fairly mature when dug. For this reason they do not skin as easily as immature ones, although in most cases they benefit from being allowed to lie on the ground for several hours after digging before being picked up (*15*). During this delay they have a chance to dry and the skin "sets" and becomes tougher so that they skin less easily than if picked up as soon as dug. They are also in less danger from the cracking and bruising incident to subsequent handling.

Early crop.—Safe and desirable methods for the field handling of early-crop potatoes are quite different in some respects from those recommended for the late-crop. The differences should be clearly understood.

Early-crop potatoes are harvested in warm, often hot, weather. Most of them are immature when dug; consequently, they skin easily and become brown at the skinned places, particularly in dry, windy weather. Because of their immaturity, they are particularly susceptible to heat injury (p. 133) if left lying in the sun too long before being picked up. It is not safe to leave early-crop potatoes exposed to the heat of the sun for more than about 30 minutes on a day when the shade temperature is 90° F. or higher. (See Tussing (*66*), Ohio, 1939; Sellers (*58*), Arkansas, 1940; Cordner (*10*), Oklahoma, 1943; and Rose (*51*), 1946.)

Potatoes that have begun to brown in the field often turn darker in transit and are likely to become sticky with a superficial decay.

Potatoes injured by heat in the field may not be detectable at loading time, but they are in danger of being attacked by bacterial soft rot (a slimy, foul-smelling decay) while in transit. Truckloads of potatoes moving from field to packing house should be kept covered with tarpaulins to prevent browning and heat injury. (See Ramsey and others (*49*), 1944.)

PICKING UP POTATOES

Various methods are used in picking up potatoes. In some sections the picking containers are wooden or metal baskets, either unlined or padded with burlap, and wire baskets the wires of which may or may not be covered with rubber. After these containers are filled, the potatoes are poured from them into field boxes or burlap sacks, which are eventually hauled from the field by truck. In other sections the potatoes are placed in a burlap sack dragged along between the legs of the picker, the sack being unhooked from the picker's belt when it contains 30 to 40 pounds of potatoes. The sacks are hauled from the field with no further filling. (See Metzger (*34*), 1938; Werner (*69*), 1947.) In Maine, potatoes are picked up in baskets from which they are poured into barrels and hauled to the storage house. The empty barrels are returned to the field. In many cases a power hoist is used to lift the barrels from the ground to the truck. (See Beverly, Libby, and Wyman (*5*), Maine, 1946; Schrumpf (*55*), 1946.)

In many sections of the Northeast, potatoes are picked up in slatted crates holding about 50 pounds, hauled to the storage house, and either stored in the crates or dumped into the bins. Edgar (*15*) stated in 1947 that handling in crates is preferable to barrels because less bruising results. (See also p. 14 and the various State publications already referred to.)

V. R. Gardner reported in 1938 that in Michigan mechanical injury to potatoes stored in crates or boxes amounted to only 1 percent whereas it was as high as 16 percent in potatoes stored in bulk (*35*).

Westover and Leach (*72*) recommended picking containers in the following order of preference in West Virginia in 1943: (1) Splint baskets with square, rigid bottoms and wooden bails, (2) wire baskets lined with heavy cloth or canvas, and (3) pails with padded bottoms. Picking up in bags is said to result in a high percentage of injury unless carefully done.

Some workers are quicker and more efficient in picking up potatoes than others. Bierly and Hardenburg (*6*) in 1944 stated that an inexperienced picker made about twice as many moves and picked up less than half as many potatoes as an experienced one. A study in Colorado reported by Paschal (*44*) in 1944 indicated that factors influencing efficiency of pickers are the type of container, use of the hands, and methods of dumping the containers. The use of the picking belt instead of the wire basket was said to enable the workers to pick up 20 to 30 percent more potatoes.

MECHANICAL INJURY

HANDLING DURING HARVESTING, STORAGE, AND GRADING OPERATIONS

The question of where injuries occur during the harvesting, storage, and grading of potatoes is one to which an answer is urgently needed. The answer is given to some extent for some areas by the results discussed herein. Only when similar information is available to a fair degree of completeness for all the chief producing areas will it be possible for growers and shippers generally to make an intelligent effort to reduce the damage that is now so common.

Numerous publications (see the various Federal and State publications already cited or cited under Potatoes in Storage, p. 62) emphasized the need of care in handling potatoes from field row to packing house or storage, in order to keep cuts, bruises, cracking, and skinning to the lowest possible amounts. The authors of these publications pointed out, for example, that potatoes should be placed in containers, not thrown into them; that truck loaders should stand on the bed of the truck, not on the filled sacks or other containers already loaded; and that the filled containers themselves should be set in place, not thrown into place, when loading the truck or when unloading at the packing house.

A study of the marketing of late potatoes reported in 1938 by Park (*42*) indicated that bruises and cuts are among the most common defects in late-crop potatoes on the market. Much of this injury could be prevented by careful handling.

It was reported by Schrumpf (*54*), Maine, in 1933 that 47.81 percent of the potatoes were affected by injuries caused by harvesting and storage operations. Of these 7.1 percent were major injuries that would affect the grade and 40.71 percent were minor injuries. Digging cuts accounted for 0.93 percent. The rest of the injuries were bruises, 2.22 percent of which were caused by picking up in baskets, 8.16 percent by emptying into barrels, 17.38 percent by digging, and 19.12 percent by placing into storage. During storage the percentage of major injuries increased by 2.55 percent.

Also it was found in Maine that the bruising of potatoes caused by moving to graders, passing over the graders, and dropping from the graders into containers averaged 43.56 percent. Major bruising amounted to 7.3 percent and minor bruising to 36.26 percent. The graders caused the largest amount, 20.23 percent, while the next largest, 13.27 percent, was caused by moving to the graders. The smallest, 10.06 percent, resulted from dropping into the containers. For further details, including suggestions about the padding of picking containers, graders, and barrels, the bulletin cited (*54*) should be consulted.

Schrumpf (*57*), Maine, in reporting other figures on mechanical injuries in grading operations in 1947, stated that the average amount of bruising was 0.5 percent grade damage and 6.0 percent minor damage at the hopper of the grader. An additional 0.3 percent grade damage and 7.5 percent minor damage occurred in potatoes passing over the grading table. In packages ready for shipment there was 0.9 percent grade damage and 14.5 percent minor damage. Schrumpf also found that bruising from digging averaged 9.3 percent and from emptying into barrels 4.3 percent. Green Mountain and Sebago varieties each averaged 11.0 percent of bruising. The other varieties, 9.4 percent of which were Katahdins, averaged 8.4 percent.

During the storage operation (putting potatoes in storage) the average amount of bruising in farm storages in the fall of 1945 was about 1 percent of grade injury and in trackside storages less than 1 percent.

Ferguson (*19*) in 1946 reported that in Colorado 12 percent of the potatoes were injured by diggers, 4 percent from the use of wire baskets, 3 percent by handling on unpadded trucks, 8 percent during sorting, and 7 percent from the sorting belts to the car. That is, more than a third were damaged enough to detract from their appearance and favor decay before they left the shipping point.

Parsons (*43*) in 1941 reported that during the 10-year period 1930–39 nearly 55 percent of all lots of Kansas potatoes receiving Federal inspection were listed as having cut potatoes and that in nearly 36 percent of the inspections bruises and other mechanical injuries were listed.

Hastings (*23*) in 1931 stated that approximately 70 percent of all grade defects in North Dakota were attributable to mechanical injury, especially during digging and picking up. In 1948 Schaffner (*52*) in North Dakota stated that of the injuries occurring on potatoes as they reached the storage 28 percent had been caused by digging, 17 percent by picking up, 16 percent by hauling from the field, and 39 percent by unloading into storage. Not all of this mechanical injury could be prevented, but it could probably be reduced by more careful handling.

In West Virginia according to Westover and Leach (*72*) in 1943 it was considered that at least one-third of the crop is usually injured during harvesting and storage and that 20 percent of it is badly injured. A large proportion of the potatoes with only minor injuries are lost during storage.

Poor washing and sorting equipment and bad handling practices were responsible for much of the damage that occurred in Idaho after the potatoes had been hauled from the field, in the opinion of Beresford and others (*4*) in 1944.

Moore (*38*) stated in 1943 that each year a large part of the Michigan crop fails to meet U. S. grade requirements because of mechanical injuries caused by carelessness in harvesting and handling the crop.

An investigation reported by Schrumpf (*57*) in 1947 on the grade quality of Maine potatoes, based on a 10-percent sample of more than 80,000 inspections made by the Federal-State Inspection Service in the 3 years 1942–44 brought out the following facts:

1. Total grade defects of the potatoes under consideration over the 3-year period averaged 4.82 percent, made up of 3.52 percent external and 1.3 percent internal. One-third of the external defects (1.6 percent) were bruises and cuts; about one-fifth (0.93 percent) were sunburn (light greening), and the

remaining 2.3 percent were various rots, growth cracks, and other minor defects, none of which accounted for more than about 0.2 percent. Internal defects consisted of net necrosis, hollow heart, and others of less importance.

2. The percentage of defects increased through the shipping season in each of the 3 years. Total defects increased from an average of 4.29 percent in the fall to 4.77 percent in the winter and 5.22 percent in the spring. The most pronounced progressive increase from fall to spring was in bruises and cuts.

In total defects the Green Mountain and Irish Cobbler potatoes with 5.68 percent and 5.92 percent, respectively, considerably exceeded Sebago, Katahdin, and Chippewa with 4.27 percent, 3.74 percent, and 2.91 percent in the order named. In all these analyses of the Maine data bruises and cuts ranked first.

Edgar, Jefferson, and Wheeler (*16*) reported in 1945 on tests in Michigan to determine the loss caused by grading. Three varieties, a lot each of Russet Rural, Katahdin, and Chippewa, were harvested and then stored field-run in picking boxes. When these potatoes had been in storage 30 days, one-half of each lot was graded and returned to the boxes. The remaining half of each lot was not disturbed. At the end of the storage period each lot was graded again, which means that half of each lot was graded twice. There was 6 percent more No. 1 potatoes at the end of the storage season from the lots of potatoes graded only once than from those graded twice.

Pullen (*47, 48*) in 1943 and 1944 reported the results of an investigation on grade defects of potatoes sold at wholesale on the Buffalo and Rochester, N. Y., markets during the 1940–41 and 1941–42 seasons. He found that total grade defects could be broken down into three classes: (1) Rot and frost injuries, (2) serious damage of such nature that 10 percent or more of the potatoes would be wasted in preparation for cooking or other processing or that it seriously impairs the appearance of the product; and (3) other damage, which results in a waste of 5 to 10 percent of the potato or materially impairs its appearance. Rots, frost injury, and other serious damage comprised about 25 percent of all damage. "Other damage," made up of bruises, cuts, scab, growth cracks, sunburn, sunscald, misshapen tubers, etc. represented about 75 percent of the total defects. In Pullen's opinion a substantial reduction of such damage may come through careful digging and handling, the use of better seed stock, and better production practices. Rot and frost injuries, although the most difficult to control, may be reduced by (1) better control of blight through spraying, (2) earlier digging, and (3) improved storage facilities.

It should be noted, however, that there are, besides late blight tuber rot, other important rots, such as fusarium rot and bacterial soft rot, and that these can be decreased by reducing mechanical injury and the length of exposure of potatoes to heat injury in the field. It is true, of course, that bacterial soft rot sometimes follows late blight tuber rot. (See Diseases, p. 125.)

Pullen found that muck-grown potatoes have considerably fewer grade defects than upland-grown potatoes, but he made no suggestion as to possible reasons for the difference.

Careful supervision of the labor throughout the harvesting, storing, and preparing of potatoes for market is necessary to insure more careful handling. Close (*9*) in Oregon in 1947 recommended frequent and detailed inspection of the produce during the various steps as an aid in detecting the place where injuries are occurring. Numerous other investigators advised the padding of diggers at all places where potatoes are likely to be injured by a drop or by striking against sharp edges or corners of the machinery. (See also the State publications cited on p. 8.)

Beresford and others (*4*) stated in 1944 that it is also important that field trucks and transport trailers be padded. Old sacks and carpets have been used effectively in padding the trucks. Beresford and others (*4*) pointed out that the amount of injury is sometimes proportional to the number of times potatoes are handled, and Bird (*7*) in Tennessee in 1942 stated that each bushel is lifted five or six times during usual handling.

Handling into and out of storage has been shown to cause considerable damage. In Maine, Merchant (*33*) in 1947 reported that nearly 0.3 percent major and 5 percent minor bruises occurred when potatoes were shoveled into barrels or onto graders. He also stated that there were an average of 0.9 percent major injury and 14.5 percent minor injury from grading. Damage at the hopper amounted to 0.5 percent major and 6 percent minor damage. An additional 0.3 percent major and 7.5 percent minor damage occurred when the potatoes passed over the grading table. West (*71*), in discussing grading machines used in Great Britain, commended American graders because rubber is used extensively on them and the potatoes are protected from uncovered metal parts. Unfortunately only part of the American graders possess these improved features. There is still room for more padding of sharp edges on the graders and the elimination of excessive drops from one part of the machine to another. (See also p. 24 of this digest.)

In some storages the potatoes are handled by means of an elevator that consists of a belt conveyor and hopper mounted on a carriage that regulates the height of the belt and makes the unit portable. This equipment makes possible rapid and careful handling of the potatoes. The slat-bottom hopper allows the dirt to sift through as the potatoes are put in storage. In one lot in Michigan, Wheeler, Linebaugh, and Jefferson (*73*) reported in 1941 that approximately 1½ pounds of dirt per bushel was removed.

When it is necessary for the workers to stand on the potatoes in the bins as when they are being filled through canvas funnels or by sliding the sacks down boards, their shoes should be thoroughly cushioned by wrapping in cloth or they should wear shoes soled with sponge rubber.

HANDLING FROM SHIPPING POINT TO CONSUMER

Unfortunately the prevention of mechanical injury to potatoes during the operations prior to shipment is only part of the story. Four investigations, one in the West and three in the East, have shown that appreciable and sometimes serious damage is done after potatoes leave the shipping point.

In 1940 and 1941 the Oregon Agricultural Experiment Station, in cooperation with the State Department of Agriculture undertook to study the problem of maintaining the quality of potatoes from shipping point to consumer (*12, 13*). As stated by DeLoach (*12, p. 3*) in 1942, reporting the results of the work done in 1941:

The Station Project included a survey and sampling of the 1941 crop year potatoes found in 200 retail stores selected at random in Portland, Oregon, and in the cities of the San Francisco Bay [Calif.] area. The investigators took a representative sample of the Oregon potatoes offered for sale in each store, graded the potatoes, compared the actual grade with the stated grade, classified the defects, and attempted to establish the cause of specific types of defects that were found in the individual samples.

Sampling of Oregon-grown potatoes in the 174 retail markets in Portland and the San Francisco Bay area in 1940 disclosed that 47.6 percent and 65.1 percent, respectively, of the samples fell below the grade marked on the containers in which they were being sold. A similar sampling in 1941 showed that 38.8 percent of the Portland offerings and 26.3 percent of the San Francisco Bay area offerings were below the stated grade. The marked improvement in quality in markets in the San Francisco Bay area in 1941 appeared to have resulted mainly from better handling that came with the increase in unit value of the offerings in that year.

The chief causes for the deterioration in quality in these samples in 1941 were the following:

1. *Broken potatoes.*—This type of injury was found in slightly more than one-half of the samples taken in the Bay markets and slightly less than one-half of the samples taken in the Portland markets. This damage must have occurred after the potatoes left the shipping point and undoubtedly was caused by rough handling by truckers and by clerks in the stores.
2. *Light greening.*—The excessive amount of light greening, 11.8 percent of the samples in the Bay area and 18.6 percent of those in Portland, shows that merchants were not familiar with the effect that exposure to light has on potatoes.
3. *Dry rot and soft rot.*—These rots result principally from faulty handling and storage practices. (See Diseases, p. 125.)

It would be interesting to know to what extent the differences found between potatoes in the two cities were the result of the rather common practice of shipping the best of the crop to distant markets and the poorer quality stock to nearby markets.

An investigation of the condition of potatoes at shipping point and in Boston, Mass., wholesale and retail markets, reported by Hincks, Spangler, and Sprague (*25*) in 1941, showed that most of the damage found in Maine potatoes inspected in Boston retail stores was present when they left the shipping point. Some additional mechanical injury was caused during the process of distribution, most of it occurring between the wholesale warehouse and the retail store, or in the retail store itself. With reference to this phase of the marketing process, Hincks, Spangler, and Sprague (*25, p. 14*) commented as follows:

Dropping or tossing of bags of potatoes from platform to truck, piling on crates of other merchandise, poor piling which later results in bags falling from the load, or dragging bags along the floor and into the truck all contributed to increased damage.

Unloading at retail stores by dropping through the basement window, dropping other merchandise crated or bagged on the potatoes, sliding potatoes and other packages into the basement of stores, piling crates on top of potatoes in the storage room, and walking over the potatoes are all factors that contribute to increased damage.

Hardenburg (*20*) in 1937 reported the results of an analysis of grade defects of potatoes on the Cleveland, Ohio, market. He found that in samples collected in stores tubers bruised but not damaged had increased nearly 60 percent by weight over those found in the car; both the damaged and the seriously damaged had increased to more than four times those found in the car. He stated (*p. 116*):

It must be concluded from this study that not only is mechanical injury the most serious defect in potatoes marketed in Cleveland, but also that more than half of the injury results from the present methods of handling after they arrive on track.

In an investigation reported in 1938 Hardenburg (*21*) found that retail-store samples of potatoes purchased in Cleveland, Ohio, and Rochester, N. Y., showing serious damage from tuber bruising represented nearly two-fifths of the total damage from all causes. Bruising damage was higher in potatoes offered for sale by chain groceries than by independent groceries and fruit and vegetable stores and least in potatoes used by hotels, cafeterias, restaurants, and hospitals. Green Mountain showed more injury than any other variety studied.

Spangler (*65*) during the period from late September 1939 to July 1, 1940, made a study of retail-trade practices and preferences for late-crop potatoes in Chicago, Ill., and suburbs. He covered a much wider field than is under consideration in this section of the present digest. Some of his conclusions are of interest, however, in their bearing on the problem of mechanical injury to potatoes. He stated (*p. 52*), for example:

Mechanical injury was named as the most serious defect of potatoes by the majority of retailers because it is most common and causes more waste than any other defect. "Dirty" was listed as the next most serious complaint against potatoes, particularly those from nearby northern producing States. . . Such defects as sunburn, second growth, growth cracks, hollow heart, scab, etc. were seldom mentioned by retailers as serious defects, probably because most lots of potatoes are packed to meet requirements of U. S. No. 1 grade and such defects are not present in sufficient quantities as to be objectionable.

He further stated (*p. 54*):

As evidenced by freshness of injury, about 41 percent of the 100-pound sacks of potatoes showed handling damage in delivery to the retail stores ranging from less than 1 percent to over 5 percent; the remainder showed no increase in such damage. On the average, consumer packages showed much less handling damage to the potatoes than those in 100-pound sacks probably because truckers and handlers did not allow the smaller packages to fall heavily on floors.[6]

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GRADING, WASHING, AND WAXING

GRADING

Grading is the operation in which the effects of all the prior treatments to which potatoes have been subjected first become clearly evident. It is sometimes done at small field sheds but gives much better results if done at a large central packing house, especially if the potatoes are washed first. Careful grading is definitely worth while. It is true that strict adherence to grade specifications will eliminate potatoes that the grower or shipper would like to sell. It is also true that grading is one of the best ways known to enforce careful handling on both grower and shipper. On the other hand, laxity in applying the grades allows many potatoes to pass that should not and causes buyers to discriminate against the pack when it reaches the market. Cuts, bruises, and skinning are not the only grade defects but, as was shown by the work reported from Maine and elsewhere, they are more important than any of the others usually encountered. (See pp. 14 to 17.)

Potato graders of the type used for grading most of the commercial potato crop consist essentially of (1) a hopper or belt in or on which the potatoes are poured, (2) a sizer which separates the No. 1, No. 2, and cull potatoes, (3) a picking belt or a table where the defective potatoes and extraneous matter are removed, and (4) a sacking arrangement.

The graders vary in size and complexity from fairly simple home-made machines, as described by Rambo (*6*) [7] in Arkansas in 1943, to large complicated commercially manufactured equipment. Some include washers, dryers, fungicidal baths, and waxers. The choice of a machine will depend on the volume of potatoes that are to be processed and on how much interest there is in producing a quality pack. Many machines now in use cause an unnecessary amount of mechanical damage to the potatoes because of the design or the manner in which they are operated. An attempt has been made to eliminate the causes of mechanical damage in some of the newer machines, but there is still much to be done.

Much of the damage during grading is caused by sharp and rough edges on the hopper, shallow cleats on the elevator belts, or overloading of the elevator belts so that the potatoes tumble back, excessive agitation over metal sizing belts, numerous and steep drops from one belt or section of the grader to another, and unnecessary roughness in filling, shaking (zigging) down, and handling the sacks. Padding or lining the sharp and rough parts

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[7] Italic numbers in parentheses refer to Literature Cited for Grading, Washing, and Waxing, p. 29.

of the hopper and grader with rubber and close supervision of the handling of the potatoes and operation of the machine will eliminate much of the damage caused in grading. Slight modifications in design will also aid.

If the grading belt is run too fast, people doing the sorting are very likely to miss potatoes that should be discarded as culls. The same thing may happen if the belt is so narrow that the potatoes are crowded closely together as they pass the sorters. If there are places in the washing and grading equipment where potatoes make an excessive drop, cuts, bruises, and skinning are likely to result. It is much better to have the graders so built that potatoes will roll, not drop, from one part to another. Padding of sharp edges that the potatoes might strike will also do much to prevent injury.

Observations by United States Department of Agriculture representatives, and doubtless by others, have shown that the grading machines themselves may cause injury. For that reason it would be well for packing-house operators, as well as persons investigating the prestorage handling of potatoes, to check up occasionally on what happens to potatoes during grading.

Packages.—The commonest container in which potatoes are marketed is the 100-pound burlap sack, but recently the 50-pound size has been growing in favor. Bushel baskets and paper sacks holding 50, 25, and 10 pounds are also used. One disadvantage of the paper sack is that potatoes in it are difficult to cool because it is fairly impervious to air movement. Slow cooling favors decay, as has been shown in numerous tests conducted by the Bureau of Plant Industry, Soils, and Agricultural Engineering and various States. (This is especially undesirable with the early crop, but is not much of a factor in the handling of the late crop.) Probably the commonest objection to paper sacks is that they are unable to withstand moisture remaining on potatoes that have been washed or occasioned by freezing or rot. "Wet strength" paper bags withstand moisture, the chief objection to them being that they are likely to come apart at the seams when wet unless moistureproof glue is used. During World War II, when it was frequently necessary to use cotton sacks, light greening was found to be worse in them than in burlap or paper sacks.

Packing.—Packing (filling the containers) should be done with as much care as is recommended for all the preceding operations. It is obviously a waste of time and effort to take all possible care in the field and during the washing and grading operations and then to damage the potatoes by throwing or carelessly dumping them into the sack or other shipping container.

Bracke in Germany (*2*) reported in 1939 that the most satisfactory speed of a grading (or sorting) belt is 40 cm. per second (8 feet per minute). The thickness of the layer of potatoes on it, at this speed, should be 7 to 8 kg. per $m.^2$ (16.5 pounds per 10 square feet) and the breadth of the band of potatoes for each person 45 cm. (1.5 feet). Better grading (sorting) is accomplished with the larger potatoes.

WASHING

Washing potatoes on a commercial scale began in this country about 1933 or possibly a year or two earlier, according to a statement by Vincent and Garver (*9*) of Washington in 1936. So far as can be discovered, it was first practiced in California and Washington but it is now used in all parts of the country.

Potato washers are of many different types, varying from simple, home-made affairs to large, fairly complicated installations. The washers are essentially the standard type of potato grader in which a presoaking vat has been substituted for the hopper, spray nozzles have been installed over the elevating belt, and an extra belt or roller conveyor with spray nozzles has been inserted either before or after the sizer. In some areas various types of drying tunnels are installed just before the picking table. Drying is done by means of fans and either infrared lamps or steam-heated hot air.

Injury can occur when potatoes are dumped onto the conveyor belt leading up to the washer and also from attempts to crowd the conveyor and washer beyond their optimum capacity and from rough handling at the grading belts or in filling the shipping containers.

One of the earliest investigations of the effect and value of washing potatoes was conducted by Vincent and Garver (*9*), of the Washington Agricultural Experiment Station, from 1933 to 1936. On the basis of these investigations it was stated (1) that washed potatoes will keep as well in storage as unwashed ones; (2) that washed potatoes are easier to grade because of the ease with which defects can be seen when potatoes are clean; (3) that washing has a precooling effect on potatoes, thus helping to reduce spoilage in transit; and (4) that washing improves the appearance of potatoes, so that they are more attractive than unwashed ones when placed on the market. It should be noted here that potatoes are not ordinarily washed before storage, but rather as they are prepared for shipment.

Little work has been reported on whether washed potatoes should be dried before shipment or may be shipped wet or at least moist. Tests by the United States Department of Agriculture in Alabama with potatoes that were washed and then shipped wet and others that were washed and then dried before shipping gave contradictory results. In the work by Ramsey and others (*7*) in 1941 and 1943 in central Nebraska with early potatoes that were washed and not dried or dried only slightly, it was shown definitely that such potatoes can be delivered on the Chicago, Ill., market in good condition if they are given adequate refrigeration in transit, furnished by initial icing, and if they were not subjected to adverse conditions during or after harvesting. The same has been found true for early potatoes shipped from Hastings, Fla., Kern County, Calif., and other sections. However, in Dade County, Fla., where a considerable part of the potato crop is dried with warm air after washing, it was claimed by Ruehle (*8*) in 1940 that this drying is very effective in preventing decay in transit.

A new method of handling potatoes used in Kern County, Calif., in 1946, which eliminated the handling and dumping of field sacks at the packing shed was claimed by carlot receivers to be the cause of heavy transit loss of the tubers due to break-down. The potatoes were bulk-hauled from the field in trucks and trailers and dumped mechanically into large vats of water at the packing sheds. The poor condition of the tubers on arrival at market was apparently due to their submersion in the water, because this tank treatment was the only essential divergence from the handling method previously used. The bulk-handling vats were 8 to 12 feet deep and large enough to hold several truckloads at once. They were constructed with the sides sloping to the bottom to feed an elevator conveyor connecting the vat to the grading belt. The vats were filled with water, and the potatoes were dumped directly into them by elevating one side of the truck.

Investigations by Dewey and Barger (*3, 3a*), of the Bureau of Plant Industry, Soils, and Agricultural Engineering, showed that the break-down reported at destination was probably caused by rot-producing bacteria in the wash water that were forced into the lenticels of the potatoes by the hydrostatic pressure resulting from deep and prolonged immersion in the vats.

On the basis of these findings, the following recommendations were made (*3, p. 9*):

(1) Shallower water depths should be used in the vats. This may be accomplished by redesigning the vats or by using the same vats with less water. It is probable that the potatoes should never be submerged more than five feet below the water surface.

(2) The quantity of tubers dumped into a vat at one time should be small enough to insure immediate movement through the vat and into the elevator. Particular care should be taken to prevent the potatoes from lodging in the corners of the vat and remaining in the water for a considerable period of time. Before shut-downs in operation, such as during the noon hour, it would be advisable to empty the vats of tubers.

(3) Sanitation should be practiced to prevent an accumulation of rot organisms in the vat water. This means that the water should be changed completely at least once each day, and preferably twice or oftener as operations permit. The treatment of the water in the vat with chlorine as practiced by commercial concerns seemed to provide satisfactory sanitation during the 1947 season.

Bulk handling was used in Kern County in 1947 and again in 1948, but with an antiseptic added to the wash water.

McLean (*5*) in 1940 stated that growers have sometimes felt that washing is a detriment to the potato industry because it makes them sell their low-grade potatoes at a discount. It should be remembered, however, that if a carload of potatoes grades 85 percent U. S. No. 1 at the time of loading the price it brings is likely to be depressed out of all proportion to the 15 percent (presumably) of No. 2 potatoes that it contains. A strictly U. S. No. 1 carload should, and usually will, bring enough more to make up for the No. 2 tubers that have been culled out. This desirable difference cannot all be credited to the washing but is partly due to the standardization that accompanies it. McLean (*p. 548*) expressed the belief that—

The practice of paying for ones and twos at the end of the grader will undoubtedly increase, and with it will increase the premium paid for good potatoes.

White (*11*) stated in 1941 that the principal advantage obtained from washing was the ability of growers and shippers to pack a better grade of attractive, clean potatoes than can be packed without washing. Such potatoes are more in demand on the market because of their appearance. The principal objection when potatoes were properly washed and dried was the high cost of washing or the lack of sufficient premium. Some growers and shippers objected to the heavier culling because of the more readily visible blemishes. White did not indicate that growers and shippers objected to the drying but merely felt that it should be done effectively.

White (*10*), reporting in 1940 on problems affecting the marketing of North Carolina potatoes, made the statement that in 1939 North Carolina potatoes reached market showing entirely too great a percentage of break-down in transit. This break-down he ascribed to the presence of numerous mechanical injuries caused by rough handling all the way from the harvest to the finished load and to too long exposure to heat in the field after digging. The author pointed out (this was more than 8 years ago) that the washing of potatoes was then definitely on the increase and that whether North Carolina growers liked it or not they would have to accept washing in order to meet competition from Florida, Alabama, California, Texas, and other States which even then were washing a large proportion of their potatoes. He believed also that washed potatoes need to be dried before shipment but must be kept at a temperature below 70° F. if rot and other deterioration are to be prevented.

Belkengren and Cieslak (*1*) investigated the effect of heat drying on the periderm of washed potatoes, using samples obtained from commercial potato-drying installations and potatoes dried in a laboratory oven. They reported in 1942 an increase in periderm thickness amounting to 0.83 cell layer in tubers of Bliss Triumph dried for 8 minutes at 145.4° F. and of 1.44 cell layers in tubers dried at 173.3° for 4 minutes. These figures are averages of 1,400 measurements made 72 hours after treatment on tubers dried in a laboratory oven. Recently harvested Bliss Triumph potatoes treated in a commercial potato drier and shipped to the laboratory showed an increase of 2.1 cell layers in one lot and of 1.06 in another.

The differences just reported are rather small. They might not prove to be significant if the data were analyzed statistically. It is possible that they resulted from natural variation in the number of cell layers in potato periderm although no available figures show that such variation occurs or how great it may be.

The thicker cell walls that were found in the periderm of heat-treated potatoes were attributed to increased suberization, but no proof of this was given and no statement was made in the paper that well-known staining tests for suberin were tried on such walls. The results were presented in the paper as an explanation of the benefits (mainly the prevention of rot in transit) claimed to result from heat drying southern potatoes prior to shipment.

The subject of washing potatoes is so important that further investigation is highly desirable. Especial attention should be given to determining (1) whether washed potatoes can be shipped wet or must be dried before shipment; (2) whether the drying should be done with heated or unheated air; (3) what temperature gives best results, if the air is heated; and (4) whether and under what conditions washed potatoes, wet or dried, need refrigeration in transit.

WAXING

Hardenburg and Platenius (*4*) in 1939 reported that treating seed potatoes with a 30-percent 231-B wax emulsion while dormant stimulated sprout growth, earlier emergence of plants, and a corresponding increase in yield. The benefits apparently resulted from conservation of moisture and sprout stimulation in the treated tubers.

A wax treatment was applied to some shipments of Kern County, Calif., potatoes in 1947. It was tried again in 1948 but was discontinued early in the shipping season because shippers found no particular benefit from waxing and they objected to the excessive feathering caused by the waxing brushes.

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VINE KILLERS

As already mentioned (p. 11), certain chemicals are used in many potato-producing areas to kill the vines and so advance the date of harvest. This is done in order (1) that growers of certified seed may ship to Southern States and Cuba for early-fall planting, (2) that harvesting may proceed before the onset of inclement weather, and (3) that leafhoppers will not spread virus infection to seed potatoes late in the season.

Fernow and Smith (*2*),[9] of New York, in a War Emergency Bulletin published in 1944 made a useful statement on the conditions under which it may be desirable to kill potato vines. These conditions may be summarized as follows:

1. Shortage of labor and equipment which makes it necessary to start digging before normal maturity.
2. Presence of late blight.
3. Potatoes becoming too large to be readily marketable.
4. Potatoes beginning to make second growth.
5. Danger that virus diseases may be disseminated.

Killing of the vines may cut the yield, but this is sometimes of less importance than danger of loss from early freezes, rot, second growth, scab, or oversize tubers.

USE OF VINE KILLERS IN THE UNITED STATES

Kraus (*5*) in work with vine killers in Idaho used 1- and 2-percent Sinox sprays, Sinox dust, and a Sinox-oil dust mixture. All of these killed the vines in 24 to 48 hours after application and reduced the amount of feathering of the tubers. The most effective treatment seemed to be Sinox dust. As in earlier work in Idaho, little if any reduction in yield was caused by killing the vines. Kraus believed that the degree of such reduction, if it occurred, would depend on the maturity of the vines at time of application.

A number of other investigators have worked on the problem and have recommended several chemicals as giving satisfactory killing.

Otis (*9*) in 1946 found that dusts could not be recommended for eastern Oregon because of the low humidity there. Ammonium thiocyanate, copper sulfate, Sinox General, and Dow Contact Herbicide as sprays are suggested.

Hoyman (*3*) in North Dakota in 1947 stated that in the absence of dew dusts were not effective. American Cyanamid Co. Weed Killer A (37½–50 pounds per 100 gallons) was the most rapid killer. Dowspray 66 Improved (2 gallons per 100 gallons) was more effective when 2 pounds of ammonium sulfate was added. The discoloration found in and near the vascular tissue of the tubers may or may not be a direct effect of the chemical, because

[9] Italic numbers in parentheses refer to Literature Cited for Vine Killers, p. 33.

mechanical cutting of the vines also produces this effect. The amount of discoloration was correlated with the rapidity of kill and was less when applications were made later in the season. Hoyman (*4*) stated in 1948 that the type of discoloration found in potatoes sprayed with Dowspray 66 Improved is not the same as the stem-end browning described by Ross and others (*11*) in 1945 and by Ross (*10*) in 1946 in Maine-grown Green Mountain potatoes or the discoloration caused by species of *Fusarium*.

Kunkel (*6*) found in 1947 that in Colorado mechanical methods such as top pulling or cutting or undercutting of roots have disadvantages under some conditions and with some varieties. Dowspray 66 (2 gallons per 100 gallons) and Sinox (2 gallons per 100 gallons plus 10 pounds of ammonium sulfate) when applied at the rate of 100 gallons per acre killed tops in about 3 days and showed most promise. Both materials induced browning or discoloration at the stem end, but the general effect was not clear as sometimes more discoloration occurred when vine killers were not used.

In some parts of the country a device known as a rotobeater is used; this beats or thrashes the vines and leaves to pieces. By many it is believed to be about as effective as chemical vine killers. Flaming of vines is another method sometimes practiced.

Further research is needed to determine to what extent vine killers are responsible for stem-end browning and what effect they have on the cooking quality or food value of potatoes from treated vines and on the value of such potatoes for processing.

In Maine, Steinbauer (*13*) reported in 1947 that several petroleum fractions that were tested as vine killers are too expensive unless special equipment can be built, or used if already available, that will give complete vine coverage with a smaller volume of spray material than has hitherto been used.

Hoyman (*4*) reported in 1948 that in the Red River Valley of North Dakota weed killer 1 (potassium cyanate), Sinox General (dinitro-ortho-secondary-amyl phenol) with ammonium sulfate and diesel oil, and Dowspray 66 Improved (dinitro-secondary-butyl phenol and mineral oil) with aluminum sulfate have given the most rapid killing when used as sprays. Pulverized AERO Cyanamid dust gave a slow kill, especially in the absence of dew. A tractor-mounted, hammer-mill type of vine chopper was also used to destroy the vines; this is the same type of machine as the rotobeater used in several other potato-producing sections. (See p. 11.)

The discoloration found in potatoes harvested from treated vines was positively correlated with the rapidity of kill and was less when vines were killed as they approached maturity. (Growers in North Dakota have observed that stem-end discoloration following killing of the vines is worse some years than others, but they do not profess to know the reason for the difference.)

Kunkel, Binkley, and Edmundson (*7*), in work with vine killers in Colorado, reported in 1948 that Dowspray 66 plus aluminum sulfate was the most effective and Dowspray 66 plus copper sulfate almost as good. Killing the vines 2 weeks prior to harvest resulted in significantly poorer color, lower specific gravity, and a decrease in the percentage of dry weight of the tubers over 2 inches in diameter. Killing the vines of Bliss Triumph 2 weeks before harvest had no significant effect on any of the factors measured —yield, grade, color, and specific gravity—a month after harvest.

McGoldrick and Smith (*8*) reported in 1948 that in field trials in New York State Penite 6 plus an activator resulted in the most efficient killing of potato vines. Dowspray 66 Improved, Penite 6 without activator, sizz flame, Sinox General, Cyanamid X-5, and Cyanamid X-1 gave satisfactory kills. The last two were especially effective on the leaves. Vine killing resulted in lower yields in rapidly killed plots than in controls or poorly killed plots; it also caused a decided increase in discoloration of the vascular region and a decrease in specific gravity of potatoes from killed vines.

USE OF VINE KILLERS IN ENGLAND

Samuel (*12*) in 1944 and an unsigned British paper (*1*) in 1945 mentioned several chemicals that were being used in England for vine killing; among these were sulfuric acid, sodium chlorate, calcium cyanamide, a mixture of copper sulfate and salt, and tar-distillate washes. The last was satisfactory but slow in action, requiring 10 to 14 days to kill the leaves. It was pointed out that vine killing is a most valuable aid in protecting potatoes from late blight infection at digging time, especially in a wet fall. If killing is done too early, the yield may be greatly reduced. Even as late as September (in England) crops with green tops can put on more than half a ton of tubers per week. On the other hand, if vine killing is done too late it may not give the desirable protection from late blight.

Wilson and Boyd (*14*) in 1947 mentioned, as vine killers used in England, calcium cyanamide, dinitro compounds, tar-oil washes commonly used as dormant sprays for fruit trees, and tar acids. As an emulsifier for the last they found a mixture of gum arabic and casein effective. It not only provides a stable concentrate but also imparts a water-resistant property to the spray that is particularly useful in wet weather. The cost, however, is about four times as much as for sulfuric acid and the mixture is only about 90 percent as effective.

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PRECOOLING AND TRANSPORTATION

LATE CROP

Late-crop potatoes are transported to market in trucks, boxcars, and refrigerator cars, the last usually without ice in the bunkers. The chief concern of shippers in nonfreezing weather is, or should be, to use loading methods that keep shifting to a minimum and allow enough air circulation through the load to prevent accumulation of the heat produced by the potatoes and to take advantage of cool night temperatures.

During the months when freezing temperatures can be expected, potatoes being hauled in trucks, either direct to market or from storage to a railroad car, may need protection from the cold such as may be afforded by a tarpaulin thrown over the load. Precautions against freezing while a truck or car is being loaded are of course indispensable.

Tests conducted by Mallison[10] and by Haller and Johnson[10] have shown that shipments moving by rail in freezing weather should be protected by heater service if it is available. Preheating cars before loading has been found desirable for shipments moving during severe weather from Maine to Boston, Mass., and other markets farther south or west.

EARLY CROP

Early potatoes are highly perishable and often need to be protected by refrigeration while on the way to northern markets. It is evident from research to date (Rose (*11*),[11] 1946, and literature cited therein) that no one type of service can be recommended for the transportation of early potatoes from all parts of the country. The following quotation from Rose (*11, p. 35*) summarizes the recommendations of the Department of Agriculture on this subject:

> The type [of service] needed for good delivery to market will depend very largely on local conditions, particularly the weather at digging time and that through which the shipment is likely to pass while en route to destination.
>
> In southern Florida early potatoes are harvested from December to May, usually in relatively cool weather, and move to market through weather that grows increasingly cooler the farther north they go. As a rule, therefore, they can be shipped satisfactorily under standard ventilation except during periods of unseasonably warm weather. Even then initial icing only will usually be sufficient, since the vents can be opened as the car moves into colder territory northward.
>
> The same methods are usually satisfactory for northern Florida, southern Alabama, Mississippi, Georgia, Louisiana, and southern Texas, where potatoes are dug and shipped in weather not much warmer than that in southern Florida, except possibly toward the end of the season. At that time or if the transit period is longer than 2 or 3 days, an initial icing may be desirable.
>
> Along the Atlantic seaboard from the Carolinas northward the weather at potato-digging time is much warmer than in the earlier districts. This brings a correspondingly greater hazard in getting shipments to distant markets, particularly because the weather through which they must pass en route to

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[10] Unpublished reports on file in the Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.

[11] Italic numbers in parentheses refer to Literature Cited for Precooling and Transportation, p. 38.

market is likewise very warm at this time. Consequently, initial icing is usually a necessity if the potatoes are to survive without undue browning and decay. For short hauls to nearby markets shipment under ventilation can be used safely if the potatoes have been picked up and hauled from the field soon after being dug.

Shipments of early potatoes from the central midwestern region are usually made during very warm weather, both in the producing area and all the way to market. They are practically certain to need good refrigeration in transit. If the transit period is to be longer than 2 or 3 days, initial icing plus re-icing in transit will usually be desirable. Precooling to an average load temperature of 60° F. followed by re-icing in transit has given good results but is relatively expensive.

Shipments from California are also generally made during hot weather, which is in addition very dry in the producing district and during the first part of the trip. Those moving to markets east of the Rocky Mountains should be under initial icing plus at least one re-icing in transit. Toward the end of the season two re-icings or even standard refrigeration may be necessary. California shipments moving to points west of the Rockies should not require more than an initial icing.

Cars equipped with fans to give positive air circulation are superior to standard cars for refrigerated shipments.

In general a pyramid load is the most desirable, although other types of loads are used and give satisfactory results if they do not allow excessive shifting. The aisle load permits faster cooling, but such a load is sometimes found badly shifted at destination.

Other statements about loads and loading, largely detailed descriptions of how to build the load, were given by Benn (*3*) in 1946, Pace (*7*) in 1943, Ramsey and others (*9*) in 1944, and Union Pacific Railroad (*12, 13*) in 1945.

Rion (*10*), of the Freight Container Bureau of the Association of American Railroads, in 1945 made the following recommendation for the loading of potatoes:

1. Two or three thicknesses of heavy paper over the floor racks for protection against freezing in winter months.
2. Bedding material, such as shredded paper, loose excelsior, single- or double-faced corrugated board or fabricated pads filled with paper or excelsior, spread over the floor racks to prevent bruising and scuffing.

Detailed descriptions of various methods of loading containers of various sizes for summer and winter shipments are given in the publication.[12]

Hickman (*6*) in 1944 stated that a check in Chicago, Ill., on the results of car-loading methods (presumably in 1944) gave the following results:

Type of load:	Loads: Shifted (percent)	Loads: Recommended
5-3-2-1	0	Yes (summer).
5-3-2-3	[1] 1	Yes (summer).
6-3-2-3	45	No.
6-3-2-1	45	No.
6-3-3-2	75	No.
Aisle load	100	No.
Fall—spring (bulkhead)	0	Yes.
Winter (bulkhead)	0	Yes.

[1] Pyramid load. For an illustration of this and the pyramid-through load, see Rose (*11*) or illustrated charts issued by the Freight Loading and Container Section, Association of American Railroads, 59 East Van Buren St., Chicago 5, Ill.

[12] Bulletins showing diagrams and describing several types of loads can be obtained by writing to the Freight Loading and Container Section, Association of American Railroads, 59 East Van Buren St., Chicago 5, Ill.

Poole and Barr (*8*) in 1941 reported the results of investigations on the precooling and drying of washed early potatoes in Louisiana. They concluded that (1) a mechanical refrigeration unit delivered less air than the bunker fans used but that the latter gave a more even distribution of temperature through the car; (2) a more thorough job of drying was done when the bunker fans were operated while the car was being loaded, before ice was added to the bunkers; and (3) more moisture was removed from potatoes in crates than from those in sacks when precooling was done with the bunker fans used in these tests.

Blount, Freight Container Bureau, (*4*) in 1942 emphasized the value of the pyramid or through load for late potatoes, with some kind of padding material placed over the floor racks before the first-layer sacks are loaded.

Barger, Shear, and Morris (*2*) reported in 1945 investigations on the effect of floor pads under the bottom layer of sacks in carloads of White Rose potatoes moving from Kern County, Calif., to eastern markets. They found that such pads greatly reduced bruising and other injury received by the load in transit. The effect was observed not only in the bottom layer but in the upper layers as well. They estimated that use of the pads effected savings of 100 to 400 pounds of potatoes per car. The pads in most cases consisted of matted excelsior enclosed in paper sleeves. Pads filled with pulped paper were about as effective as those filled with excelsior. There was no evidence that pads interfered with air circulation up through the load.

Decker (*5*) in 1940, reporting on the transportation of Kaw Valley potatoes, stated that on the basis of his experience standard refrigeration was not advisable for that crop. Potatoes in a few cars refrigerated in this way, which were examined in Chicago, appeared to be "chilled" and looked as if they would break down quickly. It is questionable, however, whether the condition seen was correctly interpreted. The potatoes in question may have failed to suberize because of low temperatures in transit and so might have been more susceptible to decay when they warmed up. White potatoes, unlike sweetpotatoes, are not susceptible to chilling injury, although they may of course accumulate so much reducing sugar at low temperatures as to make them unusable for potato chips. (See Chip Making, p. 113.) Too much refrigeration would also make them cook soggy or less mealy. Decker stated that it is better to recondition potatoes (do a good job of grading) at the shipping point rather than after potatoes reach the market. A reconditioned car (reconditioned at destination) never commands a good price.

Ramsey and others (*9, p. 3*) in 1944 summarized their work on the transportation of washed potatoes (early crop) as follows:

For regions such as central Nebraska, where relatively immature potatoes are harvested during hot windy weather and are washed, sorted, and loaded without drying, the following recommendations are made to insure the arrival of the potatoes in the best possible condition:

1. Harvest the potatoes very carefully in order to avoid scuffing and bruising.

2. Pick the potatoes promptly—i.e., within 15 minutes, putting not much over 40 lbs. into a bag. Tightly woven bags are better than burlap bags of

the type used for shipping potatoes. Pick up these partly-filled sacks and haul them to the packing shed without delay.

3. Cover the sacks with a canvas tarpaulin during loading and while hauling.

4. Protect the piles of sacked potatoes at or in the sheds from sunshine and wind.

5. When the weather is very hot and windy, wash, sort and load the potatoes as quickly as possible into pre-iced cars.

6. When the weather is moderate—and it is not dry and windy at harvest time—potatoes mechanically precooled or shipped with delayed icing should carry satisfactorily.

7. Re-icing of pre-iced cars is not necessary for shipments going no farther than Chicago—third or fourth morning delivery.

8. Standard ventilation (without icing), is not recommended for washed potatoes unless they are relatively mature and the conditions at harvesting time are exceptionally favorable for handling potatoes without damage and temperatures en route are unusually cool.

9. The pyramid method of loading sacks into cars is recommended no matter what method of shipping is used.

Barger and others (*1, p. 23*) in 1942 summed up the results of their work with new potatoes from Kern County, Calif., as follows:

During this investigation the conditions and practices contributing to the best carrying quality of new Kern County potatoes to markets as far distant as Chicago were as follows: the digging of relatively mature stock (at least 115 days from planting), morning digging, immediate pickup in sacks and by truck in the field, the use of tarpaulins over the load during hauling to the washing shed, and shipping under refrigeration. The hydrocooling of the tubers in ice water to about 50° F, followed by immediate icing of the car under Rule 240, controlled discoloration and decay and gave the best results of any of the test shipments.

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DORMANCY [13]

It was undoubtedly observed very early that after potatoes are dug there is a period during which they do not sprout, no matter under what conditions they are held. This eventually came to be known as the resting period. It must also have been observed very early that after the rest period potatoes begin to sprout if stored at ordinary temperatures but can be kept from sprouting by storage at low temperatures. In this latter state they were said to be dormant.

Extended research during fairly recent times resulted in the formulation of the theory that the failure of newly harvested potatoes to sprout when replanted immediately after harvest occurs because the buds do not get enough oxygen from the air. (See Thornton (*44*),[14] 1939, for a discussion of this.) According to this theory the skin is at first impermeable to the gas and the germination of the buds becomes possible only later when the skin becomes more permeable and permits enough oxygen to enter the potato to cause sprouting.

In 1939 Thornton (*44*) reported an important discovery, which, however, has not received the attention in potato literature that it deserves. He found that the failure of potato buds to grow is owing to the oxygen content of the surrounding air being too high, not too low, and that sprout growth will start immediately after harvest if the oxygen concentration is reduced from 20 percent to approximately 2 to 10 percent. He reported further that (1) the skin of potatoes at harvesttime is not impermeable to oxygen but, on the contrary, is more permeable then than at any later time; and (2) with time, its permeability decreases, not increases, until a stage is reached at which the supply of oxygen to the buds is sufficiently reduced to furnish the low concentrations necessary for sprouting to proceed. The decrease in permeability, he found, comes about from natural changes as the tuber grows older, because of which the skin becomes more dense, more cells are present, and the cell walls are thicker. Thornton found that the periderm thickens more rapidly in some varieties than in others, thus accounting for the difference in natural dormancy of different varieties.

These results break down, in effect, the distinction between the resting period and the dormant period of potatoes so far as the fundamental physiology is concerned. For the grower, however, especially in the South, the resting period is a reality with which he must deal when he uses northern-grown seed. In the more southerly portions of the early-crop area potato-planting time

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[13] Dormancy is used here with its present ordinary connotation although, as shown, it should be used in a somewhat different sense from the one in which it has been used for many years.

[14] Italic numbers in parentheses refer to Literature Cited for Dormancy, p. 48.

comes before such seed stock is in condition to sprout, especially if it was harvested late and has been in storage for only 4 or 5 weeks. (See Townsend (*46*), 1941.) Reducing the oxygen concentration around potatoes is not a practicable procedure for growers, and so far as known it has not been used in commercial operations.

LeClerg and Henderson (*25*) in Louisiana reported in 1943 that heat sprouting (the growth of tuber buds prior to harvest) was in inverse ratio to the length of the rest period. Heat sprouting was most prevalent in late-maturing plants. Only a very few tubers from early-maturing strains formed heat sprouts.

SPROUT ACCELERATORS

USE OF SPROUT ACCELERATORS IN THE UNITED STATES

Ethylene Chlorhydrin

Effect on sprouting.—Even before Thornton's paper (*44*) appeared in 1939 the interest of southern growers and that of investigators in Southern States had been drawn to the results of studies reported by Denny (*8, 9, 10*) in 1926 and 1928 and Guthrie (*19, 22*) in 1938 and 1939. These investigators found that the sprouting of dormant potato tubers can be hastened by treating them with various chemicals, the most effective of which were ethylene chlorhydrin and the thiocyanates of sodium and potassium. In 1938 Guthrie (*19*) reported that a substance believed to be ethylene thiocyanohydrin was effective in breaking the dormancy of potato tubers. Ethyl carbylamine also had a marked effect.

Denny and Miller (*15*) in 1938 reported that the quantity of ethylene chlorhydrin that had been absorbed by newly harvested potatoes was a reliable indication of the sprouting that might be expected; that good growth response was obtained whatever the temperature during the treatment, whether the treatment continued 1 day or 5, and whether the treatment was applied the first, second, or third week after harvest; that favorable responses were usually obtained when 100 cc. of the press juice of potato tissue had absorbed as little as 5 cc. or as much as 15 cc. of a 0.1 molar solution of ethylene chlorhydrin. They suggested a procedure for the large-scale treatment of dormant potatoes. It is based on the removal of tubers at intervals after the start of the treatment, obtaining press juice, distilling the juice, and determining the ethylene chlorhydrin by titration. By this method the time when the tubers have been brought into condition for subsequent sprouting can be determined.

Denny (*13*) in 1945 reported that a combination of ethylene dichloride and carbon tetrachloride with ethylene chlorhydrin was at least as effective as ethylene chlorhydrin alone in hastening the sprouting of dormant potato tubers. An effective combination consisted of 7 parts by volume of ethylene chlorhydrin, 3 parts of ethylene dichloride, and 1 part of carbon tetrachloride; the cost was about one-third that of the ethylene chlorhydrin that would have been needed. No report that such a mixture has been used in practical operations has been found in potato literature.

Michener (*26, 27, 28*) in 1941 and 1942 stated that in Hawaii ethylene chlorhydrin not only accelerates the sprouting of potatoes but also increases the number of stems which they produce. In his opinion this latter effect results from the removal of auxin by ethylene chlorhydrin, auxin being the means by which one bud inhibits the growth of others; the result is that a number of buds begin to develop immediately after treatment. (See also Woodbury (*50*), 1939.)

Cordner (*5*) in Oklahoma in 1942 stated that ethylene chlorhydrin was satisfactory when whole tubers were planted throughout the usual planting season, but this was true for cut sets only when the plantings were made in July (for the late crop). The treatment proved to be useless, and even a detriment, with cut sets when plantings were made in August.

Effect on seed-piece decay.—Ward (*49*) in Oklahoma reported in 1939 the results of investigations on the so-called seed-piece decay at high soil temperatures. He found that tubers treated (with ethylene chlorhydrin) at 70° and 80° F. and left freely exposed to the air for a long enough time so that their rate of respiration approached that of untreated tubers may then be planted in soil at a temperature of 90° without serious danger of break-down because of a high rate of respiration. Seed-piece decay is at times a serious difficulty in the production of late-crop potatoes in Oklahoma and other parts of the South. Cordner and Ward (*6*) in 1939 reported that seed-piece decay at high soil temperatures is not initially a true rot caused by an organism, but a physiological disturbance similar to blackheart. As one preventive measure they recommended planting of seed pieces rather than whole potatoes because oxygen penetrates more rapidly into the tissues of the former and germination is more rapid.

The foregoing reviews show that the substance most used as a sprout accelerator is ethylene chlorhydrin.

Other Sprout Accelerators

Thiocyanates.—Other substances that affect the sprouting of potatoes, however, as reported by Denny (*8, 9*) in two of his earlier papers were sodium, potassium, and ammonium thiocyanates. Results obtained with the last were reported by Townsend (*47*) in 1946. He found that, although seed pieces treated with ammonium thiocyanate sprouted somewhat more slowly than those treated with ethylene chlorhydrin, the final stands and yields were equal to, or better than, those obtained when ethylene chlorhydrin was used. Similar results were obtained by growers who made field trials of the ammonium thiocyanate treatment.

Growth-promoting substances.—Alban (*1*) in Ohio reported in 1945 that, in tests with Chippewa and Katahdin potatoes under both field and greenhouse conditions, yields were increased when the tubers had been treated with various growth-promoting substances. The dust mixtures and solutions used included a number of commercial products and five dusts. The author stated that most of the plant-hormone dusts (sold under trade names) contain about 2,200 p.p.m. (parts per million) of alpha-naphthaleneacetic acid or 1,500 to 10,000 p.p.m. of indolebutyric acid.

Carbon dioxide and oxygen.—Thornton (*45*) in 1944 reported that the dormancy of freshly-harvested Irish Cobbler and Bliss Triumph potatoes was broken and bud growth was obtained within 7 to 9 days by continuous treatment of the tubers with 2 percent of oxygen when they were in a relatively dry condition or 5 to 10 percent in a moist condition at 73.4° to 82.4° F.

Thornton (*41*) in 1933 reported that carbon dioxide was effective in breaking the dormancy of freshly harvested potatoes. In a later paper (*43, p. 204*) in 1939 he further reported that—

> carbon dioxide is most effective in breaking the dormancy of potato tubers when it acts in the presence of 20 per cent or more of oxygen and this treatment is more effective than a completely anaerobic condition brought about by treatment with nitrogen.

Thornton (*42*) found in his work on the carbon dioxide storage of potatoes in 1935 that, as the concentration of CO_2 increased, respiration, catalase activity, pH, reducing sugars, and sucrose also increased. It seems natural to conclude that these expressions of more active metabolism would also be accompanied by one more, namely the beginning of sprouting.

However, Blood and Kardos (*2*) in 1945 reported that in New Hampshire Green Mountain potatoes that had just begun to break dormancy remained dormant for 39 days in containers in which a 10-percent content of CO_2 was maintained. The temperature range during this period was from 49° to 52° F. After 69 days there was some sprouting of potatoes in the containers with a high content of CO_2, but much more in the aerated containers.

Investigations reported by Kardos and Blood (*24*) in 1947 indicated that the carbon dioxide storage of potatoes seemed to be as effective as the hormone treatment in retarding germination, when temperatures were equivalent to those normally occurring in May and June (in New Hampshire). The concentration of carbon dioxide in the storage space varied from less than 1 percent to approximately 12 percent. The hormone used was the methyl ester of alpha-naphthaleneacetic acid, in the form of a dust at the rate of 0.45 and 0.9 gm. per bushel of potatoes. No adverse effect on cooking quality was noted. Slow sprouting after the potatoes were removed from CO_2 storage makes further investigation desirable before the treatment can be recommended for seed stock.

There appears to be need for further investigation of this subject, in order to explain the apparent discrepancy between Thornton's results (*42*) and those of Blood and Kardos.

USE OF SPROUT ACCELERATORS IN OTHER COUNTRIES

Pal and Nath (*29*) reported in 1938 that the most successful method for shortening the rest period of potatoes in India is to peel the potatoes (care being taken not to injure the eyes) and store them in moist sawdust for a week. The use of ethylene chlorhydrin by either the vapor method or the dip method was successful for cut tubers but not for whole ones.

Hutton (*23*) in 1942 stated that in Australia very satisfactory sprouting of potatoes could be obtained by treating them with a solution of acetylene and with a 2-percent solution of thiourea. Both of the solutions were cheaper than chlorhydrin. To obtain the quickest results, cutting the tubers just before they are treated is necessary. The acetylene treatment was considered the best for the Snowflake variety, but the acetylene and the thiourea treatment were about equally satisfactory for the Factor, Carman, Bismarck, and Katahdin varieties.

PRACTICAL APPLICATIONS

An important reason for the use of sprout accelerators in the United States, aside from breaking the dormancy of recently harvested potatoes, is to furnish southern growers with a means of obtaining advance information on the virus content of seed stocks late in January from samples harvested in the North as late as early October. Denny (*12*) suggested such use in 1943, but the work on which his suggestion was based consisted of experimental studies with small quantities of potatoes. In 1947 Porter and Simpson (*30*) reported the use of ethylene chlorhydrin in gaseous form for treating approximately five carloads of potatoes destined for use as seed stock in Florida. Summarizing their results, they stated (*pp. 12, 13*):

> Stand counts indicate that there is some difference between varieties but that better than 95 per cent of the gassed potatoes emerge and produce plants large enough to read for virus disease by the end of January. In 1945 the emergence of Irish Cobblers was 95 per cent; Chippewa, 96; Green Mountain, 95; Katahdin, 96; Sebago, 95; and Russet Rural, 95 per cent.

Somewhat different treatments were needed for breaking the dormancy of the different varieties, as is shown by the details given in their report.

Practical use of these various chemicals has brought out facts that growers and shippers need to consider. Townsend (*46*) in 1941 reported that the ethylene chlorhydrin dip treatment for hastening the sprouting of dormant potatoes increased the stand and yield of most stocks of potatoes. The ethylene chlorhydrin gas treatment and the thiocyanate dip treatment were less successful. Details of the methods to be used in applying the treatments are available from experiment stations and will not be gone into here. One thing which Townsend emphasized is that immature stocks that must be forced for early sprouting are the most productive.

SPROUT INHIBITORS

Just as hastening the sprouting of dormant seed potatoes is often important for the southern grower, the prevention of sprout growth is important for dealers in table stock. During the past 10 years considerable research has been conducted to discover chemicals that are effective for this purpose.

USE OF SPROUT INHIBITORS IN THE UNITED STATES

Guthrie (*20, 21, 22*) in 1938 and 1939, Denny, Guthrie, and Thornton (*14*) in 1942, and Denny (*11, 13a*) in 1942 and 1945 reported the results of research on preventing sprouting in potatoes, by the use of growth-regulating substances. Of the substances tested, the methyl ester of alpha-naphthaleneacetic acid proved to be the most effective. When this substance was used at the rate of 400 mg. per kilogram of potatoes (1 to 2,500) sprouting was completely inhibited for a year. When the amount was reduced to 100 mg. per kilogram of potatoes (1 to 10,000) there was a slight development of sprouts after 6 to 8 months. At 50° F. potatoes were stored under the methyl ester treatment for at least a year without either sprouting or shrinkage of tubers. At 59° sprouting was inhibited satisfactorily for at least 8 months, but there was some shrinkage because of loss of moisture. Sprouting was inhibited for 3 to 6 months at 64.4° and at approximately 73°, but there was some shriveling.

Guthrie (*20*) reported in 1938 that (1) potassium naphthaleneacetate inhibited the growth of the buds of nondormant potato tubers; (2) if potato seed pieces were treated with ethylene chlorhydrin after treatment with potassium naphthaleneacetate they started to sprout much sooner than similar pieces not treated with ethylene chlorhydrin. These latter results are like those obtained by treating dormant tubers with ethylene chlorhydrin.

Thomas and Riker (*39, 40*) reported in 1944 and 1945 that sprouting of potatoes stored at a temperature about 70° F. was prevented for from 2 to 3 weeks to 4 to 5 months by treatments with the plant hormone methyl ester of alpha-naphthaleneacetic acid. Treatments made just before the advent of warm weather seemed most effective. This finding is not in agreement with most others. Generally the best results have been obtained when the treatment was applied early, before the potatoes begin to sprout. In other tests the chemical was applied at the rate of 0.9 gm. per bushel in dilute alcohol, lanolin emulsion, talc, or walnut-shell flour dusts or impregnated in shredded paper. The tests were run 2 to 4 months at about 70°. The checks sprouted and became worthless whereas treated tubers, although they lost some water, were still marketable after several months in warm storage.

Alban (*1*), working with naphthaleneacetic acid, indolebutyric acid, naphthoxyacetic acid, and 2,4-dichlorophenoxyacetic acid, their salts, and methyl ester, in Ohio reported in 1945, as did Smith (*33*) in 1940 and other workers, that the methyl ester of naphthaleneacetic acid was the most effective as a sprout inhibitor. Dust treatments gave better results than any of the others used.

According to a report by Daines and Campbell (*7*) in 1946, the methyl ester of alpha-naphthaleneacetic acid inhibited sprouting of Katahdin and Cobbler potatoes. It was more effective when applied as a dust than when distributed through the packages on paper strips. The amount to be used may vary somewhat with the storage temperature but the ester should be effective if used at the rate of ⅔ to 1⅓ gm. to a bushel of potatoes. It was stated by Van Stuivenberg (*38*) in 1947 that the sprout-inhibiting action of the methyl ester of alpha-naphthaleneacetic acid can be stopped by coumarin.

Smith (*34, 35*) reported in 1946, as a result of a 4-month storage of Katahdin potatoes in bushel crates at high temperatures, that the treatment with the methyl ester of alpha-naphthaleneacetic acid from an aerosol with methyl chloride resulted in less weight loss than from any other treatment. Sprout growth was slightly greater than when the methyl ester was atomized from a spray gun. With the Sebago variety the best results were obtained when methyl-ester-impregnated paper was used. However, treatment with ester-impregnated dust was only slightly less effective.

Pujals, Nylund, and Krantz (*31*) in 1947, stated that tubers dusted with the methyl ester of alpha-naphthaleneacetic acid produced no measurable weight of sprouts in 99 days, whereas tubers that had been sprayed and tubers that were untreated sprouted freely during the same period. When tubers that had previously been treated to prevent sprouting were treated with ethylene chlorhydrin just before planting, they sprouted more rapidly than comparable tubers not treated with ethylene chlorhydrin. The final stand from tubers treated with ethylene chlorhydrin was as good as that obtained from tubers not subjected to any chemical treatments. Tubers treated with ethylene chlorhydrin produced more stems per hill and greater yields than untreated tubers.

Various commercial forms of sprout inhibitors are on the market, but to date tests of these have not been extensive enough for a statement as to their relative effectiveness.

Smith and Scudder (*37*) reported in 1947 that not until the fall of 1945 was the methyl ester of alpha-naphthaleneacetic acid used on a large scale by New York State growers to reduce or inhibit sprout growth on potatoes. The chemical had been used experimentally for that purpose since 1939.

Ellison and Smith (*16*), continuing the work begun by Smith, Baeza, and Ellison (*36*), reported in 1948 results from spraying potato plants in the field on three different dates with MENA (the methyl ester of alpha-naphthaleneacetic acid) at concentrations of 3,500 and 7,000 p.p.m. The July application reduced both yield and specific gravity, but no bad effects were associated with the two later treatments. The most interesting result was that spraying potato vines with MENA inhibits the sprouting in storage of tubers produced by sprayed vines if the treatment is not applied too late in the growing season. Sprouting in storage was controlled best by the July application, to a lesser degree by the August application, and not at all by the one made in September. No significant differences were found in rate of respiration between treated and check tubers. MENA was as effective at 3,500 p.p.m. as at 7,000 p.p.m. The authors believed it possible that a concentration lower than 3,500 p.p.m. might prove satisfactory.

Under some conditions carbon dioxide acts as an inhibitor. (See p. 43.)

USE OF SPROUT INHIBITORS IN OTHER COUNTRIES

Brown (*3*) in 1947 reported that in Great Britain chlorinated nitrobenzene applied as a dust to certain early and second-early potato varieties in pits has a pronounced effect in reducing the amount of sprouting that takes place over winter and in preventing damage to the sprouts by *Rhizoctonia solani*. (So far as noted in the literature, no other sprout inhibitor has such an effect on decay organisms.) No information was obtained by the author as to whether the chemical has any tainting effect on the potatoes or any toxic effect that becomes evident when they are used as food.

Colin (*4*) in 1948 discussed the use of the methyl ester of naphthaleneacetic acid in North Africa for preventing the sprouting of potatoes. During that discussion he referred to the work of Ulrich (*48*), who reported that under certain conditions the treatment of potatoes with hormones accelerated the respiration of potato tubers and brought about oxidations that were harmful to quality. The author then mentioned a newly developed, patented dust which is said to hasten the healing of wounds on potatoes and seems to reduce the risk of contamination of healthy tubers by others which have been attacked by *Fusarium* or other decay-producing organisms. This dust, when combined with a hormone (presumably the methyl ester of naphthaleneacetic acid) made it possible to keep potatoes in good, fresh-appearing condition until July the year following harvest. The composition of this new dust was not given.

Fourmont (*18*), in France, reported in 1943 that by exposing potatoes to sulfur dioxide in a closed space he was able to kill the buds (or sprout initials) without injuring the tubers. In large-scale tests 250 to 500 kg. (550 to 1,100 pounds) of potatoes was held for 3 hours in a chamber of 15 $m.^3$ capacity (about 530 cubic feet) in which was released the sulfur dioxide by burning 250 gm. (approximately 9 ounces) of "Sulfor," a commercial preparation of sulfur used in France as an insecticidal fumigant. After this treatment the buds withered and finally dried up completely. Similar tests with larger quantities of potatoes gave similar results. It is obvious that the treatment would be useful only for food stocks. Nothing is said in the report as to whether it had any effect on the taste of treated tubers.

Rosella (*32*) in France described in 1947 the use of phytohormones (which would include the methyl ester of alpha-naphthaleneacetic acid as well as others) for preventing or delaying the sprouting of potato tubers. He mentioned a commercial preparation, Rhizopon C, used in the Netherlands.

Estienne (*17*) reported from Belgium in 1946 that Rhizopon, which he described as a commercial preparation of methyl alpha-naphthaleneacetate, was effective in retarding the spring germination of potatoes stored in a dry cave (temperature 36.4° to 50° F.), but that it did not prevent decay.

FURTHER RESEARCH PROBLEMS

Further research in this field probably should include tests to determine (1) the effectiveness of commercial preparations in accelerating and inhibiting sprout growth; (2) what the effect of such preparations is on the healthfulness and food value of potatoes; and (3) whether potatoes treated with them can be used satisfactorily for processing. It is possible, also, that further tests should be made to determine the productiveness of vines grown from treated seed.

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STORAGE (STRUCTURES AND OPERATION)

Storage is a highly important part of the process of caring for the potato crop of the United States. In many States potatoes are grown in such immense quantities that they cannot all be marketed as soon as dug except at prices that would be ruinous to growers, even if adequate transportation facilities were available. These facts were, of course, evident years ago. The result was that, early in the history of potato growing in this country, growers felt forced to provide themselves with means for holding a large part of their crop for later, more orderly disposal at prices that presumably would be more likely to yield a profit. Profits have not always been large, and sometimes there have been losses to both growers and shippers. There is no doubt, however, that adequate, efficient storage facilities have done much to stabilize prices and all the other conditions that affect the growing and marketing of late-crop potatoes.

It must always be remembered, however, and probably is generally realized, that not all of the potatoes grown in the United States—early, intermediate, and late crops—are in equal need of being stored.

Competent authorities in the United States Department of Agriculture have estimated that a month's supply of potatoes for the Nation, at the present rate of consumption, is about 30 million bushels. Using this as a yardstick, they made the following statements:

1. The early crop, harvested over a period of about 5 months, January through May, represents a 2-month supply for the United States and normally need never go into storage.
2. The intermediate crop is harvested over a period of about 3 months, June through August, and represents about a 1-month supply for the United States. Normally it does not need to go into storage except that, because of overlapping with the late crop in August and September, part of it may sometimes be stored to advantage.
3. The late crop, harvested over a 3-month period, September through November, represents about a 9-month supply for the United States. Obviously this must be stored, a large part of it for as long as 6 to 8 months.

The extent to which storage is needed or has to be used depends not only on the size of the crop but also on local and national distribution and marketing patterns. For example, in 1948, when a total surplus of about 84 million bushels was produced, there was a surplus of each of the three crops. Some of these surpluses had to be stored before they could be disposed of. In years of smaller surpluses difficulties connected with distribution, storage, and marketing would not be so great.

KINDS OF STORAGES

Most of the discussion that follows relates to the late and intermediate crops. A brief statement concerning storage of the early crop appears on page 57.

Storages used have been of many different kinds, varying from pits, mounds, or earth-covered cellars of small capacity to modern storages wholly above ground or partly below ground, capable of holding several hundred to half a million bushels.

Pits, mounds, or earth-covered cellars are economical to build; the last, when properly constructed and managed give fair protection from water and freezing and in cool climates keep potatoes in excellent condition. The newer, more modern storages use insulated and weathertight roofing and wall siding, have provision for handling potatoes conveniently with a minimum of bruising, and are easy to manage. (See Edgar (*11*),[15] 1947.)

Pits, mounds, and similar storages.—Barker and Wallace (*2*) in Great Britain in 1946 published the results of an investigation on the distribution of temperature in potato clamps (pits in the United States). They reported that records of the temperatures in a sectioned potato clamp of normal construction during two successive winters showed that the mean temperature in the clamp was a few degrees Fahrenheit above the mean temperature of the surrounding air. The clamp coverings had an insulating effect, the variations in the temperatures of the clamps being much smaller than those in the air temperatures. Marked differences in temperature were found between various positions in the clamp, and these variations were, in general, correlated with differences in the extent of sprouting and content of total sugar determined when the sections were opened.

Ramsay (*34*) in 1942 in discussing the pitting of potatoes in Australia referred to it as the best method of storing potatoes that have to be kept for several months and are intended for consumption. He pointed out (*p. 357*) that the term "pitting" does not mean that potatoes when "pitted" are placed in a hole in the ground, but that "they are actually stored at above-ground level." His recommendations for the construction, filling, and covering of pits are substantially the same as those made in the United States for similar storage places. He stated explicitly that the method is not applied to potatoes intended for seed purposes.

Smith (*35*) in Scotland in 1934 and Barker in Great Britain (*1*) in 1939 reported the results of storing new potatoes in a mixture of peat moss and sand and in peat moss alone. The method would not be practicable for use with large quantities of potatoes, but it might be useful for small lots to be stored for some special purpose. It consists in holding the potatoes in a mixture of approximately equal volumes of peat and sand containing 10 to 12 percent of moisture (*35*) or in peat alone (*1*), presumably with about the same moisture content. In peat only, the stored potatoes retained their new-potato characteristics for about 2 months (*1*).

Storage buildings.—No attempt will be made in this digest to discuss details of construction of storage houses for potatoes. Such matters are well taken care of by Edgar and Long (*16, 18*) in 1944, by Edgar (*11*) in 1947, and by the Union Pacific Railroad (*39*) in 1945 and in other references cited on page 54 and obtain-

[15] Italic numbers in parentheses refer to Literature Cited for Storage (Structures and Operation), p. 59.

able from the sources indicated. There are, however, certain basic principles that should govern the construction and use of such storages and should be clearly understood by anyone concerned with storing potatoes. (See the publications cited on p. 54; Mattingley (*29*), Australia, 1945; McPherson (*28*), New Zealand, 1939.)

As pointed out by Edgar (*12, p. 871*) in 1947 the marketing of potatoes and, therefore, the objectives of research on their storage have become more complicated than they were in an earlier day. A part of his statement on the subject is quoted as follows:

> A larger proportion of the seed potatoes for central and southern areas is grown in the North, and northern-grown seed potatoes may have to be stored under one of three sets of conditions: At a relatively cold temperature for 7 or 8 months, when intended for seed to be used locally; at moderate temperatures for 6 or 7 months, for planting in the Central States; or at a relatively high temperature, to get them through the dormant period quickly, for early planting in the South.

Table-stock potatoes for early consumption can be kept at higher temperatures and with less air circulation than those intended for long-period storage and later consumption. Potatoes for dehydration or for use in making potato chips require special storage conditions. (See also Edgar (*11*), 1947.)

The temperature at which potatoes are actually stored depends largely on the type of storage available if they are not to be refrigerated. It also depends on the prevailing weather at time of harvest, the use that is to be made of them as just indicated, and the time of year when they are to be marketed.

A method of storing potatoes which has proved successful for one Scottish grower, but which would be usable for only a few, if any, localities in the United States, was described by Keith (*22*) in 1941. It consisted in holding potatoes in unheated, uninsulated sheds, essentially earth floors raised 3½ feet above ground and surrounded and covered by walls and a roof, both constructed of wood. The sheds were capable of holding 200 tons of potatoes in a layer 3 feet deep. Each had a door wide enough to let in a motortruck. Seven large windows on each side provided lighting, but this could be easily blacked out if the potatoes were to be used for food. The report stated that the sheds not only gave perfect storage for the crop but cut out all risk of wetting and frost injury, made sorting (grading) easy and comfortable for the workers, insured delivery at any time, did away with the heavy labor of covering and uncovering pits, and saved an enormous amount of straw.

INSULATION

The amount and kind of insulation needed will depend on the part of the country where the storage is to be built and on the type of structure desired. A storage in Maine, Michigan, or the Red River Valley will need heavier insulation than one located in Kansas or Pennsylvania. Likewise, a storage of the above-ground type so commonly used in Maine and other Northern States will have to be as well insulated as a cold-storage warehouse in any part of the country, whereas a storage that is mostly below ground will need insulation chiefly in the roof or ceiling and, in extremely cold climates, in such part of the walls as project above the ground level.

In more moderate climates Goodman (*20*) in 1943 and Edgar (*11*) in 1947 suggested that it is desirable to leave uninsulated the top of the outside masonry wall (in storages that are mostly underground) to furnish a cold place where moisture from inside the storage may condense instead of on wooden members of the structure. Another advantage of such construction is that the condensed moisture evaporates back into the atmosphere of the storage, thus helping to keep up the humidity and prevent shrinkage.

In any case, sufficient insulation should be used so that during average winter weather for the locality the heat from the stored potatoes and the floor of the storage will balance that lost through the walls and ceiling. It is important that the ceiling or roof have enough insulation to prevent condensation of moisture which may drop back on the tubers and predispose them to decay. Such condensation may also lead to the rotting of wooden members in the storage structure. Best results are obtained when the insulation is protected by a vapor barrier or seal according to Cropsey (*4*) in 1940, Goodman (*20*) in 1943, Edgar (*11*) in 1947, and Werner (*41*) in 1947. (For references on insulation and other matters pertaining to potato storage houses see Cropsey (*4*), 1940; Decker, Elmer, and Dean (*5*), 1944; Edgar (*6*), 1937, (*7, 8*), 1938, (*9*), 1940, (*10*), 1941; Edgar, Jefferson, and Wheeler (*15*), 1942; Edgar and Long (*17*), 1944; Edmundson, Landis, and Schaal (*19*), 1945; [Great Britain] Agricultural Research Council (*21*), 1947; Merchant (*30*), 1947; Prince and others (*33*), 1943; Smith (*36*), 1933, (*37*), 1943; Werner (*40*), 1945, (*41*), 1947; Wilson and Hardenburg (*42*), 1931; and the State publications cited on pp. 9 to 13.)

A report (*31*) in 1946 on the work of D. C. Sprague in Pennsylvania stated that timbers in potato storages may fail in 5 to 7 years because of dampness and the resulting rot when inadequate ventilation is provided over straw insulation and summer ventilation is neglected. Other authors have commented on the danger of deterioration in storage structures because of dampness.

VENTILATION AND AIR CIRCULATION

The terms "ventilation" and "air circulation" as applied to potato storage do not mean the same thing, but the distinction between them is not always clearly brought out in publications dealing with the subject. The best statement which the reviewers have seen is contained in the report in 1947 of the (British) Potato Storage Mission to the United States and Canada (*21, p. 6*). It is as follows:

> The term *ventilation* is used here to indicate introduction of outside air into the store, while the term *circulation* implies movement of air within the store. The processes are frequently interrelated, the method used for one of necessity determining that used for the other; nevertheless their arbitrary distinction clarifies description. The purpose of ventilation is primarily to cool the potatoes. Under certain circumstances it may also be used to reduce humidity. Circulation reduces temperature variation and so facilitates cooling.

The report went on to say (*p. 6*) that both methods as observed in the United States may be classified—

> under the major headings of (1) "Gravity" and (2) "Forced draught." In

the case of air circulation these may be further sub-divided into (a) "Through," where air is passed through the mass of potatoes, and (b) "Shell," where air is circulated in enclosed spaces round the bins.

These are not new ideas, but the statement of them in this form furnishes a basis for clearer thinking than is sometimes evident in publications on potato storage. Potato storage houses in the United States are of many different kinds; their construction and the methods by which they are operated are the result of the practical application (not always conscious perhaps) of the principles stated in the paragraphs just quoted.

Aside from pits, probably the simplest of all are the storages in which ventilation and air circulation are brought about solely by gravity, the warm air being allowed to escape through ventilators in the roof or along the sides and the cooler outside air entering through open doorways or special openings at a lower level than those used for the escape of warm air. Such air circulation as occurs in these storages is of the "through" type and results from the combined action of two kinds of air movement just described. Flues of various types, either through the mass of potatoes or underneath the floor, which is sometimes slatted, facilitate the "through" air movement. Edgar (*11, 12, 13*) in 1947 and 1948, and Edgar and Childers (*14*) in 1947 reported, however, that such through-the-bin circulation reduces the vitamin content and increases the shrinkage of stored potatoes.

In another type of storage ventilation is by gravity but air circulation is by forced draft established by portable fans placed in the driveway immediately in front of the entrances to flues at the base of bin partitions.

Some storages have forced-draft ventilation established by fans in either the air inlet or the outlet. Ventilation is accomplished as just described. Other storages have forced-draft ventilation and forced-air circulation, both accomplished by means of a great variety of flue and fan locations. The air circulation is of the blow-through type.

Some storages, especially in the humid parts of the country, have slatted false walls all around the storage space, as well as a slatted floor. Such construction, however, gives less satisfactory results in late-crop, less humid areas than the "shell" type because, as mentioned previously, it increases shrinkage of the stored potatoes. In a shell-type storage a continuous space for air circulation is provided between the bins and the outside walls and between the bottom of the bins and the main floor. The inner walls and floor are tight, not slatted, so that the air is circulated under and around the bins, not through the mass of potatoes.

In any type of common storage, ventilation is the quickest means of changing both temperature and humidity inside a storage house.

In the fall, when it is desirable to cool without excessive drying, night ventilation is best because at that time the outside air is more humid than during the day and consequently has less drying effect. In the winter, when condensed moisture should be removed with a minimum of cooling, Edgar (*12*) recommended day ventilation because then the outside air is less humid than at night and has a greater drying effect. Danger of freezing is lessened if ventilating is done when the outside air is only slightly cooler than the storage. However, under gravity circulation the air moves very slowly and therefore the cooling period must be long. This involves some risk from freezing if the outside air temperature drops suddenly during the protracted cooling period. On the other hand, effective and safe cooling can be quickly obtained by the use of thermostatically controlled fans if the storage is of such a type as to make their use practicable. Since any ventilation tends to lower storage humidity it is desirable either to have a minimum of ventilation or to prevent the dry outside air from coming directly in contact with the potatoes (as in shell-cooled storages).

In some shell-type storages ventilation is by gravity, but better results are obtained by the use of motor-driven fans, preferably with thermostatic controls. Such an arrangement improves the regulation of both humidity and storage temperature, especially in the warmer parts of the late-crop area; that is, in locations where the average January temperature is above 35° F. (See Edgar and Childers (*14*), 1947.) One arrangement for using fans and thermostats was described by Long (*25*) in 1942. The controls required are of the type used by heating and ventilating concerns in various domestic installations and should be obtainable through local dealers.

Yung (*43*) in Nebraska in 1947 described a bimetal differential thermostat that can be used in potato storage houses equipped with thermostatically controlled ventilating fans.

The extent to which the shell-type storage is being used is shown by Edgar's statements (*12, 13*) in 1947 and 1948 that at least 10 million bushels of late-crop potatoes are stored annually in shell-cooled storages.

Taintor (*38*) is the authority for the statement in 1944 that most of the large, newer potato storages in the Red River Valley are of the blow-up-through type. The bins have tightly boarded sides and are about 12 feet wide, up to 20 feet deep, and as long as is wanted. In that area some storages have the appearance of Quonset huts; these are insulated and ventilated in various ways. Similar storages were described and illustrated by Edgar, Jefferson, and Wheeler (*15*) in 1942. Taintor estimated that, if potatoes that are stored in the fall are free of bruises or rots, the loss from time of storage until they begin to sprout in the spring averages 0.5 of 1 percent a month.

MISCELLANEOUS STORAGE RECOMMENDATIONS

Potatoes when stored should be dry and reasonably free from dirt. If excess dirt accumulates in the bin or under the slatted floor, air circulation is hindered. All rotted, bruised, and badly cut tubers, as well as those that are badly scabbed, should be culled out before the crop is stored. (See Diseases, p. 125, and also Edgar (*11*).)

The storage house should be so designed and used that potatoes can be put in or removed with a minimum of labor and of damage from bruises and cuts.

The bins are often 20 feet deep and sometimes more. If the potatoes are poured through holes in the roof, serious injury from the long fall is likely to occur, even if a twisted or zigzag chute or some other kind is used. In large, deep storage cellars, filling the bins from overhead driveways or from drive alleys down the middle of the cellar is very much better than filling by means of a chute.

If potatoes are handled directly from truck to bin, padded planks to prevent bruising of the tubers should be provided in the bins for workmen to walk on while carrying the sacks or other containers or the men should wear shoes soled with sponge rubber or wrap their shoes in cloth. Mechanical pilers or elevators have been found satisfactory in some storages (*15*). The possibility of using them more extensively should be investigated. One type of piler was described and figured by Edgar, Jefferson, and Wheeler (*15*) in 1942. Edgar (*11*) in 1947, however, is the authority for the statement that where bulk potatoes are moved into bins the mechanical conveyors and pilers often cause large losses from mechanical injury.

Daylight should be excluded from the storage because the greening which it produces injures both the appearance and the eating quality of table stock.

In late-crop sections that have a relatively mild climate it is not advisable to store potatoes more than 5 or 6 feet deep. According to Lombard, Brown, and Dykstra (*24*) in 1948, when the weather is cool at digging time it may be safe to store potatoes 12 feet deep in the bins, but before spring the depth should be reduced if potatoes are to be held late. In Maine, North Dakota, and other sections having a similar winter climate, the depth may be 12 to 26 feet (*11*) although when the extreme depth is used some bruising and cracking may occur in tubers at the bottom of the bin.

Lutz (*27, p. 209*) in 1947 made the following comments on the storage of early-crop potatoes:

> Potatoes are generally grown in the south as a spring crop. Since they are harvested about 90 days after planting, they are marketed before they are fully mature. Probably the most important reason for harvesting potatoes in this immature state is that the price generally drops as the season progresses. Another reason for harvesting early in much of the south is that if the potatoes are left in the ground too long they are subject to decay both in the field and after harvest, caused by *Sclerotium rolfsii*. . . In addition some other crop usually follows potatoes and there is often a desire to remove the potatoes to make way for the succeeding crop.
>
> Immediately after the shipping season from the south ends, it is necessary to ship in potatoes from more northern points. Often southern potatoes are sold at very low prices and later, when potatoes are shipped in from the north, prices become much higher.

Tests conducted by Lutz (*27, p. 219*) in 1941, 1942, and 1944 in Mississippi justified the following recommendations:

> For best results, if the storage period is to be two or three months or less, it is suggested that potatoes be stored at 50° F. immediately after harvesting. If this temperature is not available, either 60° or 40° would be suitable, but they should be cured four days or longer at 60° to 80° before storage at 40°. It is suggested that the curing period be made as short as possible, especially

if the curing is done at room temperatures, because of the danger of decay at this relatively high temperature. For five months' storage, cured potatoes stored at 40° had the best keeping quality, although those stored immediately at 50° had fair keeping quality.

Investigations in Louisiana by Kimbrough (*23*) in 1938 and 1939 showed that spring-crop potatoes grown in the southern part of that State can be successfully kept in common (unrefrigerated) storage through the summer in the locality where they are grown. They should, of course, be carefully sorted before storage to remove all tubers affected with decay, serious bruising, and cracking. It was found in these tests that there was consistently a little less shrinkage in tubers of the Katahdin variety than in those of the Triumph variety, although the gross shrinkage in both during storage was considerable—approximately 15 to 20 percent. Triumph potatoes rotted significantly more than Katahdin potatoes.

Cordner (*3*) in Oklahoma considered refrigerated storage at 50° F. following a curing period best for the spring crop of potatoes. If refrigeration was not available, an underground storage cellar or cave was considered next best provided the temperature could be held below 70° and a fairly moist atmosphere maintained to avoid excessive shrinkage.

Results similar to those obtained in Louisiana, Mississippi, and Oklahoma could probably be expected under similar conditions in other sections where there is interest in storing part of the early crop. It is obvious that early, or spring-crop, potatoes, chiefly because of their immaturity, are not adapted to protracted storage under any conditions.

Phillips (*32*) in 1947 discussed the construction and operation of potato storages for Canadian conditions and emphasized the fact that the best results have been obtained where the storage has been designed and used for potatoes only. His recommendations for the physical features of the storage and its operations are much the same as those recommended for the colder parts of the United States. He noted that air circulation is frequently confused with ventilation. (See p. 54 of this digest.)

Long (*26*) in 1942 reported the results of temperature studies in various types of potato storage houses in North Dakota. As would be expected, differences were found in the temperatures at different levels in the bins and at corresponding levels in houses of different construction, in which air circulation was obtained in different ways (by gravity or by means of fans). There was also a gradual lowering of potato temperature in all houses from October to December or January and a slight rise in March if the period of observation included that month. For the most part, however, the differences found at comparable times or locations were small and, except during about the first 2 months of the storage season, temperatures were very close to those desirable for the storage of potatoes. After the first month the warmest potatoes in all houses were from the middle of the bin to the floor. No information is given in the publication as to what kind of instruments were used for taking temperatures or where the temperatures were taken—whether at the sides or along the center line of the bins.

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POTATOES IN STORAGE

The behavior—it might be called the physiology—of potatoes in storage is a complex subject which can be discussed adequately only by considering the operation and effects of a considerable number of factors. Among these are (1) the variety; (2) the conditions under which the potatoes were produced; (3) the condition of the potatoes when they go into storage as to degree of maturity and freedom from mechanical and heat injuries and diseases; (4) methods of grading and packing; (5) the temperature and humidity at which they are held; and (6) the length of time they are stored. The effects of vine killers (p. 31) and of treatment of the tubers with sprout inhibitors (p. 44) must also be taken into account. The ones that seem to need discussion here are shrinkage, other effects of temperature and humidity, and some of the effects of field conditions although not all of these are treated in strictly delimited sections. No attempt is made to cover in detail the subject that might be designated as the fundamental physiology of the potato tuber—an immense field, whose adequate treatment might well constitute a major enterprise in itself.

SHRINKAGE

Potatoes are alive and by virtue of that fact, they carry on within themselves several of the processes characteristic of all living things. In their respiration, the oxygen of the air is combined with carbon from sugars and other substances in their tissues, the end products being carbon dioxide and water. During this process, heat is also evolved.

Respiration causes a slight loss in weight (shrinkage), but as reported by Appleman, Kimbrough, and Smith (*2*)[16] in 1928 the principal shrinkage of potatoes in storage aside from rot is from transpiration or loss of water. This begins soon after digging and continues throughout storage and during subsequent stages in the marketing process.

A detailed table showing the relation of storage conditions to physiological losses in potatoes in storage was presented in a bulletin by Edgar (*7*) in 1938. Other data on the subject were published by Smith (*23*) in New York in 1933, Murphy (*13*) in Maine in 1945, Werner (*29*) in Nebraska in 1936, Kimbrough (*11*) in Louisiana in 1944, and Parsons (*17*) in Kansas in 1942. Figures on loss of weight in early potatoes in transit were published by Rose (*18*) in 1946. The data in all of these publications are too extensive for detailed discussion here. The general conclusion to be drawn from the storage studies is, as would be expected, that loss of weight in potatoes increases with temperature and the

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[16] Italic numbers in parentheses refer to Literature Cited for Potatoes in Storage, p. 67.

length of the storage period and decreases as humidity increases.

Smith (*22*) in New York in 1933 reported that in potatoes piled in a bin to a depth of 5½ feet, separated into three layers each 22 inches deep, the smallest loss from moisture loss was in the middle layer; the greatest was in the bottom layer; and the intermediate loss was from the top layer. He stated, however, that whether the top or the bottom layer of tubers loses most weight depends on the length of the storage period and the degree of sprouting near the end of storage.

Butler and Blood (*5*) in 1940 investigated the effect of position in the bin and temperature differences on loss of weight of potatoes in storage in New Hampshire. They found that loss of weight after 56, 120, and 186 days' storage was as shown in table 3. In bin A the air intake opened below a false floor of slatted boards; in bin B it opened into a conduit with slatted cover that ran down the middle of the bin for its entire length; and in bin C the intake opened onto the floor of the bin.

TABLE 3.—*Loss in weight of potatoes after storage periods of various length and mean temperatures at top and bottom of bin*

[Adapted from Butler and Blood (*5*)]

Bin	Loss in weight after indicated storage period			Mean temperature in bin for entire storage period	
	56 days	120 days	186 days	Top	Bottom
	Percent	*Percent*	*Percent*	*°F.*	*°F.*
A	1.56	2.22	2.53	43.92	41.65
B	1.81	2.77	3.51	42.97	41.57
C	2.26	3.46	3.86	42.98	42.71

Cordner (*6*), working with early-crop potatoes in Oklahoma in 1938 and 1939, reported that when stored without refrigeration potatoes kept best in an underground storage cellar having an average temperature of about 78° F. Immature potatoes, the skin of which was damaged by harvesting and subsequent handling, stored best at 50° following a curing period of 2 weeks. This curing treatment apparently permitted renewal of the periderm and as a result there was less loss of weight during the time they were in cold storage. Potatoes damaged by heat in the field, even before digging, were kept from decaying by immediate storage at about 50°, but had very poor keeping quality at higher temperatures.

The average percent loss in weight for the whole storage period in a sweetpotato house having a mean temperature of 84° F. was greater for Bliss Triumph than for Warba and Red Warba and greater for all three varieties in the sweetpotato house than in cold storage (mean temperature 50.8°) or in an underground cellar (mean temperature 78.0°). The average loss for all three varieties was least in cold storage.

Alban and Tussing (*1*) in 1946 in Ohio reported on loss of weight in Katahdin potatoes in various containers held in storage at 60° to 80° F. and 35° to 45° for 12 weeks. They found that during the first 8 weeks cold-storage lots lost only about one-third as much as those held at the higher temperature. After that time, the sprouting of the potatoes held at room temperature resulted in a greater difference between the lots. The total losses at the end of 12 weeks are shown for various treatments as follows:

	Loss (percent)		Loss (percent)
Cold storage:		Room temperature:	
Net bag	4.5	Net bag	13.3
Paper bag	3.2	Net bag and Brytene 489A	13.0
Paper bag and Brytene 489A	3.3	Paper bag	10.7
Paper box, wax, and ethyl naphthalene-acetate (ENA)	5.1	Paper bag and Brytene 489A	9.2

The tubers treated with paraffin wax plus 2 percent of the methyl ester of naphthaleneacetic acid showed a break-down at room temperature within 8 weeks and lost more weight than resulted from any other treatment (in cold storage).

On the basis of these results it would be necessary for paper sacks with a gross weight of 15.5 pounds when packed to reach the consumer within 5 weeks if stored at room temperature and before the end of the thirteenth week if held in cold storage, if they were to weigh not less than 15 pounds when marketed.

It was reported by Parsons (*16*) in Kansas in 1940 that washed potatoes of a low No. 2 grade in storage 5 months shrank 13.8 percent and unwashed ones of the same grade shrank 9.2 percent. In another lot the shrinkage from sorting at the end of 6 months was 15.09 percent in the washed and 10.2 percent in the unwashed lots. The potatoes were stored August 1. (See p. 26 for further discussion of the effects of washing.)

Fox (*10*) in 1942, on the other hand, reported, as a result of 2 years' work in Kansas, no appreciable difference in shrinkage of washed and unwashed potatoes. Total shrinkage in 6 months was greatest in Chippewa (9.5 percent) and least in Cobbler (7.1 percent). The greatest shrinkage occurred in the most openly woven sacks and the least in the most closely woven type. The potatoes were washed and stored the day they were dug. It would be of interest to know the stage of maturity of these potatoes, since Smith (*24*) in 1943 reported that storage losses, presumably shrinkage from moisture loss, are always greater with immature tubers than with mature ones.

During the first few weeks of the storage period, according to Edgar (*9*) in 1941, and Werner (*31*) in 1947, potatoes lose water at the rate of about 2 percent a month unless ventilation is restricted so as to hold the temperature at 55° to 60° F. and prevent the escape of moist air from the storage space. Artschwager (*3*) in 1927 showed that under these conditions the healing of cuts and bruises takes place very rapidly. This in itself is another factor that cuts down water loss. A low temperature at the beginning of the storage period is not necessary to prevent sprouting because the potatoes are then in a state of dormancy (Thornton (*27*), 1939, and p. 40 of this digest) and is actually undesirable in the opinion of Werner (*30*) because it prevents or retards wound healing.

After the preliminary curing period temperatures should be lowered; 38° F. is desirable for the storage of seed potatoes since at this temperature they will not sprout; 50° is better for table stock. During the holding period, which may last for several months, the loss of weight or shrinkage of potatoes will normally amount to about 0.5 of 1 percent a month until sprouting begins, when the rate increases very rapidly. Mature potatoes will begin sprouting in about 90 days if stored at 60° and in about 120 days if stored at 50°. Edgar (*9*) stated that when potatoes are stored at 40° sprouting will never cause much loss. (See also Rose, Wright, and Whiteman (*21*), 1949.)

About 2 weeks before potatoes are to be removed from storage their temperature should be raised to approximately 50° F. if this can be done without raising the temperature of potatoes in adjoining bins that are intended for continued storage at 40°. The higher temperature will permit periderm to form if it has not formed already and will reduce injury from bruises during grading and other handling, according to Edgar (*8, 9*), in 1940 and 1941.

Even though proper storage conditions at the proper time favor the healing processes, it has been found repeatedly that potatoes with a high percentage of mechanical injuries shrink much more in storage than those that show only a small percentage of such injuries or none at all. (Smith (*23*), New York, 1933.)

How great this handicap of injuries may be is shown by the following statements by Werner (*29, p. 35*) in 1936:

> According to the records of inspections made in the bins of certified potatoes the percentage of mechanically injured potatoes during the years 1928 to 1935 amounted to 31.1, 16.0, 16.6, 23.6, 17.6, 18.8, 9.5, and 12.7 percent or an average of 19.5 per cent for the eight years. These averages are based on the annual inspection of 200 to 380 lots totaling [each year] from 86,000 to 700,000 bushels.
>
> As the certified seed producers constitute the most expert group of growers, these figures are more likely to understate than to overstate this situation as it applies to the potato regions of the state.

The bulletin went on to say that weight losses were always greater in mechanically injured than in sound potatoes stored under the same conditions. Under the best conditions the sound potatoes in June constituted 85 to 89 percent of the October weight when whole potatoes were stored as compared with 56 to 68 percent when tubers which had been subjected to fresh mechanical injury for experimental purposes were stored.

Werner's summary (*29, p. 3*) continued as follows:

> The losses in storage increased as the severity of the damage to the tubers increased. The severity could be said to increase as the area of the cut or damaged surface increased.

Investigations in New York State in 1930–31 by Smith (*23*) showed that carefully handled and harvested potatoes lost less weight in storage than those handled in the usual way. This was true with both immature and mature tubers at the end of 1, 3, 5, and 7 months' storage. The average loss in weight of all carefully handled lots was 2.4 percent compared with 4.8 percent for those with normal handling.

Shrinkage of potatoes in storage is increased not only by mechanical injuries but also by the decay that follows such injuries and heat injury. Investigations by Parsons (*16, 17*) in Kansas during three seasons (1939–41) showed that poor-quality potatoes containing decay and heat damage shrank in weight during 6 months in cold storage about twice as much as U. S. No. 1 potatoes. U. S. commercial potatoes shrank in weight about 16 percent more than those of U. S. No. 1 grade.

Cordner (*6*) in Oklahoma in 1943 and Parsons (*17*) in Kansas in 1942 did not define the terms "heat injury" and "heat damage" as used in their reports. In other papers the terms "scald," "deep scald," "sunscald," and "sun injury" are used, all apparently to signify the same phenomenon, namely injury to potatoes by sun heat in the field. It was suggested by Rose (*18*) in 1946, on the basis of work by Rose and Schomer (*20*), reported in 1944, by other investigators in the United States Department of Agriculture, and by Nielson (*14*) and Nielson and Todd (*15*) in 1946, that such injury be referred to only as heat injury. Rose and Schomer found that potatoes can be injured by exposure to radiant heat from the sun or electric infrared lamps. According to these investigators, it is sun *heat,* not sun *light,* that causes the damage in the field. Sunlight (daylight) causes greening.

The symptoms of heat injury will not be described in this section, because they are given in the statements devoted to the subject in the section on Diseases (p. 133).

Browning of potatoes at skinned places was reported by Rose and Fisher (*19*) in 1940 to be caused by desiccation, not by heat. It is possible that some of the injury included by Cordner (*6*) and Parsons (*17*) under heat damage or heat injury consisted of browned skinned areas that had become sticky with an overgrowth of bacteria. (See Browning, p. 128.)

CHANGES IN STORAGE

The broad question as to the effect of low temperature on potatoes has been answered somewhat more specifically, in one respect at least, by Steward and others (*25*) in Great Britain in 1943 than had been done previously. In their studies disks were cut from random-sampled tubers previously stored at 35.6° F. and 51.8° and their composition with respect to carbohydrates and various nitrogen fractions was determined before and after a period of 48 hours under standard conditions normally conducive to salt accumulation, during which their respiration and bromide uptake were measured. From the results of these and other experiments the authors (*p. 254*) concluded that—

> prolonged storage of tubers at 2° C. inactivates at one and the same time the ability of the cells to grow, as shown by their healing in moist air, by their ability to synthesize protein, and by their metabolic properties such as phenolase activity, deamination of amino-acids, &c., which are linked with it.

They (*p. 245*) also stated that—

> storage at 2° C. caused the respiration of cut discs to increase progressively with storage time—the increase being perceptible before 20 days of such storage and after 200 days the respiration was approximately double that of discs from normal tubers.

When potatoes were held in 20 percent oxygen and various concentrations of CO_2, Thornton (*26*) in 1935 reported that there was an increase in the rate of respiration and in the specific conductivity of leachings from the potatoes. Under the same conditions, catalase, reducing sugars, and sucrose increased.

In Victoria Province, Australia, Tindale and Mattingley (*28*) in 1945 reported that cool storage of main-crop potatoes of the Late Carman variety is not warranted before the end of August, that is, not until the potatoes are nearing the end of the winter rest period. Cool storage in this Australian report means approximately 42° F. The authors found that at 32° potatoes have an excellent appearance but have lost greatly in cooking quality because of the conversion of starch to sugars.

Barker (*4*) in Great Britain in 1937 stated that in storage at 50° F. the sugar content of King Edward VII potatoes decreased slowly until April, remained constant until the middle of May, and then began to rise. The same sequence of changes occurred at 59°, but more quickly, the minimal sugar content, lower than that at 50°, being reached in February. At 45.5° a small increase of sugar was recorded in the first 50 days, but the sugar then decreased and in May had fallen below the corresponding figure for 50°. At 41° the sugar content increased rapidly at first and continued to increase throughout the experiment.

Kröner and Völksen (*12*) in Germany in 1941 reported that the sap of potato tubers stored in pits had a higher refraction value and a lower pH, particularly toward the end of the storage period, than that of potatoes in storage cellars. The conductivity of the sap of potatoes was about the same whether they were stored in pits or in storage cellars.

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COMPOSITION AND DIETETIC VALUE

The potato is best known as a starchy food, but it has other properties that give it high dietetic value. These are that it gives bulk, supplies the essential minerals, phosphorus, iron, and potassium in liberal quantity, neutralizes body acids, and supplies certain health-giving vitamins. (See Hardenburg (*10*),[17] 1939, quoting Canon (*3*), 1915.) Sweetman (*15, p. 372*) in 1936 referred to potatoes as—

> an economical and well-balanced food, their principal deficiencies being their relatively low calcium and vitamin A contents and, if they were to be considered as the sole or principal article of diet, their bulkiness and incomplete protein. They may be substituted for such sources of energy as sugar and milled cereals to whatever extent desired with consequent advantage to the nutritional quality of the diet.

Many analyses of potato tissue have been made, and the results have been published in what Lampitt and Goldenberg of Great Britain (*12, p. 748*) characterized in 1940 as "a vast literature." It is obviously impossible here to attempt even to summarize these published results. A choice must be made of what to present, but the reader should remember that the raw material of the potato is continually changing in composition; it is changing throughout all of its growth and during the rest period after it has been dug. Nevertheless, the variations for normal potatoes, so far as the essential constituents are concerned, fall within fairly well defined limits.

Another British comment worth quoting here is from an unsigned article in Nature (*1, p. 104*) in 1941. It reads as follows:

> The survey of the literature . . . [by Lampitt and Goldenberg (*12*), 1940] with its reference to some 250 papers, seems to prove that very few of the statements that have been made have been definitely corroborated. It was pointed out that many of the observations recorded are either fragmentary or directed towards some isolated problem. The non-static character of the potato itself is to some extent responsible for the lack of uniformity of the results obtained. Variety, age and condition of growth are all major factors in the composition of the potato, and when to these are added the fact that the potato is not homogeneous, and that the greater number of workers have failed to state whether their analyses were conducted on peeled or unpeeled tubers, the chaotic condition of the data is to be understood. Lack of details of the method used in preparing a sample for examination is one of the most common failings in the description of much of the work on "natural" products in the food world, and it is a point of interest that. . . attempts to summarize present knowledge demonstrate the great importance of such elementary precautions.

An illustration of the variability in chemical composition of potatoes appears in results reported by Thiessen (*16*) in 1947. She found, as a result of chemical analyses, that (1) no two tubers taken from the same lot had identical chemical composition; (2) there seemed to be no consistent difference in the mineral value of one variety as compared with the other. (This apparently is

[17] Italic numbers in parentheses refer to Literature Cited for Composition and Dietetic Value, p. 74.

meant to apply to Wyoming-grown Bliss Triumph and Irish Cobbler.) In the limited number of tests made, the small and medium-sized potatoes had a higher percentage of phosphorus than the large ones.

Sweetman (*15, p. 309*) in 1936 stated that—

probably the most commonly quoted figures for the average composition of potatoes in the United States are those of Atwater and Bryant (1906) based on analyses of 136 samples of the fraction usually eaten, which they considered to be the inner 80 per cent.

Atwater and Bryant's figures (*2*), together with those reported by Goldthwaite (*9*) in 1925, by Chatfield and Adams (*4*) in 1940, by Thiessen (*16*) in 1947, and by Hutchison (*11*) in 1940, are given in table 4.

TABLE 4.—*Chemical composition of white potatoes grown in the United States*

Author	Water	Protein	Fat	Carbohydrates	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Atwater and Bryant (*2*)	78.3	2.2	0.1	18.4	1.0
Goldthwaite (*9*)	77.23	2.02		19.79	0.95
Chatfield and Adams (*4*)	77.8	2.0	0.1	19.1	0.99
Thiessen (*16*):					
Wyoming potatoes	72.00 to 82.00	1.80 to 2.40	0.04 to 0.16	12.50 to 23.53	0.68 to 0.71
Potatoes from other sections	72.10 to 80.00	2.00 to 2.50	0.05 to 0.11	12.60 to 24.60	0.96
Hutchison (*11*)	81.3	0.19	0.1	15.7	0.9

Chick (*5*) in Great Britain in 1940 quoted figures for the average composition of potatoes, white bread, and whole meal (whole wheat) bread as published by McCance and Widdowson (*13*) in Great Britain in 1940. Chick's table I (*5*) is quoted as table 5. (In this connection the reader may be interested also in McCance and Widdowson (*14*), 1947.)

Chick (*5*) also quoted figures published in two tables by Fixsen and Roscoe (*7, 8*) of Great Britain in 1938 and 1940 and by Fixsen (*6*) in 1938. The data in these two tables (combined in table 6), as well as those of McCance and Widdowson (*13*), quoted from Chick, in table 5, show the importance of potatoes in the human dietary.

[TABLE 5.]—*Average composition of the potato, compared with that of white bread and whole meal bread* (*McCance and Widdowson* [(*13*)], *1940*)[1]

	Percentage composition				Calories per 100 g.		Reckoned on dry wt.		Minerals, mg. per 100 g.					
									Fe		Ca	P		K
	N	protein* (N× 5.7)	carbo-hydrate %	water	fresh wt.	dry wt.	pro-tein %*	carbo-hydrate %	Total	available		Total	available	
Potato,† raw	0.34	1.94	21	76	94	393	7.9	87	0.75	0.75	7.7	40	—	570
" peeled and boiled	0.23	1.32	19.7	80	87	435	6.6	98	0.5	0.5	4.3	29	23	325
" baked in skin (flesh)	0.41	2.35	25	71	113	389	8.1	86	0.9	0.9	9.2	48	—	680
White bread‡	1.26	7.2	54	32	260	382	10.6	79	1.0	0.9	23	73	69	115
Whole meal bread§	1.34	7.6	44	37	229	363	12.0	70	2.7	2.2	30	213	136	238

*Reckoning all nitrogenous matter as protein. †"Old," variety not stated. ‡Average of 9 samples. §Average of 6 samples.
[1]Quoted verbatim from Chick's table I (*5*).

TABLE 6.—*Vitamin B and C contents of potatoes and effect of cooking*

[Adapted from Fixsen (*6*) and Fixsen and Roscoe (*7, 8*)]

Condition or treatment	Vitamin B	Vitamin C
Raw	30–60 international units per 100 gm.	3–40 mg. ascorbic acid per 100 gm.
Peeled and boiled	25 percent lost [1]	32 percent destroyed.
Peeled or unpeeled, steamed 45 minutes		20 percent diffused. [2]
Peeled:		
Boiled 25 minutes		No loss.
2 hours in cooking box		50 percent lost.
6 hours in cooking box		90 percent lost.

[1] Probably by diffusion.
[2] In some instances an apparent increase in ascorbic acid was demonstrated.

The figures published by Werner (*17*) in 1947 and presented in table 7 are also of interest.

TABLE 7.—*Amounts of various important food constituents supplied by an average serving of potato as compared with accepted daily requirements of 1 man*

[Adapted from Werner (*17*)]

Constituent	4 ounces (113 gm.) of potatoes	Daily requirement of 1 man
Calories	85	3,000
Ascorbic acid (vitamin C) milligrams	15–50	75
Thiamine do	.14	1.8
Niacin do	1.32	18
Riboflavin do	.05	2.7
Vitamin A international units	35	5,000
Iron milligrams	10	12
Protein do		70
Calcium do		.8

The value of potatoes in preventing scurvy has been well known for many years. In addition, potatoes contain minute quantities of oxalic and citric acids and possibly traces of succinic, malic, and tartaric acids according to Lampitt and Goldenberg (*12*), in 1940. Potatoes are a good source of vitamins B and C (ascorbic acid), and they also contain vitamin A, although not in sufficient supply for the normal diet.

For a fuller discussion of the chemical composition and food value of potatoes, the reader is referred to Sweetman's bulletin (*15*) published in 1936, the paper by Lampitt and Goldenberg (*12*) published in 1940, the voluminous literature which they cite and review, review of the literature by Hardenburg (*10*) published in 1939, and other review papers cited on page 160. (See also Chick (*5*), 1940.)

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VITAMIN C CONTENT

The importance of vitamins in the diet and the long-recognized fact that potatoes are a valuable source of vitamin C (ascorbic acid), of which the discovery was reported by Szent-Györgyi (*52*)[18] in 1928, have led numerous workers to investigate the effect of various factors on that constituent of the tubers. An immense amount of work has been done, but the review of it can be shortened considerably by merely citing authorities when several agree in the results reported.

VITAMIN C CONTENT OF VEGETABLES

Tressler (*56*) in 1942 published a table showing the vitamin C content of 26 freshly harvested vegetables including potatoes, which is reproduced as table 8. It will be noted that the vitamin C content of potatoes is of about the same magnitude as that of endive, lettuce, radishes, and rhubarb, slightly greater than that of sweet corn, slightly less than that of tomatoes, and far below that of broccoli, cauliflower, kale, kohlrabi, parsley, and spinach.

TABLE 8.—*Vitamin C content of 26 kinds of freshly harvested vegetables expressed in percentage of pure vitamin C*

Vegetable	Average vitamin C	Vegetable	Average vitamin C	Vegetable	Average vitamin C
	Percent		*Percent*		*Percent*
Asparagus	0.040	Kale	0.129	Potatoes	0.015
Beets	.005	Kohlrabi	.078	Radishes	.014
Broccoli	.120	Lettuce	.015	Rhubarb	.014
Cabbage	.041	Lima beans	.042	Snap beans	.018
Cantaloup	.030	New Zealand spinach	.043	Spinach	.075
Carrots	.005	Parsley	.152	Swiss chard	.040
Cauliflower	.094	Parsnips	.036	Sweet corn	.011
Eggplant	.007	Peas	.029	Tomatoes	.025
Endive	.013			Turnips	.042

RELATION OF VITAMIN C CONTENT TO VARIETY AND FERTILIZER TREATMENTS

Scheunert, Reschke, and Kohlemann (*46*) in 1940, Wachholder and Nehring (*60*) in 1940, Westas (*64*) in 1941, Murphy, Dove, and Akeley (*33*) in 1945, Tedin (*53, 54*) in 1939 and 1941 reported that the vitamin C content of potatoes seems to bear no relation to

[18] Italic numbers in parentheses refer to Literature Cited for Vitamin C Content, p. 90.

variety or fertilizer treatment. Scheunert, Reschke, and Kohlemann found no relation between vitamin C content and fertilizers, and Kröner and Völksen (*26*) in 1941 reported none between vitamin C content and varieties.

On the other hand, Wachholder and Nehring (*59*) in 1938, Zilva and Barker (*68*) in 1939, Esselen, Lyons, and Fellers (*10*) in 1942, Karikka, Dudgeon, and Hauck (*22*) in 1944, Werner and Leverton (*62*) in 1946, Baker, Parkinson, and Lampitt (*2*) in 1946, and Baker, Parkinson, and Knight (*1*) in 1948 reported that they found differences in vitamin C content, sometimes only slight, between different varieties of potatoes. In the last two papers, both from a British journal, the authors attempted a rough classification of potato varieties as to their vitamin C content. Kröner and Völksen (*25*) in 1941 stated that it is not yet possible to recommend the discarding of potato varieties that are poor in vitamin C. Murphy, Dove, and Akeley (*33*) in 1945 concluded from their results that genetic constitution is undoubtedly a determining and limiting factor in vitamin C synthesis in plants, although in potatoes they found a wide overlapping of values among varieties and wide variations within varieties. There seems to be varietal stimulation or depression in vitamin C synthesis in response to external factors.

Branion and others (*7*) in 1947 stated that ascorbic acid content of any given variety seemed to be fairly constant, no matter where it had been grown.

Baker, Parkinson, and Lampitt (*2*) in 1946 reported that nine varieties of potatoes analyzed in October and November 1945 could be arranged in descending order as to vitamin C content from 0.22 down to 0.13 mg. per 100 gm. In March 1946 after storage in pits these figures had a range of 0.15 to 0.11 mg. per 100 gm. (a much narrower range than earlier) and the order of varieties as to vitamin C content had changed slightly. They added the comment (*p. 429*) that—

> the average figure obtained in 1946 is higher than the average figure obtained in 1943 by an amount roughly equal to the average figure found in 1946 for the concentration of dehydroascorbic in the potatoes, i.e., 0.05 mg./g.

The average concentration of dehydroascorbic acid was appreciably higher than had hitherto been found in potatoes. The effect of varying manurial treatments on potatoes grown on experimental plots did not appear to be significant.

Baker, Parkinson, and Knight (*1*) in 1948 in a paper on the same subject reported that they found certain significant varietal differences in the vitamin C content of potatoes (1946 crop). On the basis of these and previously obtained figures they attempted a rough classification of some potato varieties as to their vitamin C content. They found again that the application of different manurial treatments to potatoes of the same variety did not seem to have any significant effect on vitamin C content. The content of dehydroascorbic acid found in the 1946 crop was about normal; hence they concluded that the high values obtained for potatoes of the 1945 crop were caused by some seasonal factor. They gave vitamin C analyses for 13 varieties at harvest and after storage of 5 to 6 months. These, they found, can be grouped as high, average, and low in vitamin content.

It seems clear that further research is needed on vitamin C content of potatoes as affected by variety and fertilizers.

EFFECT OF OTHER EXTERNAL FACTORS EXCEPT STORAGE ON VITAMIN C CONTENT

Lyons and Fellers (*29*) in 1939 reported that vitamin C content was rather constant from the first digging until the potatoes were fully matured and there were no consistent differences between large and small tubers.

Wachholder and Nehring (*60*) in 1940 reported that the vitamin C content of potatoes was influenced much more by the kind of soil on which they were grown than by variety or fertilizer.

Tedin (*53, 54*) in 1939 and 1941 reported, as have other investigators, that there are great differences in vitamin C content between different tubers from one small plot of a potato variety. Samples from widely different parts of Sweden showed in some cases great differences in this respect and in other cases no difference. In some cases a particular variety had either a high or a low content in all places where tested; in others a given variety had comparatively low vitamin C values in some places and high in others.

Esselen, Lyons, and Fellers (*10*) in 1942 reported that in general there was no significant difference in the vitamin C content of a variety of potatoes grown in widely separated States in the United States.

Westas (*64*) in 1941 reported that the vitamin C content of potatoes is not influenced by fertilizers. Soil type has some effect; a sandy soil is better than a clay one although in a dry season a clay soil was better. Loss of vitamin C during storage varied greatly among varieties.

In the work of Woods and Bolin (*66*) published in 1944 it was found that new potatoes have extra antiscorbutic value. This finding has also been reported by other workers.

Murphy, Dove, and Akeley (*33*) in 1945 and Werner and Leverton (*62*) in 1946 reported variations from year to year in the vitamin C content of potatoes. Werner and Leverton found that potatoes grown on dry land generally had more ascorbic acid than those grown on irrigated land. Lampitt, Baker, and Parkinson (*28*) in 1945 reported no significant differences in vitamin C content between potatoes of one variety grown on silt land and black land. According to Werner (*61*) in 1945 potatoes from green vines are superior in vitamin C content to those from mature or dead vines; straw-mulched potatoes have higher values than nonmulched potatoes.

Murphy, Dove, and Akeley (*33*) in 1945 reported that (1) raw potatoes grown in Aroostook County, Maine, in 1942 had ascorbic acid values comparable with those of raw tomatoes; (2) locality differences, when they occurred, seemed to be the result of extraneous influences that vary with season and locality; (3) there was no relation between vitamin C content and the shape of the tubers;

(4) there was a tendency for parents that bear tubers having high vitamin C values to produce offspring that bear tubers medium high to high in vitamin C content and for parents that bear tubers low in vitamin C to produce offspring that bear tubers medium low to low in vitamin C; (5) correlation coefficients between ascorbic acid values and resistance to 13 common diseases were very low; (6) 20 late-maturing varieties averaged 3.8±0.56 mg. per 100 gm. higher in ascorbic acid values than 10 early-maturing varieties. Since the latter were immature when dug, the physiological age of the tubers may have been responsible for the difference.

Scheunert and Reschke (*45*) in 1940 reported that in potatoes that had been frozen and then thawed there was some reduction in the vitamin C content but that the reduction occurred during the thawing, not during the freezing or while the potatoes were in a frozen condition. They believed that destruction of the cell structure during thawing hastens the oxidation of vitamin C.

Smith and Gillies (*47*) in Scotland reported in 1940 that the concentration of ascorbic acid is greater in tubers affected with leaf roll than in tubers presumed to be healthy. In healthy tubers the concentration reaches a maximum in August and decreases rapidly thereafter.

Kröner and Völksen (*25*) in 1941 reported from their investigations that it is possible that virus diseases may affect the vitamin C content of potatoes.

DISTRIBUTION OF VITAMIN C IN THE TUBER

Kröner and Völksen (*24*) in 1938 reported that vitamin C occurs in higher concentration in the pith than in the outer tissues, is higher at the bud end than at the stem end, and is never deposited just under the skin. Therefore, ordinary kitchen preparation of potatoes for cooking removes only the parts that are poor in vitamin C. This is not in agreement with the results of Wolf (*65*) in 1940 and Julén (*19*) in 1941.

Wolf (*65*) in 1940, as a result of investigations on the distribution of vitamin C in the potato, reached the following conclusion: The skin of the potato is richer than the inner part in the form of ascorbic acid that is directly titratable with dichlorophenolindophenol. (This is the reduced form, the one that occurs most commonly.) If with this is included the dehydroascorbic acid, the vitamin C content of the skin is 8 to 46 percent greater than that of the inner part. The author, like Roe and Oesterling (*43*), stated that the dehydro form of the vitamin has antiscorbutic value.

Esselen, Lyons, and Fellers (*10, p. 10*) in 1942 reported that—

> there was an even distribution of vitamin C in the raw tuber itself, with a lesser amount in the skin.

During the cooking process, however, something happens to change the distribution, so that the vitamin C content is greater in the central than in the outer portion. Esselen, Lyons, and Fellers considered it possible that (1), when potatoes are either boiled or baked, the temperature of the outer portion remains higher than that of the inner portion throughout the cooking process and

(2), when potatoes are boiled, there is some loss of the vitamin through the leaching action of the cooking water.

Lampitt, Baker, and Parkinson (*28*) in 1945 reported that when storage conditions did not induce sprouting (37.4° F. in the dark) the concentrations of vitamin C in the eyes, in the peel, and inside of the tuber were not significantly different but that when sprouting occurred the concentration of vitamin C in the sprouts and in the eyes carrying sprouts was usually much higher than in the remainder of the tuber and often greater than that in the unsprouted tuber. The concentration of vitamin C in new tubers tended to increase with period of growth and was greatest just before normal harvesting time. The highest vitamin C content was found in the leaves. These authors determined the distribution of vitamin C in the stem and bud ends, but did not consider their results conclusive.

Julén (*19*) found that at time of sprouting vitamin C accumulated in the eyes and to a greater extent in the sprouts than in the tubers. He also found more vitamin C in the outer part of the tubers (a layer about 5 mm. thick) than in the inner part.

VITAMIN C CONTENT AS AFFECTED BY STORAGE

Investigators have found, in general, that vitamin C in potatoes decreases in storage and the loss is greater the lower the storage temperatures. Wachholder and Nehring (*59*) in 1938 said that it decreases steadily from harvest until spring; Rolf (*44*) in 1940 reported that it is much more dependent upon the time that elapses after harvest before the potatoes are consumed and the temperature at which they are held; Werner and Leverton (*62*) in 1946 stated that it is lost at a fairly constant rate in storage at a given temperature but that the loss steadily increases as the temperature is lowered. These last authors stated that potatoes stored continuously at 40° F. lost as much vitamin C by mid-November as others stored at 50° or 60° lost by late February or March.

In contrast to Werner and Leverton, other workers found that the loss in vitamin C was most rapid during the first part of the storage period. (See Lampitt, Baker, and Parkinson (*28*), 1945; Zilva and Barker (*68*), 1939; Scheunert and Reschke (*45*), 1940; and Murphy (*32*), 1946. The results reported in some of these and other papers are summarized in table 9.)

Mayfield and others (*31*) in 1937 reported on the effect of winter storage on the vitamin C content of potatoes grown in Montana. They found that Netted Gem (Russet Burbank) after 6 months in a warm, dry cellar (55° to 60° F.) had not lost in vitamin C content according to both animal and chemical tests. The same variety in a cool, damp cellar (37° to 46°) had not lost in vitamin C in the raw state according to animal tests, but had lost one-third, as determined chemically. After cooking, the loss in vitamin C was about 45 percent by both animal and chemical tests.

Bliss Triumph after 6 months in a cool, damp cellar had lost one-third to one-half of its vitamin C content, according to both animal and chemical tests, when analyzed in the raw state, and

TABLE 9.—*Vitamin C content of potatoes as affected by storage*

Authors and kind of storage	Storage temperature	Length of storage	Storage period	Peeled or unpeeled	Loss in storage	Variety
	°*F.*	*Months*				
Mayfield and others (*31*):						
Warm, dry cellar	55–60	6		Unpeeled [1]	0	Russet Burbank.
Cool, damp cellar	37–46	6		Unpeeled [1]	⅓	Russet Burbank.
Warm, dry cellar	55–60	6		Unpeeled [1]	20 percent	Bliss Triumph.
Cool, damp cellar	37–46	6		Unpeeled [1]	⅓ to ½	Bliss Triumph.
Kroker (*23*)	(2)		Harvest to following September.	Unpeeled	⅔ to ¾	(2).
Wachholder and others (*58*)	(2)		October to June.	Peeled	100 percent	(2).
				Unpeeled	25 percent	
		Weeks				
Zilva and Barker (*68*)	50	3		Unpeeled	22.9 mg. per gram	(2).
Scheunert, Reschke, and Kohlemann (*46*).	(2)		October to December	Unpeeled	3 mg. per gram	(2).
			December to February		3 mg. per gram	
			February to April		2 mg. per gram	
			April to June		1 mg. per gram	
		Months				
Esselen, Lyons, and Fellers (*10*).	36; 40–50	6		Peeled and unpeeled.	16 to 50 percent [3]	(2).
Fellenberg and Wuhrmann (*11*).	(4)		Harvest to middle of January.	(2)	54 percent	(2).
			Harvest to July.		58 percent	
Woods and Bolin (*66*)	(2)		Harvest until between February and May.	(2)	Slightly more than 3 times as much in new tubers as in others.	Russet Burbank.
Lampitt, Baker, and Parkinson (*28*).	(2)		Harvest until end of December.	Unpeeled	0.2 gm. per gram	(2).
			Harvest until January		0.2 mg. per gram	
			Harvest until following July.		0.2 mg. per gram	

Branion, Roberts, and Cameron (*6*).	([4])	6–7		Unpeeled	60 to 70 percent	Chippewa, Cobbler, Green Mountain, Katahdin, Dooley, Warba.
Werner and Leverton (*62*)	40			([2])	Ascorbic acid lost in storage at fairly constant rate. Those stored at 40° lost as much by mid-November as those stored at 50° and 60° by late February or early March.	Triumph and Red Warba.[5]
	50					
	60					

[1] Apparently.
[2] Not stated or not given.
[3] Data not differentiated for peeled and unpeeled.
[4] Common storage.
[5] Used most extensively.

55 percent, according to animal tests, after cooking. In a warm, dry cellar this variety lost 20 percent from the raw potato according to both animal and chemical tests. There was further loss on cooking, according to animal tests, but the percentage of loss was not stated. No loss was shown by chemical tests.

In these tests storage temperature was not controlled very closely and hence the results reported can hardly be considered as reliable or informative as those reported from other work in which temperature was controlled within narrow limits.

Wachholder and others (*58*) in 1938 recommended using certain (named) varieties early in the storage season, certain others midway in the storage season, and still others toward the end. The choice made depends on which varieties lose their vitamin C early and which retain it longer or longest. It is possible that this procedure might prove advantageous within limits with varieties grown in the United States.

Fellenberg and Wuhrmann (*11*) in 1942 reported that even in the spring and summer the vitamin C content of potatoes harvested the fall before is large enough to make them a valuable source of the vitamin during the transition period of the year when the food available is poor in vitamins. (This would lose some of its force if applied to conditions in the United States, because of the great variety of fresh vegetables available on our markets the year round.)

Karikka, Dudgeon, and Hauck (*22*) in 1944 reported that ascorbic acid tends to decrease more slowly in potatoes stored at 50° F. than in those stored at 40°.

Murphy (*32*) in 1946 reported the changes in vitamin C content of six varieties of potatoes held at 32°, 36°, 50°, 60° or 65°, and 70° F. for 7 months in two successive seasons. Mohawk with the highest average value and Chippewa with the lowest decreased 22.7 to 6.3 mg. per 100 gm. of tissue in 7 months. One-third to one-half the loss occurred during the first month. Vitamin C was retained best at 50°. Her results are summarized in table 10.

TABLE 10.—*Losses of vitamin C from potatoes stored for 7 months at different temperatures (Fahrenheit)*

Variety	Loss in vitamin C in indicated season and at indicated temperature (°F.)									
	1943–44 [1]					1944–45 [2]				
	32°	36°	50°	65°	70°	32°	36°	50°	60°	70°
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Mohawk	35	56	36	42	52	44	66	51	59	62
Green Mountain	55	52	29	31	32	64	63	47	51	59
Sebago	74	73	51	48	52	76	75	58	65	63
Irish Cobbler	67	69	53	43	43	76	78	55	60	55
Chippewa	55	58	50	40	40	64	66	58	63	58
Katahdin	65	72	52	47	50	65	67	51	58	58

[1] Least significant difference at 1-percent level 11; at 5-percent level 9.
[2] Least significant difference at 1-percent level 8; at 5-percent level 6.

Zilva and Barker (*68*) in 1939 published that the vitamin C content decreases rapidly in storage.

Kroker (*23*) in 1938 reviewed an extensive literature on the physiology, composition, and vitamin C content of potatoes appearing from 1885 to 1937. His conclusions as to vitamin C content, based on this review, are as follows:

1. The vitamin C content of potatoes in storage from harvesttime to the following September is reduced by two-thirds to three-quarters.
2. It does not appear that the vitamin C content of potatoes can be preserved any better at 40° F. than at temperatures existing in the usual storage cellar.

Results published by Van Stuivenberg (*51*) in 1947 show that vitamin C is present in potatoes immediately after harvest in varying amounts but after storage for some months all varieties show about 10 mg. per 100 gm.

Branion, Roberts, and Cameron (*6, p. 422*) in 1947 reported that—

the ascorbic content of potatoes decreased during storage, so that at the end of 6 to 7 months after harvesting, 60 to 70 percent of that originally present had been lost.

Baker, Parkinson, and Knight (*1*) in 1948 found that values for stored potatoes are very low. One variety retained vitamin C very well in storage. No influence of various fertilizer treatments upon the vitamin content could be detected in the varieties tested.

CARBON DIOXIDE STORAGE AND VITAMIN C

Thornton (*55*) in 1938 reported that when Green Mountain potatoes were exposed to 30 to 60 percent of CO_2 for various periods at 77° F. during the first 15 days after harvest their ascorbic acid content was reduced by 16 to 40 percent. Carbon dioxide accumulating from respiration of the tubers caused a reduction of 8 percent in the ascorbic acid content. (One might question here whether the CO_2 was responsible for all of the reduction in vitamin C or whether part of the reduction was merely the result of natural causes. Other authors (see p. 79 of this digest) have found that the vitamin C content of potatoes decreases very rapidly for a short time after harvest.) The gas had no detectable effect on the ascorbic acid content of Green Mountain potatoes 150 days from harvest. Results obtained by Van Stuivenberg (*51*) showed that storage in CO_2 is accompanied by a great initial loss of vitamin C but that later on the content does not differ from the 10 mg. per 100 gm. found in potatoes in ordinary storage.

Kröner and Völksen (*26*) in 1941 found that vitamin C values were less in pits than in cellars. The pits were found to contain a higher percentage of carbon dioxide than the cellars and the authors suggested that this difference may account for the irreversible decrease in vitamin C. They believed that the changes in pH and vitamin C during the CO_2 storage (in the pits) are a further proof that vitamin C is closely connected with the transformation of other materials and properties.

EFFECT OF METHODS OF COOKING ON VITAMIN C

Most of the authors who have expressed themselves on the matter have stated that the best way to preserve vitamin C during cooking is to boil or steam potatoes in their jackets and the poorest is to peel potatoes and then boil them. However, all methods of cooking—boiling, steaming, baking, french frying, and frying as in a saucepan—cause some loss. Most loss occurred in mashed potatoes. (See Wachholder and Nehring (*59*), 1938; Lyons and Fellers (*29*), 1939; Rolf (*44*), 1940; Olliver (*36*), 1941; Esselen, Lyons, and Fellers (*10*), 1942; Richardson and Mayfield (*41*); Karikka, Dudgeon, and Hauck (*22*), 1944; Van Duyne, Chase, and Simpson (*57*), 1945; and Streightoff and others (*50*), 1946.)

Richardson, Davis, and Mayfield (*40*) in Montana in 1937 reported the following results from their work on the vitamin C content of potatoes cooked in various ways: (1) Boiling potatoes for 35 minutes at 203° F. (at 4,800 feet above sea level) caused no loss of the vitamin; (2) steaming for 45 minutes seemed to increase vitamin C; (3) there was a slight loss when potatoes were held in a pressure cooker at 17½ pounds' steam pressure for 12 minutes; (4) some loss occurred when potatoes were fried in butter; (5) mashed potatoes, with milk, butter, and salt added, were comparable to boiled potatoes in vitamin C potency; (6) escalloped potatoes retained all of their original vitamin C but the vitamin C per gram was reduced by the large quantity of milk added.

Wachholder and Nehring (*59*) in 1938 stated that loss in vitamin C on boiling can be very considerable, but is very different among varieties. Potatoes grown with mineral fertilizer did not have less and often had a greater vitamin C content than those grown with barnyard manure. Potatoes grown with barnyard manure were usually more sensitive to boiling (lost more vitamin C), but the difference in vitamin C content between the two groups cannot be explained on the basis of a difference in oxidase content. In evaluating potato varieties as a source of food, it is vital to take into account their sensitiveness to boiling.

Olliver (*36*) in 1941 reported that the loss of ascorbic acid in cooking is in nearly all instances of small practical importance compared with the variation in antiscorbutic value of the raw material. She emphasized that keeping vegetables hot for protracted periods should be rigorously avoided. When potatoes have to be kept hot, as on a steam table, some loss in vitamin C is unavoidable.

Esselen, Lyons, and Fellers (*10*) in 1942 reported that the best method of cooking so far as retention of vitamin C is concerned was boiling whole and unpeeled in salted water.

Daum, Aimone, and Hollister (*8*) in 1943 reported that during cooking losses of ascorbic acid in new potatoes were 6.6 percent and in old potatoes, 10.0 percent; after holding for 1 hour on the steam table the losses increased to 50.0 and 44.4 percent, respectively.

Rolf (*44*) in 1940 reported that boiling pared potatoes, the method most commonly used, caused the greatest loss in ascorbic acid. Losses caused by other methods of cooking are smaller and fairly comparable.

Karikka, Dudgeon, and Hauck (*22*) in 1944 found that in their cooking tests about two-thirds of the vitamin C content of the raw tuber remained after it had been boiled.

Van Duyne, Chase, and Simpson (*57*) in 1945 reported that peeled, halved Chippewa potatoes held in a refrigerator 24 and 70 hours after boiling lost 53 and 82 percent, respectively, of their original ascorbic acid content.

Wertz and Weir (*63*) in 1946 reported that steam-cooked potatoes lost an average of 54 percent of their original ascorbic acid content and mashed potatoes lost 52 percent of the ascorbic acid in the cooked potato.

EFFECT OF LENGTH OF BOILING AND STARTING TEMPERATURE OF WATER

Janse-Stuart and Bever (*17*) in 1938 reported that the procedure in the cooking vessel, as well as the time of keeping the cooked foods (potatoes) warm, has a marked influence on the vitamin C content. Peeled potatoes boiled for 5 minutes and then kept 3½ to 4 hours in the boiling vessel contained 50 to 90 percent less vitamin C, depending on variety and age, than potatoes boiled done in 15 minutes.

Julén (*19*) in 1941 reported that long boiling (up to 60 minutes) of unpeeled potatoes causes very little reduction in vitamin C. Most American workers recommend only enough boiling to get the potatoes done.

Tedin (*54*) in 1941 reported that peeling or boiling by steam decreases the content of vitamin C. He also reported that more vitamin C is preserved if potatoes are put into cold water than if the water is boiling. He felt that this result needs confirmation and should direct the interest of investigators to further study of cooking methods.

Randoin and Gachignard (*39*) in 1941 reported that losses in vitamin C were least when potatoes were put directly into boiling water, higher when they were put into cold water and brought to boiling, and greatest (up to 100 percent) when potatoes were boiled slowly in a kettle.

SMALL-SCALE VS. LARGE-SCALE COOKING

The chief point made by authors who investigated the effects of large-scale cooking for institutions, restaurants, and hotels is that the long periods during which potatoes are likely to be kept warm in such places are very destructive to vitamin C. (See Heller, McCay, and Lyon (*14*), 1943; Woods and Bolin (*66*), 1944; Gleim and others (*12*), 1946; Bolin and Woods (*4*), 1946.)

Streightoff and others (*50*) in 1946 studied the changes in vitamin content of mashed, steamed, boiled, and baked potatoes. Because of the significant loss of the vitamin during holding, they recommended that potatoes be consumed as soon as possible after being cooked. Long cooking by any of the methods used was found to be undesirable. Their summaries of the results of other investigators on vitamin C losses in potatoes in small- and large-scale cooking are given in tables 11 and 12. (See also table 6.)

Jenkins (*18*) in 1943 stated that during 3 hours' standing at room temperature mashed potatoes lost more ascorbic acid than did whole potatoes. Mashing small quantities of potatoes had no immediate effect on their ascorbic acid content, but if they were subsequently heated the rate of loss of the vitamin was greatly accelerated. If the mashing took more than a short time, there was some loss during the process.

Kahn and Halliday (*20*) in 1944 reported that steaming in the skins was the only method that caused no loss of ascorbic acid in potatoes. French-fried potatoes showed a small loss when the temperature of the fat was kept constant; if it was allowed to vary or if the fries were allowed to stand after cooking, the potatoes so prepared could not be considered a reliable source of ascorbic acid; baked potatoes lost 20 percent of their ascorbic acid

TABLE 11.—*Loss of ascorbic acid in small-scale preparation of potatoes* [1]

[Adapted from table 1 of Streightoff and others (*50*)]

Author [2]	Loss with indicated method of preparation					
	Boiled	Pressure-cooked	Steamed	Baked	Mashed	French-fried
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Lyons and Fellers (*29*)	40					
Kahn and Halliday (*20*)			[3] −2	[3] 20, 58	39	23
Oser, Melnick, and Oser (*38*)	12		2			
Richardson and Mayfield (*41*)	19, [3] 0	11				
Van Duyne, Chase, and Simpson (*57*)	13, [3] −3	15	14	[3] 12, [3] 12		
				[3] 13, [3] 22		
Esselen, Lyons, and Fellers (*10*)	27–53			[3] 2, [3] −66	54–69	33
Halliday and Noble (*13*)	18–52					
Richardson, Davis, and Mayfield (*40*)	4	2–12	0–10		9–21	
Higgins	58					
Olliver	39					
Smith and Caldwell (*48*)	25				55	
McGregor	10, 11, 16	0	8			
Ireson and Eheart (*16*)	11					

[1] Losses calculated from peeled potatoes unless noted otherwise.
[2] Italic numbers in parentheses refer to Literature Cited for Vitamin C Content, p. 90. Citations for names not followed by such numbers can be found in Streightoff and others (*50, pp. 126–127*).
[3] In jackets.

TABLE 12.—*Loss of ascorbic acid in large-scale preparation of potatoes* [1]

[Adapted from table 2 of Streightoff and others (*50*)]

Author [2]	Loss with indicated method of preparation					
	Soaked	Steamed [3]	Mashed	Baked	Boiled	French-fried
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Booth and others ("Marrack") (*5*)	9					
Wertz and Weir (*63*)	3	55, 58	79			
Streightoff and Kornblum	2	16	34	[4] 28		16
			[5] 63	[5] 42		[5] 35
Kardo-Sysoeva and Ulanova (*21*)		40				
Nagel and Harris (*35*)		–68				
Heller, McCay, and Lyon (*14*)		51, 90				
Orent-Keiles, Hewston, and Butler (*37*)			80	56, 72	60	
				[4] 50		

[1] Losses calculated from peeled potatoes unless noted otherwise.
[2] Italic numbers in parentheses refer to Literature Cited for Vitamin C Content, p. 90. Citations for names not followed by such numbers can be found in Streightoff and others (*50, pp. 126–127*).
[3] Includes values for potatoes steamed with and without pressure.
[4] In jackets.
[5] After standing warm for 1 hour.

during baking and a total of 59 percent after standing 43 minutes on a steam table. Mashed potatoes and creamed potatoes lost 39 percent of their ascorbic acid during steaming and 95 percent after preparation and standing on the steam table.

Branion and others (*7*) in 1947 reported that the percentage loss of vitamin C during cooking was less from new (freshly harvested) potatoes than from old potatoes. Loss of vitamin C from uncooked potatoes standing in water after peeling was low, but loss during storage in a refrigerator after cooking was high. Cooking potatoes in their jackets is a better method of preserving vitamin C than any method that involves the cutting or breaking up of the potatoes.

METHODS OF ANALYSIS

It is probably advisable to use some caution in drawing conclusions from discussions and data published hitherto concerning the vitamin C content of potatoes, as well as of other vegetables. To realize the correctness of this attitude, it is only necessary to consider the results published in several fairly recent papers.

Mack and Tressler (*30*) in 1937 reported on an investigation of the Tillmans method for the determination of ascorbic acid in vegetables. For routine analysis they recommended the use of an acid which is ionized sufficiently to prevent enzymic oxidation of ascorbic acid and the reduction of other substances that may interfere with the analysis by reacting with the titration reagent.

Roe and Oesterling (*43*) in 1944 described a method of determining dehydroascorbic acid and ascorbic acid by means of the color reaction of 2,4-dinitrophenylhydrazine. According to these authors all three possible forms of ascorbic acid—the reduced form, the dehydro form, and the bound form—are biologically available. It seems advisable, therefore, that under conditions where more than one form exists, or is believed to exist, methods of analysis should be used that will determine (1) the quantity of each one present or (2) the total ascorbic acid.

Holtz and Reichel (*15*) in 1940 stated that the ascorbic acid in plant tissues occurs in part in the bound form. By the use of a method which they described they were able to demonstrate it in potatoes, carrots, apples, onions, celery, and sauerkraut, but not with certainty in cauliflower, radishes, and turnips, which contain very large amounts of free ascorbic acid. Bound ascorbic is biologically available, according to these authors, as is also the dehydro form.

Kröner and Völksen (*27*) in 1943 credited Lauersen and Orth (reference not given) for raising the question concerning bound ascorbic acid and for pointing out the great uncertainty of current (1943) determinations of vitamin C.

By means of a method by which dehydroascorbic acid as well as ascorbic acid can be determined it was shown by Woods and Bolin (*67*) in 1945 that the total ascorbic acid in cooked potatoes may vary considerably from that found by the dye (2,6-dichlorophenolindophenol) method because of the dehydroascorbic acid that may be present. Both methods give about the same results if potatoes are analyzed immediately after baking; if they are held for some time, however, considerable amounts of dehydroascorbic acid may be formed and the dye method of analysis (2,6-dichlorophenolindophenol) will not give the true value.

Bolin and Woods (*4*) in 1946 reported that ascorbic acid in warm potatoes changes very quickly into another form known as dehydroascorbic acid. This has antiscorbutic properties but is not detected by the method of chemical analysis commonly used for ascorbic acid. The method used by Woods and Bolin (*67*) in 1945 that will detect this second form of the vitamin was used for further analysis.

The authors believed that the discrepancies among results as to vitamin C content of potatoes reported by various investigators may be due to the method of analysis used and the variety and stage of maturity of the potatoes, but most probably are due to the differing lengths of time allowed to elapse between cooking and serving and the temperature at which the potatoes are held during that time.

Three other papers worthy of attention in making analyses to determine the vitamin C content of potatoes may be mentioned.

Roe (*42*) in 1936 described a method for determining ascorbic acid as furfural. This, he said, is of value for its high specificity for the determination of ascorbic acid in tissues to which the indophenol titration may not be applied as a method for determining dehydroascorbic acid.

Musulin and King (*34*) in 1936 described a modification of an older titration procedure to include the presence of 2 percent metaphosphoric acid with acetic acid or trichloracetic acid during extraction and titration.

Bessey (*3*) in 1938 described a photoelectric indophenol method of determining small quantities of dehydroascorbic acid in turbid or colored extracts.

Among other authors who have taken account of the possible presence of dehydroascorbic acid in their material are Esselen, Lyons, and Fellers (*10*) in 1942, Wachholder and others (*58*) in 1938, Branion and others (*7*) in 1947, Kröner and Völksen (*25*) in 1941, and Werner and Leverton (*62*) in 1946.

Souci (*49*) in 1948 cautioned that in the determination of the vitamin C content of plant tissues by chemical methods—for example, that in which the sodium salt of 2,6-dichlorchinophenol nitrogen is used—there are several sources of error that need to be considered. The avoidance of these cannot always be satisfactorily accomplished. Many results given in the literature of the subject are of limited value and therefore in need of being reviewed, since it is not certain whether sufficient account has been taken of the possibility that such errors might have affected the results. In particular, the results of rapidly conducted series of determinations are in many instances to be questioned.

In the first place, determining l-ascorbic acid without at the same time taking account of the dehydroascorbic acid can justify no conclusion as to the vitamin C value of a given food material. In addition, the retarding, or inhibiting, influence of many accompanying substances on the oxidation of the vitamin should be considered. In many instances one has to reckon with the presence of either chemically or absorptively bound ascorbic acid. If one determines ascorbic acid by titration with an indicator of reoxidation the presence of different, either originally present or newly produced, accompanying substances may bring about a reduction and thereby simulate vitamin C or augment its apparent value. Especially when food materials are heated this kind of reducing substance may be formed.

In order to obtain an approximately correct picture of the vitamin C content of a food material by means of chemical methods, it is desirable to compare the results obtained by several methods and to consider these in the light of the possible sources of error mentioned above. Such a procedure will take time, but not as much as is required for a biological assay.

Dodds, Price, and Moore (*9*) in 1948 made such a comparison as Souci recommended in their report on vitamin C values obtained from analyses of sweetpotatoes. The methods compared were (1) the indophenol method of Loeffler and Ponting, (2) the indophenol-xylene extraction method of Robinson and Stotz and the formaldehyde modification of it, and (3) the 2,4-dinitrophenylhydrazine method of Roe and Oesterling for dehydroascorbic acid and total ascorbic acid. The two indophenol methods gave results that were in agreement. The results obtained by the 2,4-dinitrophenylhydrazine method for total ascorbic acid and dehydroascorbic acid did not show agreement with those obtained by the indophenol methods and were variable.

VITAMIN C PROBLEMS NEEDING FURTHER INVESTIGATION

In further investigations on this subject work appears to be needed on the following:

1. The vitamin C content of potato varieties. Is it constant, reasonably constant, or variable?
2. Distribution of vitamin C in the tuber. Does paring remove much or little of the vitamin?
3. Methods of analysis and a determination as nearly as possible of the relative quantities of the three possible forms of ascorbic acid (dehydroascorbic acid, the reduced form, and bound ascorbic acid) after different cultural conditions and during and after storage at different temperatures. Such research should also deal with the question of how important it is to determine the three different forms of the acid.
4. Relative vitamin C content of immature and mature potatoes that are otherwise comparable.

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COOKING QUALITY

The most comprehensive discussion of factors affecting cooking quality of potatoes that has been found in surveying potato literature for this digest is that of Sweetman (*34*) [19] in Maine, which appeared in 1936. She reviewed publications on the subject issued from 1895 to 1935 and one paper published in 1936. In Sweetman's bulletin cooking quality of potatoes is defined as the rating given them according to accepted standards of palatability when cooked. It is questionable whether there exists at present a set of standards generally accepted by investigators. If not, it seems possible that the formulation of such a set by a committee of investigators would be of use to all concerned. An obvious advantage that can be foreseen, if agreement could be reached as to procedure in investigating an admittedly complex problem, is that workers in different parts of the country would be using, or could use, the same terminology in reporting their results. In this connection, Sweetman's remarks (*34, p. 377*) relative to conflicting statements in published reports on cooking quality of potatoes (down to 1936) are very much in point. She wrote as follows:

> These [statements] are probably due to the subjective nature of the standards of evaluation used, to incomplete control of all variables other than the one tested, and to the interrelationship and cumulative effect of different factors. A mechanical test for mealiness is needed.

(This was written before the development of the specific-gravity test for determining potato quality.)

M'Intosh (*17*) in 1942 defined cooking quality, as understood by Scottish consumers, as a composite character, the main components of which are mealiness, consistency, that is, the retention of shape, combined with ease of mashing, definite but not earthy flavor, and white to pale-yellow color. He found it unfortunate that at the time he wrote there was no standard objective method of judging cooking quality, and in this he agreed with Sweetman (*34*), who investigated the subject about 6 years earlier. He pointed out a fact well known in this country, though not often explicitly stated, that new potatoes and mature potatoes are judged by different standards.

Haddock and Blood (*13, p. 126*) in 1939 stated that—

> cooking quality, as considered by most investigators, includes (a) texture (mealiness), (b) flavor, and (c) color of flesh after cooking.

The more important conclusions presented in Sweetman's bulletin (*34*) are given here as a basis for comparison with the results of subsequent research:

> 1. The physiological changes taking place in potatoes during cooking include hydrolysis of the protopectin and solution of the pectin with resulting increase in ease of separation of the cells. In addition there is at least partial

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[19] Italic numbers in parentheses refer to Literature Cited for Cooking Quality, p. 102.

gelatinization of the starch, softening of the cellulose and more or less caramelization of the sugar. (See also Sweetman (*33*), 1933.)

2. The qualities of most importance in judging the palatability of cooked potatoes are texture, cohesion, color, and flavor. Most consumers in the United States prefer a high degree of mealiness, no sloughing, a snowy white color when potatoes are baked, boiled, or mashed, a light golden brown when they are fried, and a characteristic, mild flavor. (See Consumer and Market Preferences, p. 121.)

3. It is apparently not possible to predict, on the basis of external appearance or internal anatomy, the degree of mealiness that a potato will show when cooked.

4. Tubers vary considerably in mealiness even when grown in the same field, as well as when grown under different conditions. Every year some varieties tend to be more mealy than others.

5. Environmental factors such as temperature and rainfall, acidity and fertility of the soil, diseases, cultural practices, and storage conditions probably affect mealiness, although only the last has been extensively investigated under controlled conditions. According to several investigators, a temperature of 50° to 60° F. is desirable, at least for a period of 2 weeks before use.

6. Solanin, acids, ash constituents, and sugar probably account for much of the taste of potatoes, but flavor is a composite of taste and odor and the odoriferous components are not known. It is common knowledge that exposure of potatoes to daylight causes them to turn green. What is not so commonly known is (1) that during this light greening solanin accumulates in the greened part of the tuber and (2) that solanin is a highly undesirable and even toxic substance so far as human consumers are concerned.

Sweetman (*34*) stated in 1936 that there is apparently a wide optimum range for proportion of potash in fertilizers under Maine conditions, as measured by relative mealiness. Cobb (*9*) in 1935 reported that temperature and variety are the most important factors affecting mealiness. According to his results varieties which mature late benefit from lower average temperatures during the period of tuber formation. In contrast with Sweetman (*34*), who found a positive correlation between percentage of starch or dry matter and mealiness but many exceptions to the general rule, Smith and Nash (*28*) in 1939 reported that the percentage of starch and the protein-starch ratio apparently do not affect the mealiness of potatoes.

O'Connor (*20*) in Ireland said in 1948 that it is recognized that there are three factors concerned in potato quality: Color, texture, and flavor. Color means freedom of potatoes from blackening when boiled and allowed to cool. Texture may be close and sticky at one extreme and broken and mealy at the other. Flavor is a matter of taste, but bitter, insipid, and sweet tastes are not likely to be confused. Taste tests have shown that quality is influenced by site, variety, and fertilizer treatment, site being by far the most important factor. O'Connor stated further that it cannot yet be foretold whether a given soil type will give potatoes that blacken after boiling. In the tests carried out blackening occurred on potatoes from both limy and acid soils. He thought it probable that blackening is not influenced by the acidity of the soil, although if a little vinegar is added to the boiling water blackening is decreased.

Potash increased yield and was the only element that decreased blackening to any extent. Phosphate increased mealiness, but nitrogen fertilizers did not give consistent results. Barnyard manure decreased blackening on potash-deficient soils, but it tended to give excessive mealiness resulting in watery and broken tubers on boiling.

Major differences in quality may be caused by weather conditions. Parker (*21*) in England commented in 1932 on the need for a mechanical or objective method for measuring the quality (cooking quality) of potatoes. He stated that up to that time the only method that had been found useful was actual tasting of cooked tubers by a trained staff who rated the samples under test by comparing them with a control variety which had proved to be uniform throughout the season.

Such tests showed that there was exceedingly little variation in the results of tests obtained at different times, that differences in districts in which the potatoes were grown resulted in greater quality differences than did differences in variety among those already popular, that color after cooking and, to some extent, consistency of flesh were influenced by soil rather than by variety; flavor seemed to be a varietal rather than an environmental character.

Freeman (*12*) in 1941 described a new technique for scoring baked potatoes by scoring dried slices of the baked tubers. He claimed the following advantages: A permanent set of standard samples is always available for direct comparisons; the dried slices from each experiment may be kept as a permanent record of the assay; samples may be exchanged by different laboratories thus affording standardized scoring systems. The technique is based on the familiar observation that the cells of mealy potato tissue tend to separate, whereas the cells of waxy tissue adhere closely to one another. This method of Freeman's and the specific-gravity method (p. 99) may be considered a partial answer to Sweetman's suggestion (*34*) that more objective tests are needed for the evaluation of cooking quality in potatoes.

Briant, Personius, and Cassel (*7*) in 1945 reported results indicating that the degree of mealiness of cooked potatoes may be associated with some of the physical properties of the starch of the raw tubers.

RELATION OF VARIETY TO COOKING QUALITY

American investigators agree that variety is the most important factor affecting the cooking quality of potatoes. M'Intosh (*17*) in 1942 in Scotland was of the same opinion. Pollard (*22*) in 1947 in Great Britain put site first. Stevenson and Whiteman (*32*) in 1935 concluded (1) that there are inherent differences among varieties, because in their tests one variety tended to maintain better cooking quality than another over a wide range of conditions; and (2) that if comparisons are to be made between two varieties it is necessary to know that they were grown under very similar conditions. Nash (*18*) reported that Green Mountain and Pioneer Rural were more mealy than Houma, Sebago, Katahdin, Warba, Irish Cobbler, Pontiac, Chippewa, and Earlaine. The last 3 were usually the least mealy. The importance of varietal differences was also stressed by Thiessen (*35*) in 1947, Blood and Prince (*5*) in 1940, and Smith (*25*) in 1945.

Jehle and McPheeters (*14*) reported on the cooking quality of 21 varieties of potatoes grown in Maryland. Their results are summarized as follows:

General purpose:
- Green Mountain
- Potomac
- Irish Cobbler
- Smooth Rural
- Pontiac
- Russet Rural
- Triumph
- Earlaine
- Sebago
- Earlaine 2
- McCormick

Baked:
- Potomac
- Russet Burbank
- Smooth Rural
- Russet Rural
- Green Mountain
- Pontiac
- Sequoia
- Triumph
- Up-To-Date
- McCormick

Chips and french fries:
- Spaulding Rose
- Smooth Rural
- Russet Rural
- Warba
- Chippewa

Steamed:
- Pontiac
- Potomac
- Triumph
- Spaulding Rose
- Irish Cobbler
- Dakota Red

Boiled:
- Green Mountain
- Potomac
- Pontiac
- Smooth Rural
- Dakota Red
- Irish Cobbler
- American Giant
- Mesaba

Salad:
- Chippewa
- Katahdin
- American Giant
- Dakota Red
- Mesaba

Brasher (*6*) in 1944 reported that in baking tests with certain varieties of potatoes in Delaware, Sebago and Katahdin were judged best on taste, color, and texture followed in order by Dakota Red, Chippewa, Green Mountain, Irish Cobbler, Sequoia, Houma, and Pontiac.

RELATION OF FERTILIZERS AND OTHER FACTORS TO COOKING QUALITY

Fertilizer treatments usually have been found to be definitely of less importance than variety in determining cooking quality. Smith and Nash (*27, 28*) in 1938 and 1939 reported better cooking quality when boron in the form of borax, 20 pounds to the acre, was applied to the soil than when it was not applied, but they found no consistent differences in cooked potatoes from different fertilizer treatments. From further work reported in 1942 (*31*) these authors concluded that environmental factors other than nutrition are of major importance in determining the cooking quality of potatoes. Thiessen (*35*) in 1947 reported that potatoes of excellent cooking quality were produced on both dry and irrigated land during favorable seasons, although the same variety varied in quality from one year to another. She concluded that there are inherent differences in cooking quality between certain varieties when grown under the same conditions from year to year.

Blood and Haddock (*4*), on the other hand, stated in 1939 that the fertilizer ratio has a pronounced effect on the cooking quality (mealiness) of potatoes. Fertilizers with a relatively high potash ratio decreased the cooking quality of potatoes. Extra phosphorus increased cooking quality slightly. Unlike Smith and Nash (*27*), Blood and Haddock found that boron seems to improve the appearance of potatoes but does not improve their cooking quality.

Nash and Smith (*19*) reported in 1940 that, in tests on shading of potato plants, combined with various fertilizer treatments, periodic shading in every treatment decreased the specific gravity, dry weight, and mealiness. They (*p. 865*) suggested that—

differences in the amount of sunlight and alterations in the amount of sunlight during the period of tuber formation may be important in explaining the differences in quality of potatoes grown in different regions and in different years.

In a study on the sloughing, or "cooking to pieces," of potatoes, Barmore (*1*) found in 1937 that there is close relation between starch and softening as measured by the penetrometer. According to his report, there is a time in the cooking of potatoes during which they do not soften further and may actually become more firm. In 1938 the same author (*2*) reported that when potatoes slough on boiling, the property is caused by the turgidity of the tubers and that the tendency to disintegrate will decrease if tubers are stored in a relatively warm place (about 65° F.) for a few days before cooking.

Pyke and Johnson (*23*) reported in 1940 that a saturated solution of calcium sulfate (artificial hard water) serves admirably to control sloughing. The total salinity of cooking water should be about 1 percent.

SPECIFIC GRAVITY AND COOKING QUALITY

Apparently the first investigators who reported the use of the specific-gravity method for determining dry-matter content and cooking quality of potatoes were Bewell (*3*) in 1937 and Haddock and Blood (*13*) in 1939. In both investigations the method was found to be rapid, easy to use, and practical, and its application in determining quality in potatoes was recommended. As a result of this early use of the method, Bewell (*3*) reported that high dry matter means good cooking quality, whereas low dry matter means poor cooking quality.

In 1940 Clark, Lombard, and Whiteman (*8*) presented further evidence of the usefulness of the method. Since that time numerous papers have appeared concerning investigations in which it has proved to be a valuable adjunct to other tools of research. (See Blood and Prince (*5*), 1940; Haddock and Blood (*13*), 1939; Smith and Nash (*29*), 1940, (*30*), 1941; Pyke and Johnson (*23*), 1940; Dunn and Nylund (*10*), 1945; De Willigen (*36*), 1942; LeClerg (*16*), 1947; Smith and Ellison (*26*), 1946; Smith (*25*), 1945; Fineman (*11*), 1947; Kunkel, Shall, and Binkley (*15*), 1948.)

Conclusions as to factors affecting or determining potato quality which have been reached by the use of the specific-gravity method are about the same as those based primarily on cooking tests. Here again variety has been found to be the most important factor, outranking fertilizer treatments, location, climatic conditions, and soil type in this respect. (See Haddock and Blood (*13*), 1939; Blood and Prince (*5*), 1940; Pyke and Johnson (*24*), 1941; LeClerg (*16*), 1947; Smith (*25*), 1945.)

Studies by Smith and Nash (*30*) in New York in 1941 on the effect of fertilizers on specific gravity showed (1) that specific gravity and dry weight increased as fertilizer applications are increased from 1,000 to 3,000 pounds per acre, (2) that irrigated tubers were lower in specific gravity at each application than those not irrigated, (3) that tubers from plants receiving the heaviest potash and nitrogen applications were lower in specific gravity, dry-weight percentage, and texture rating than those receiving the least potash and nitrogen, and (4) that immature tubers were lower in specific gravity than mature tubers from the same fertilizer treatments. From their results Pyke and Johnson (*24*) in Colorado concluded in 1941 that potatoes of relatively high specific gravity more nearly meet requirements as to starch content, mealiness, chip color, and chip yield than those of low specific gravity. In Minnesota Dunn and Nylund (*10*) in 1945 reported that the greatest differences in specific gravity were between potatoes from different locations. A nitrogenous fertilizer had no apparent effect on specific gravity and a phosphate fertilizer only a small effect. When potash fertilizers were used, the chloride caused a marked reduction and the sulfate none. Smith and Nash (*29*) in 1940 also reported that a fertilizer in which potash was in excess reduced the specific gravity. However, in their tests the highest specific gravity and the most mealiness were found in Green Mountain potatoes grown on plots on which potatoes are grown every year and which receive no fertilizer or cover crop.

In work by Smith and Ellison (*26*) it was found that specific gravity and mealiness of potatoes decreased as the rate of application of fertilizer increased and also that in areas (in New York State) where potatoes matured in cool weather the potatoes were of higher specific gravity and greater mealiness than those produced in warmer areas. Smith and Ellison further reported that spraying potato vines with the methyl ester of alpha-naphthaleneacetic acid resulted in potatoes of reduced specific gravity.

In work by Smith and Nash it was found that the average specific gravity and mealiness of potatoes increased with increase of pH of the soil from 4.88 to 5.30 up to 6.73 to 7.19.

De Willigen (*36*) in 1942 concluded from a review of previous literature on potatoes that (1) information concerning the relation between specific gravity and starch and dry-matter content was at that time incomplete; (2) when new potatoes or potatoes from different localities are being investigated it is especially important to determine starch by chemical analysis; (3) the composition of potatoes, especially their starch content, can vary greatly from one tuber to another; and (4) starch content is affected by soil, variety, fertilizers, and the incidence of disease.

Haddock and Blood (*13*) in 1939 from their study of the cooking quality of different varieties recommended that the sample used should consist of at least 50, preferably 100, tubers. From this work they reported that Irish Cobbler, Russet Rural, Warba, and Smooth Rural are somewhat lower in quality than Green Mountain and Red McClure; also that the quality of varieties varies from field to field and that some varieties are relatively higher in quality than others, regardless of cultural conditions. Varieties of the same specific gravity in the raw state are very similar in cooking quality.

In the work reviewed on pages 99 and 100, the specific-gravity method for determining cooking quality of potatoes seems to have been used only on a laboratory scale. Recently, however, considerable interest has developed in the possibility of using it on a commercial scale for separating out, from large quantities of potatoes, the potatoes that could be sold as being definitely of good cooking quality. In furtherance of this interest, a project has been authorized under the Research and Marketing Act for a study of the problem.

In applying the specific-gravity test to potatoes, two or more solutions of common salt (sodium chloride) may be used, depending on the number of grades into which the tubers are to be separated. Different varieties and different lots of the same variety vary in the proportion that will fall into any particular grade based on specific gravity.

The proportion of dry matter, mainly starch, in potatoes is the chief factor that determines their mealiness when cooked. Consequently, the principle underlying the specific-gravity test and one well established by experience is that the potatoes that sink, even in the stronger solution used, are the highest in starch and so are the most mealy when cooked.

Those who use the method should realize that there are practical difficulties in judging a lot by sample because of the variability there may be among potatoes of a given lot. They should also realize that frequent testing of the solutions by means of a spindle (hydrometer) is needed in order to keep them at a constant strength. Dilution may be brought about in various ways, but chiefly by moisture adhering to the potatoes.

FURTHER RESEARCH PROBLEMS

Research is still needed on (1) differences in cooking quality of varieties as affected by cultural conditions, including fertilizers, part of the country where the crop is grown, and time of harvest; (2) effects of storage temperature and length of the storage period; and (3) effect of vine killers and sprout inhibitors. Some of these problems are now being investigated intensively under projects of the Research and Marketing Administration. In addition it still seems to be as desirable as in 1936 when Sweetman's bulletin (*34*) was published to develop a mechanical test for determining degree of mealiness. In fact, research on all phases of the problem would probably be aided greatly by the development of various other tests as objective as the specific-gravity method, with less dependence on subjective methods that may give widely different results, depending on the training and experience of the investigator. Tests that might be useful would be a mechanical measurement of the color of the cooked product, a mechanical or physical measure of sogginess, and increased use of chemical analyses to measure pectic constituents of tubers before and after cooking. A standard cooking temperature and standard length of cooking period would be useful in making the results of different investigators comparable. It does not seem possible that a mechanical test will ever be developed for measuring the flavor of cooked potatoes. There is no substitute for the taster's tongue and sense of smell.

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DARKENING OF POTATOES ON COOKING

Darkening of potatoes on cooking is a major problem in many parts of the United States in connection with the use of potatoes in the home, in restaurants and hotels, and also in commercial processing. It was particularly troublesome in dehydrating some varieties of potatoes during World War II. Investigations dealing with it fall roughly into two groups: (1) Those that attempt to discover the relation of the chemical composition of tubers to blackening; and (2) those that seek to learn whether, and to what extent, external factors have a determining effect. Several investigators have studied the influence of both internal and external factors.

Work reported by Tinkler (*22*)[20] in Great Britain in 1931 indicated that blackening after cooking is probably due to oxidation but cannot be due to enzymic oxidation because during cooking the temperature is about 212° F. for approximately 20 minutes. Furthermore, if a portion of a potato that blackens after cooking is placed at once in an atmosphere free of oxygen and there allowed to cool, it does not blacken.

Tottingham and his coworkers (*13, 23, 25, 26*) in Wisconsin from 1936 to 1943 published the results of investigations of the chemical composition of potatoes in relation to their propensity to darken after cooking. The only consistent relation they found was that potatoes that darken after cooking contain relatively high proportions of free amino acids, particularly tyrosine; they reported also that tyrosinase activity is higher in such potatoes than in those that do not darken.

Robison (*11*) in Great Britain reported in 1941 that she had found no correlation between the development of the pigment and the activity of the enzyme tyrosinase as estimated by the Warburg technique and none between blackening and the tyrosine content of the potatoes.

In the work by Tottingham and his coworkers, incidence of darkening did not seem to be determined by degree of maturity of the tubers, storage at high temperature, disturbance of balance of the content of different minerals in tubers, content of reducing sugars, the total reduction function in potato flesh, ascorbic acid content, mineral nutrition of the plant, heat, drought, or a combination of the last two factors. In 1943 Tottingham and others (*26*) concluded that darkening of potatoes after cooking is an inherited varietal characteristic. One of their reasons for this statement is that they found few consistent differences in degree of darkening because of different fertilizer treatments.

Riemann, Tottingham, and McFarlane (*10*) in 1944 investigated potato varieties with respect to their propensity to blackening

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[20] Italic numbers in parentheses refer to Literature Cited for Darkening of Potatoes on Cooking, p. 111.

after cooking. The whitest cooking varieties, Bliss Triumph and Chippewa, showed only half as much blackening as the two dark-cooking varieties Rural New Yorker and Russet Rural. White-cooking tendencies shown by the closely related Chippewa, Katahdin, and Sebago varieties suggested to these investigators that the three varieties carry genetic factors for white tuber flesh after boiling. They concluded, as did Tottingham and others (*26*) in 1943, that the tendency of certain varieties to cook dark is an inherited characteristic.

Nash and Smith (*7*) in New York reported in 1940 that in fertilizer plots to which nitrogen had been added the incidence of blackening was increased by shading.

Ross and Tottingham (*12*) in Wisconsin reported in 1938 abnormal proportions of free amino acids and tyrosine in discoloring potatoes, 30-percent and 40-percent increase, respectively. Discoloring tubers showed a considerable increase of the tyrosine equivalent during autolysis, as compared with normal tubers. The authors believed that increase of free amino nitrogen does not result primarily from abnormal activity of proteolytic enzymes.

Tottingham and Clagett (*24*) reported in 1941 that their investigations indicated that departure from the normal respiratory relations after harvesting is a primary cause of darkening of boiled potatoes. They based this statement on their finding that the polyphenolase system in potato tubers is much more active in the oxidation of catechol than of tyrosine; they took this to indicate that compounds of the latter type may not accumulate in proportion to the capacity of the tuber for discoloration. (See also Clagett and Tottingham (*2*), 1941.)

Bandemer, Schaible, and Wheeler (*1*) in Michigan in 1947 concluded from their research that moisture is a dominant factor in the discoloration of cooked potatoes, but that its influence is upon some more directly involved component. They found that discoloration increased with increased moisture content and decreased pH.

Nutting (*8*) in 1942 reported the isolation of a gray pigment and a yellow flavonelike pigment from water extracts from discolored potatoes by chromatographic absorption. A similar yellow pigment was obtained from nonblackened tubers. The property of the gray pigment and the blackened portions from which it was separated were unlike those of the melanin from raw potatoes.

Nutting and Pfund (*9*) in 1942 concluded from their studies that the blue-black stem discoloration of cooked potatoes, designated as blackening, is the result of an oxidation which, however, cannot involve tyrosinase or any other enzyme whose activity is destroyed at 208° F. Blackening was markedly decreased or entirely prevented by the use of cooking waters of pH 4.1 to 4.9, but a tough layer was found on the outside of tubers so cooked. Blackening was unchanged or only slightly increased by cooking waters of pH 8.4 to 10.0.

Lewis and Doty (*5*) in 1947 isolated a colorless precursor of the pigment which caused some white potatoes to turn gray or black when cooked. This substance was fluorescent and unsaturated and contained a carbohydrate group and a nitrogenous group, probably an amino acid or a peptide. It contained no tyrosine or tryptophan. (See Wager (*28*), Great Britain, 1947.)

Robison (*11, pp. 777-778*) in Great Britain stated in 1941 that the black discoloration which develops in some potatoes on boiling cannot be melanin, because the color disappears rapidly in acid solutions at about pH 3.0, whereas at this pH melanin is quite stable. The tentative hypothesis was suggested that—

> in the raw tubers the precursor of the black pigment exists in the form of ferrous iron bound in a loose complex, possibly in combination with proteins. This complex is hydrolysed on boiling and the iron is then precipitated as a colourless ferrous compound, probably the hydroxide, which is gradually oxidized to the black oxide as air penetrates to the tissues.

In 1941 a similar theory was advanced by Cowie (*3*), who reported that he had found the typical gray to black discoloration that developed after boiling was confined to tubers grown on potash-deficient plots in association with a relatively high nitrogen level in the soil.

Wager (*27*) in 1945 concluded from his studies that stem-end blackening is caused by a single pigment whose color is reversibly affected by pH and that variation in the degree of blackening between different stocks results from the presence of different amounts of this pigment. On the basis of his own results and those reported by Nutting (*8*) in 1942 and Robison (*11*) in 1941 he considered it fairly certain that the pigment is not melanin.

Wager (*28*) in Great Britain reported in 1947 that potatoes dug early are on the average less liable to stem-end blackening (after cooking) than those dug later, that the amount of blackening increases during storage at 46.4° F., and that certain samples develop much stem-end blackening if stored at a low temperature immediately after digging. He suggested that the results reported by Smith, Nash, and Dittman (*21*) in 1942 and by Smith and Kelly (*19*) in 1944, in which the amount of stem-end blackening was reduced by very high temperatures or anaerobic conditions, were probably due to a reduction in the pH of the tubers and to a change in the total amount of the precursors present.

Wager (*28*) in 1947 reviewed American and British work on the darkening of cooked potatoes and suggested the following as a possible explanation: One or more precursors (A) are formed in the tops and move into the tubers and there are transformed into a second precursor or a group of precursors (B). During cooking the B precursors are changed to one or more compounds which are oxidized by atmospheric oxygen to the stem-end blackening pigment. According to this theory, the products of the A precursor would be increased by low temperatures during the last stage of growth. They may possibly be degradation products formed during the death of the tops.

The results of a rather thorough investigation of the darkening of potatoes were published in a series of papers by Schmalfuss and his collaborators dating from 1938 to 1943. In the first paper Schmalfuss, Stelzner, and Kröner (*18*), 1938, began by noting the well-known fact that wounded (cut or peeled) potatoes or juice from them darkens on contact with the air. They also noted the difficulties encountered in the preparation of potato starch, since the darkening of the ground-up potatoes or the juice thereof is likely to cause an undesirable color in the starch. They found, however, that the darkening was less troublesome during the drying of potatoes because the ground-up tubers used for this purpose are passed over steam-heated rollers and the potato "mash" is dried rapidly and consequently darkens less than the flesh of raw tubers. They also noted that in Germany potato flour is particularly difficult to keep white without considerable effort and expense. The undesirable color here is presumably owing to the off-color of the starch. Schmalfuss, Stelzner, and Kröner distinguished three kinds of darkening: (1) Darkening on heating, (2) natural darkening, and (3) darkening that occurs because of excitants or accelerators for darkening that get into the potato mass during processing.

Under heat darkening they left out of consideration the darkening that may occur in diseased potatoes and that which occurs in certain sound tubers and varieties after simple boiling, since these can be sorted out. With the topic thus limited they stated that the causes of heat darkening are essentially two: (1) Dark-colored substances that may be produced by the heating of starch and (2) melaninlike substances that may be formed by means of heat-stable oxygen carriers.

They defined natural darkening (a propensity which they considered heritable) as that which occurs when injured (cut or peeled) potatoes are exposed to the air. Such darkening is not limited to potatoes but occurs in many other plants and in animals including man. In order for such darkening to occur, Schmalfuss, Stelzner, and Kröner (*18*) and Schmalfuss (*14*) stated that the following conditions are necessary:

1. A suitable color precursor, for example, a phenol derivative such as tyrosine.
2. At least one excitant or activator.
3. Sufficient oxygen.
4. A minimal quantity of oxygen consumer.
5. A suitable quantity of water.
6. A suitable degree of acidity.
7. A suitable temperature.

By oxygen consumers they meant substances that take up oxygen more rapidly than the precursor does.

Of these seven conditions, five are inherent in potatoes and two are furnished by the environment. They do not operate separately, but as a composite partly with and partly against each other. For example, if the water content of the system is reduced, the contents of precursor and of activator increase and favor darkening. On the other hand, if the reduction in water content increases, the relative content of ascorbic acid also increases, an unfavorable degree of acidity occurs, and the propensity to darken is reduced. (See also Schmalfuss and Bumbacher (*15*), 1943.)

Darkening by iron refers, of course, to darkening caused by iron or iron salts in the cooking water. Experiments in which comparison was made between the degree of darkening of potatoes peeled and cooked without any contact with iron or iron salts and of comparable potatoes similarly treated except that the cooking water contained a small quantity of an iron salt were described. By a method developed by the authors it was possible to determine the degree of iron darkening, that is, the difference in degree of darkening between the two samples. The effect, as understood by Schmalfuss and his coworkers, of different quantities of precursor and of activator on darkening is shown in figure 2. (So far as known this description, textual and graphic, has not been confirmed by other workers. However, it seems worthy of further study and testing. As understood by the reviewers, the method for measuring iron darkening gives a quicker reading than one that would determine only what Schmalfuss, Stelzner, and Kröner (*18*) and Schmalfuss (*14*) called natural darkening. It would be useful, moreover, in connection with the processing of potatoes.)

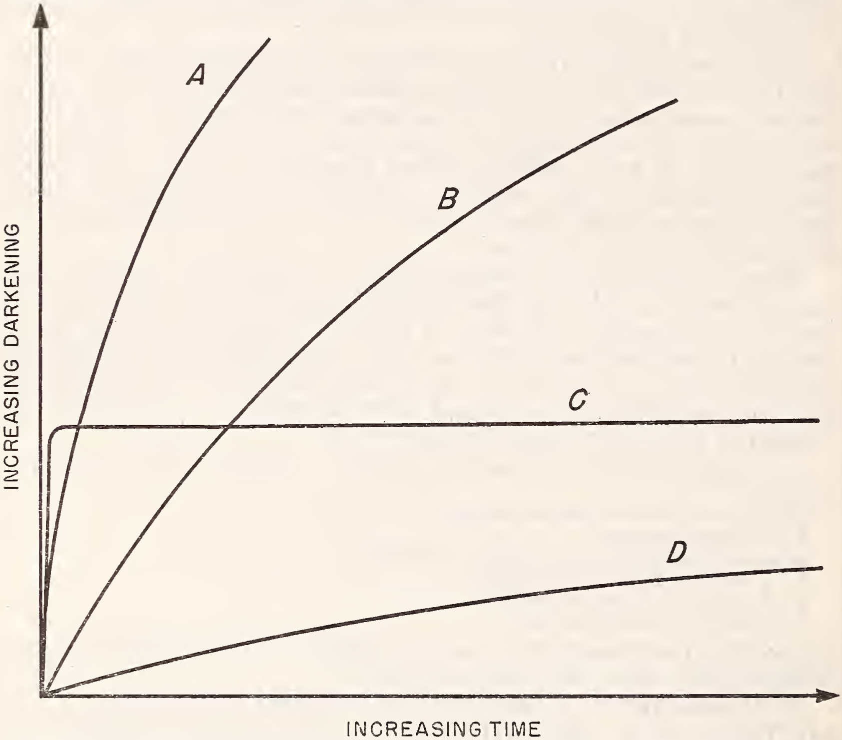

Figure 2.—Effect of different quantities of precursor and of activator on darkening of potatoes after cooking. *A*, Much precursor and much activator; *B*, much precursor and little activator; *C*, little precursor and much activator; *D*, little precursor and little activator. (Adapted from Schmalfuss, Stelzner, and Kröner (*18*), 1938, and Schmalfuss (*14*), 1940.)

Using the methods just discussed, Schmalfuss and Stelzner (*17*) in 1942 took up the problem of developing varieties that would not darken on cooking and tested 362 varieties, mostly old ones. Of these 17 cooked without darkening, 231 darkened moderately, 15 became moderately dark to dark, and 99 became dark. In another lot of 49 varieties, 2 did not darken on cooking, 29 became moderately dark, 13 moderately dark to dark, and 5 dark. After various field tests Schmalfuss and Stelzner concluded that the degree of darkening shown by a potato variety is a property that is very easily modified by the environment in which it is grown, so that it is very difficult to determine precisely what behavior on cooking is typical for a variety. They found, for example, that the variety Ovalgelbe, which cooked dark at the beginning of their field tests, had so changed after 6 years' culture that the tubers failed to darken at all after cooking. It is possible that some of this change was the effect of light and temperature, as described by Smith, Nash, and Dittman (*21*) in 1942, and by Wager (*28*) in 1947, although it is not likely that there would be secular changes in light and temperature that would cause a gradual change in the propensity of potatoes to darken.

Schmalfuss, Schmalfuss, and Pezold (*16*) in Germany in 1943 in a further discussion of the subject noted as an accepted fact that boiled potatoes darkened more strongly in the presence of iron than in its absence. This, they thought, might result in three ways:

1. Fe ions form dark-colored iron compounds directly.
2. Fe ions are capable of hastening the usual darkening.
3. Fe ions are capable of bringing about a kind of darkening that is not usual in their absence.

The authors described a procedure for determining differences among potato varieties as to immediate and subsequent darkening, 1 and 3 just listed, but the details do not seem properly to belong in this digest. They might be of interest to American investigators who care to consult the original paper. (See also p. 106.)

In 1938 Kröner and Schmalfuss (*4*) in Germany recommended that thin disks of potatoes believed likely to darken after cooking be spread out on a moving belt freely exposed to the air. Those that have the property of darkening to an objectionable degree will darken quickly enough to make the dry disks dark or off-color. This procedure will show which lots or varieties are suitable and which unsuitable for the preparation of dried potatoes.

Schmalfuss and Bumbacher (*15*) in Germany in 1943 concluded from their investigations that free l-tyrosine is a color precursor of potatoes. They suggested further problems for investigation as follows:

1. How much l-tyrosine the different varieties of potatoes grown in Germany contain on the average.
2. Why many varieties darken beyond red and why many beyond brown.[21]
3. Whether, along with l-tyrosine, there are other color precursors in potatoes.

(The question can be raised whether the precursor mentioned here, l-tyrosine, is the same as the precursor assumed by Wager (*28*) in 1947.)

Smith and Kelly (*19*) in New York in 1944 discussed and described methods for preventing the graying of potatoes during dehydration. Since dehydration is not now so important a factor in the utilization of potatoes as it was during World War II, no more will be done here than to cite the paper.

Evidence from research on the relation of external factors to the darkening of potatoes after cooking has been more enlightening

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[21] In a color series devised by the authors for use in their investigations.

than that from chemical analyses. Nash (*6*) in 1941 reported that in New York varieties which were the most mealy showed the greatest amount of blackening. He also reported that varieties which mature under higher temperatures and more favorable light conditions show a lesser degree of blackening than those maturing when temperatures are lower and light conditions are less favorable. A more specific statement concerning this relation was made in New York in 1942 by Smith, Nash, and Dittman (*21*), who reported that little or no blackening after cooking was found in potatoes that matured under mean temperatures of 70° F. or higher, whereas potatoes that matured under mean temperatures of 60° or less usually blackened on cooking. In parts of the State (New York) in which blackening is a serious problem, the growing of earlier maturing varieties than Pioneer Rural, Green Mountain, and Sebago wherever feasible might be worth while. Exposure of tubers known to blacken severely to a temperature of 100° for 3 to 4 days prevented practically all blackening when they were boiled. No evidence that helped to explain this effect of high temperature was obtained. The authors reported that if hydrogen-ion concentration is increased, as can be done by storage at high temperatures, storage in certain gases, or boiling in certain acidified solutions, blackening is decreased. Hydrogen-ion concentration is decreased and blackening increased by boiling in certain alkaline solutions. The results of this research were further confirmed by Smith and Nash (*20*) in 1942 and Smith and Kelly (*19*) in 1944.

Smith and Nash (*20*) summarized this series of studies with the statement that their results would lead one to believe that environmental factors other than nutrition are of major importance in determining the cooking quality of potatoes (referring particularly, of course, to blackening after cooking). Wager (*27*) in 1945 mentioned the work of Cowie (*3*) who in 1941 reported that variety and agricultural conditions influence the liability of tubers to blacken.

Further research is needed on differences among varieties with respect to blackening or graying after cooking of potatoes grown in different parts of the country and as early and late crops in the same field. This should give additional information on the incidence of blackening as affected by growing conditions, particularly light intensity and soil and air temperatures during the period when the tubers are maturing. Attention probably should be given also to testing out Wager's theory (*28*), 1947, that precursors whose formation in the vines is stimulated by low temperature eventually move down into the tubers and are there changed into compounds which are oxidized into a black or blue-black pigment by cooking. Attention might well be given also to the suggestions made by Robison (*11*) in 1941 (p. 106 of this digest) as to the possible relation of iron to tuber darkening. Work on this phase of the problem might show the applicability of results from earlier chemical studies that have heretofore seemed to be without significance. The problem is also one of developing varieties that in addition to having other desirable characteristics, do not darken on cooking.

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PROCESSING AND BYPRODUCTS

Two serious problems that confront the potato industry—continuing surplus production and declining per capita consumption—have already been mentioned (p. 2). According to Taylor (*18, p. 175*),[22] of the American Farm Bureau Federation, in 1948:

> The most promising method for increasing consumption would seem to be a substantial improvement in the quality of the potatoes marketed. Although there is great need for further research on this subject, it seems that consumption could be enlarged considerably if the consumer is offered a good quality of potatoes at all times, which obviously is not the case now.
>
> The substantial shift in certain producing districts to red varieties emphasizes the demand for a better quality of potatoes. At least a portion of the shift of acreage to the irrigated areas from other producing districts reflects the same desire for superior potatoes, especially those which are well adapted for baking purposes. There is much to be done to provide new varieties which will be more suited to production and consumption needs.

Superior-quality potatoes are needed not only for sale in the fresh state direct to consumers, but also for chip making, french "fries" sold canned in the frozen state, and dehydration.

Dehydration has not been much of a factor in the utilization of potatoes since the war ended.

Industries that at present can use low-grade and cull potatoes are those that make potato flour, potato starch, and industrial alcohol. Possibly other uses can be found. One that seems promising is mentioned in a quotation by Taylor (*18, pp. 178–179*), from a report issued by the United States Bureau of Agricultural and Industrial Chemistry. The quotation reads as follows:

> Correlation of available data on the feeding value of dried potatoes for cattle, sheep, and hogs showed that, in general, they can be considered to have a value of about nine-tenths that of No. 2 yellow corn. On this basis, and at an estimated cost of $23 per ton for processing the potatoes, the net income from sale of dried potatoes for feed in competition with No. 2 yellow corn at $2 a bushel would be enough to permit the payment of about $8.75 per ton for raw potatoes delivered at the factory and to give a return of 10 per cent on the investment.

CHIP MAKING

According to the National Potato Chip Institute the potato-chip industry uses about as many potatoes annually as are sold as certified seed. It is a stable outlet for high-grade potatoes and not one for disposal of surplus.

In the merchandising of potato chips the factor that always receives most consideration by both manufacturers and consumers is color. Chips that are nearly colorless or only a very light brown are the most desirable. Definitely brown to dark-brown chips are held to be unsalable and are in fact seldom offered for sale. Consumers do not want them. These facts were known years ago so that very early in the history of chip making it became important

[22] Italic numbers in parentheses refer to Literature Cited for Processing and Byproducts, p. 119.

for processors to know what conditions cause brown color in potato chips and how the browning can be prevented. It is desirable, therefore, to set forth the information brought out by research on the subject.

The early work of Wright (*22*), published in 1932, that of Wright and others (*24*) in 1936, and that of Sweetman (*17*) in 1930 showed (1) that chips made from tubers stored at temperatures between 32° and 37° F. were darker in color than those made from tubers stored at temperatures between 40° and 55°; (2) that total sugar was higher at the lower temperatures; and (3) that the caramelization of sugar by heat was responsible for the brown color of chips made from cold-stored tubers.

In a series of papers published from 1940 to 1943 Thornton (*19*), Denny and Thornton (*5, 7, 9, 10*), and Thornton and Denny (*20*) reported finding that it is the concentration of reducing sugar, not of sucrose, that is responsible for the color of potato chips and that reducing sugar, not sucrose, is the sugar that consistently increases at temperatures below 40° F. They found that good chips could be made from Russet Rural, Chippewa, Carman No. 3, Irish Cobbler, and Katahdin under most of the test conditions used. All of these varieties ran low in reducing sugar. Bliss Triumph and Green Mountain, both of which were high in reducing sugar, gave chips that were too brown; varieties that gave intermediate degrees of brown in chips—Russet Burbank, Blue Victor, Early Ohio, and Spaulding Rose—were also intermediate in reducing sugar. The authors stated that reducing sugar values of the lots stored at 44.6° were only about 35 percent of the values at 41° and those at 46.8° were only about 16 percent of those at 41°. Reducing sugar values increased more rapidly and reached a higher level if the potatoes were stored soon after harvest, but there was no agreement in the results as to the proper time to obtain the lowest amount and rate of accumulation of reducing sugar. In this phase of the work storage was at 41°.

Denny and Thornton (*7*) in 1941 reported no important differences in reducing sugar content of potatoes that could be related to fertilizer treatment or locality. Potato varieties of the Rural group were outstanding in maintaining low values for reducing sugar in storage. Other varieties with low reducing sugar but outside the Rural group were Blue Victor and Chippewa. Varieties unsuitable for chip making because of high amounts of reducing sugar were Eureka, Green Mountain, Axtell's Delaware, Bliss Triumph, Pride of Multnomah, Spaulding Rose, Blue Mercer, Warba, and Burglers.

A temperature of 7° C. (44.6° F.) was favorable for storage for chip making since many of the varieties were maintained at low reducing sugar values for 108 to 131 days at that temperature.

Denny and Thornton (*6, 8, 11*) from 1941 to 1943 reported that by using carbon dioxide at a concentration of 5 percent in the atmosphere surrounding potato tubers stored at 41° F. for 2 months the reducing sugar content can be held low enough for the production of chips of good color. Potatoes stored in air for the same length of time at the same temperature become worthless for chip making, because of accumulation of reducing sugar. The content of sucrose was increased by the CO_2 treatment, but, as has been reported by these authors, reducing sugar, not sucrose, is the decisive factor for color in potato chips. The work of Patton and Pyke (*15*) reviewed on page 116 suggested that other factors may also play a part.

Denny and Thornton (*6, p. 80*) stated that the CO_2 storage of potatoes could not be recommended at the time they wrote—

> since, even if the method should prove to be feasible and economical, the effects upon tuber characteristics other than sugar content and color of chips have not been determined.

Denny and Thornton (*10*) and Thornton and Denny (*21*) in 1943 reported that potatoes prestored at 59° F. and then placed in cold storage at 41° developed only about half as much sucrose as potatoes prestored at three higher temperatures. Evidence was also obtained that the reducing sugar formed during cold storage was lowered by about 20 percent as a result of prestorage at 59°. The postharvest, prestorage conditions did not affect the sugar content of the potatoes during the prestorage period.

Wright and others (*24*) in 1936 reported that when potatoes were moved to 70° F. for 6 weeks after 6 weeks' storage at 40°, 36°, and 32° the sugar content of those from 40° storage was found to be close to that of similar lots when first put into storage; however, in the lots from 36° and 32° the sugar content was still relatively high.

Denny and Thornton (*8*) in 1942 reported that desugaring at 80.6° F. for 10 to 20 days after a storage temperature at 41° was at a satisfactory rate with all varieties except Green Mountain and Chippewa. Tubers desugared, or "conditioned," in this way gave chips of acceptable color. When storage was at 33.8° the accumulation of sugar had been so great that a reducing sugar value low enough for giving a desirable chip color was not obtained within 20 days with either Irish Cobbler or Green Mountain, but was obtained with White Rural. Results reported by Sweetman (*17*) in 1930 showed that potatoes of three varieties (Green Mountain, Bliss Triumph, and Irish Cobbler) held in cold storage at 32° to 37° for 2 weeks or more produced chips very much darker than those made from tubers of the same lot cooked at the beginning of the experiment or held in storage at 40° to 55°. Desugaring at room temperature for various lengths of time from 1 to 8 weeks gave chips of a lighter color than was obtained immediately after cold storage. Change in color was correlated with changes in sugar content under the different storage conditions. Immature potatoes gave darker chips than mature potatoes.

Results similar to those of Wright and others (*24*) and of investigators at the Boyce Thompson Institute were reported by Campbell and Kilpatrick (*4*) in 1945 as a result of a study of the effect of storage temperature on potatoes later used for dehydration.

The browning of potato chips is believed to be one manifestation of the troublesome browning reaction encountered frequently during the dehydration or other processing of various kinds of animal and vegetable material. According to one hypothesis it is essentially a caramelization of sugars; according to another, it is essentially a Millard-type reaction between reducing sugars and amino acids that results in the formation of amino-sugar compounds. Evidence that the latter hypothesis may help to explain the browning that sometimes occurs in potato chips was obtained by Patton and Pyke (*15*). They reported in 1946 that the browning of potato chips is not caused solely by the presence of reducing sugar, but by the combined effect of reducing sugar and amino acids. They found that a brief hot-water treatment after slicing removed the amino acids and reducing sugar and that satisfactory chips can be made from potatoes immediately after removal from storage if the hot-water treatment is used. The hot-water treatment is useful for another reason, namely that it removes loose starch adhering to the surface of the chips so that they do not stick together during the processing. It is not believed that any starch is leached out from below the cut surfaces.

Ross and others (*16*) in 1946 made the following suggestions for selecting and handling potatoes so as to avoid darkening: (1) Lots containing over 3 percent but less than 6 percent reducing sugar can be conditioned to a satisfactory level for processing in 2 to 3 weeks at 70° F. (2) Those containing above 6 percent can be conditioned if necessary, but should be rejected if possible. (3) All potatoes that are sound when dug but that are not expected to store well should be used as soon as possible. (4) Potatoes to be used during the first 3 months after digging should be stored at 50° and never be allowed to go below 46°. (5) Potatoes to be used 3 to 6 months after digging should be mainly those of low-sugar varieties. High-sugar varieties or lots should be used only if they can be conditioned before processing. The recommended storage temperature is between 40° and 45°. (6) Potatoes that have been in storage for more than 6 months should be avoided because of poorer quality and greater cost. If necessary to hold potatoes this long, only low-sugar varieties should be stored unless extensive facilities are available for conditioning. The storage temperature should be kept as close to 40° as possible.

It should be remembered that these recommendations are based on the knowledge available in 1946. Changes may be necessary as a result of later work or work now under way.

Recent work in the United States Department of Agriculture on a project authorized under the Research and Marketing Act was reported by Wright (*23*) in 1948. Wright stated that of the varieties tested (all grown in Maine on the same type of soil) a promising new variety named Kennebec made about the best looking chips. Of the other 33 varieties tested Chippewa, Irish Cobbler, Netted Gem, Pawnee, Russet Rural, Sebago, and Teton made good chips.

More recently Wright and Whiteman (*25*, *26*) reported more fully on the work just discussed. They stated that the varieties that proved to be unsuitable for chip making, since they did not make a salable-grade product even when stored at 55° F. or could not be satisfactorily conditioned (desugared) at 70° after storage at 40° were Earlaine 2, Green Mountain, Menominee, Mohawk, Pontiac, Potomac, Red Warba, Sequoia, Triumph, Warba, White Rose, and Seedling 24642.

The varieties that produced chips of salable grade but were not considered of outstanding attractiveness were Calrose, Cayuga, Earlaine, Erie, Houma, Irish Cobbler, Kasota, Katahdin, Mesaba, Pawnee, and Seedlings B61-3, B69-16, and 47258. These varieties produced chips of salable but not outstanding grade when conditioned, except that Erie, Houma, Mesaba, and Seedlings B61-3 and B69-16 could not be satisfactorily conditioned after storage at 40° F.

The varieties that produced chips of outstanding attractiveness after storage at 55° F. and after conditioning at 70° after storage at 40° were Chippewa, Kennebec, Netted Gem (Idaho Russet), Norkota, Rural New Yorker, Russet Rural, Sebago, and Teton.

Research needed on problems of chip making includes work on (1) time and temperature requirements for proper conditioning of potatoes that have become too sweet in storage; (2) suitability of varieties from different regions; (3) effect of cultural conditions; (4) further exploration of the possibility that other substances than reducing sugar, particularly amino acids, are responsible for the brown color of chips made from certain lots of potatoes; (5) differences between early-crop and late-crop potatoes for chip making; (6) effect of "chilling," such as might be produced by precooling or by shipment under refrigeration; (7) effect of temperature at harvesttime; and (8) effect of vine killers, sprout inhibitors, and spray materials.

POTATOES IN OTHER PROCESSED FORMS

POTATO STARCH

The making of potato starch is a valuable outlet for the utilization of surplus, especially cull, potatoes in some parts of the country. Parsons (*14, p. 157*) in 1940 stated, however, that according to authorities on the subject—

> it is not practicable to produce less than 10 tons of starch per day from a factory. This means that 2,000 bags, or approximately 3,400 bushels, of potatoes must be supplied daily for at least 100 days [the average operating season for most potato-starch factories in the United States], or a minimum of 350,000 bushels of potatoes must be guaranteed each year if the factory is to operate profitably.

A similar caution is implied in statements made by Beresford and Aslett (*3*) in Idaho in 1945.

These suggestions should be kept in mind by people or associations that contemplate the erection and operation of potato-starch factories.

POTATO FLOUR

The manufacture and industrial uses of potato flour were discussed by Barker (*2*) in England in 1942. He stated that before World War II the production of potato flour in England was only in the experimental stage and that only one plant was then in operation. Subsequently, but before 1942, four more plants were erected and operated. Details of making cooked potato flour (ex-flaking units) and uncooked potato flour (ex-hand units) are given briefly.

Uses listed for potato flour are (1) as an improver in bread mixtures, (2) as a "duster" for preventing dough from sticking to wood and metal surfaces during its handling and rolling in bakeries. The flour has been found to have several advantages over the materials customarily used—rice cones and ordinary wheat flour—because only half the usual amount is needed, because it has better filming properties, and because it imparts a more desirable crust to the loaf. At the time Barker wrote, potato flour was also being used in England (1) in soup chowders, (2) as a thickening agent for sauces or gravies, (3) in the confectionery trade, (4) as a core gum for casting operations in foundries, (5) as a base for certain types of adhesives after suitable chemical treatment, and (6) in the preparation of tubes for shell cases and cartridges, for which manioc and rye flour were formerly used.

According to Fitch (*12*) in 1948 a plant at Muscatine, Iowa, used the following process in manufacturing potato flour: The potatoes are washed out of the car with fire hose and the washing is finished off with jets. The potatoes are then sliced and run through a large long steam pipe under 30 pounds' steam pressure. This treatment cooks them thoroughly. If necessary, water is added so that the mash can be pumped. It is then whipped, and most of the particles of skin are taken out on a sieve. After this the hot and finely emulsified mash is picked up by slow moving, hot rollers (heated by steam). By the time these rollers reach the other end of the machine the flakes of mash, well dried by that time, scale off in large thin sheets. These are ground or broken up and screened.

Two types of potato flour are said to be in common use; one is fine, like the finest of wheat flours, and the other is in very small pellets.

Problems that need to be investigated in connection with potato flour are the following:

1. Uses in baking, mixture with wheat flour.
2. Keeping quality in storage.
3. Proper storage temperature.
4. Whether the flour can be stored in bulk or will have to be stored in sacks.

PREPEELED POTATOES

One of the newer processes for the utilization of high-grade potatoes was described by Havighorst (*13*) in 1948. It has been developed to provide restaurants with peeled potatoes, and, according to the author, it does so at significant savings. As used in one commercial plant it consists essentially of a mechanical processing line where the potatoes are washed, peeled (by high-pressure steam), washed again, trimmed (by hand to remove the eyes and remaining skin), plasmolyzed, and treated to retain their natural color. The plasmolyzing bath sterilizes the surface of the potatoes and plasmolyzes those parts that were recently hand-trimmed. The final treatment, to retain their natural color, is a quick immersion in a sulfite solution of controlled pH. The potatoes are then packaged and stored at 35° F. until wanted. Under proper refrigeration the processed tubers may be held for 5 days and with controlled temperature as long as 10 days. (The distinction between proper refrigeration and controlled temperature is not made in the article.) Losses from this treatment are said to be much less than the 46 percent (estimated) that results from manual and some abrasive peeling and trimming operations in restaurants.

CANNED POTATO SALAD

An unsigned article in Food Industries for July 1948 (*1*) dealt with a patent recently issued on a process for preparing canned potato salad. By this process, cut potatoes are allowed to stand for 8 to 68 hours in water acidulated with vinegar or any other acid which has proved harmless in food. They are then cooked in the acidulated water, and the water is drained away. The potatoes, together with other "light-pickled" materials such as onions and pimientos, are mixed with an emulsified dressing and the mixture is processed in sealed containers at approximately 190° F.

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CONSUMER AND MARKET PREFERENCES

Garey (*3, p. 23*)[23] as a result of a survey that antedates the others reviewed in this section reported in 1935 that—

> in metropolitan centers [in Minnesota] there is a considerable demand for the very best quality of potatoes. This is especially true of hotels, restaurants, and other commercial eating establishments, and the higher-income groups of consumers.

The two outstanding requirements in hotels were satisfactory cooking quality—particularly baking and scalloping—and uniformity of size. Consumer and market preferences are probably about the same in Minnesota and the rest of the United States in 1949 as they were in 1934. In fact there are indications that consumers are even more critical of potato quality than they were one or two decades ago.

Motts (*9*) in 1937 published results on the marketing of potatoes in Michigan based on studies conducted from 1922 to 1937, inclusive. In the section devoted to market preferences he reported that most consumers (housewives) preferred medium-size, oval-type, white-skinned potatoes; the second choice was large, long-oval, and russet potatoes.

Grocers expressed about the same preferences for potatoes as did their customers. Restaurants apparently preferred a somewhat larger size than housewives. First choice in regard to shape was oval, second long oval, and third round. There was a two-to-one preference for white-skinned potatoes. Most hotels and dining-car services preferred medium-size or large, oval, white-skinned potatoes. Hotels and restaurants preferred potatoes that bake, boil, or fry white and remain white for at least an hour on the steam table.

Dean (*2, p. 12*), a New York potato grower, made some interesting comments in 1938 on consumer preferences that are still pertinent, more than 10 years later. They were as follows:

> We have an easy way to tell what consumers want most. Money talks louder than words. Market prices in the big cities for different grades, for different varieties, and for the same variety as grown under different conditions tell us exactly what consumers want.
>
> When Chicago buyers pay more for Idaho Russet Burbank Twos than for USOne Northern Round Whites, it would appear to an eastern man that Chicago consumers are thinking more about how those Russet Burbanks cooked than how they looked.
>
> When New York City markets pay more for the much despised Maine Utility grade Green Mountains than for the Western New York State Whites, an up-state grower has to figure on one of two things. Either those 11,000,000 consumers in New York and Jersey are all crazy, in which case nothing can be done, or else the up-state section had better get busy and try to grow the qualities in potatoes that New York City wants.
>
> The science of plant breeding has been revolutionized in the past forty years. Plant breeders can now design new varieties to possess the particular

[23] Italic numbers in parentheses refer to Literature Cited for Consumer and Market Preferences, p. 124.

qualities most demanded by consumers with a good chance of getting them. Look at the Number 45 cantaloupe for example.

Idaho, Washington and Oregon need a new Russet Burbank that will grow 90 per cent USOnes under irrigation conditions. The rich limestone soils of Southern Pennsylvania need a high quality variety that will neither scab nor go to pieces in a drought season. Maine needs a new Green Mountain that will not blight or rot nearly every year. Everywhere in the United States, the potato industry needs most the breeding of new varieties of such high table quality that consumers will be glad to pay high prices for them.

Much work has been done since 1938 on developing and introducing desirable new varieties of potatoes. Dean's statements are still worth considering, however, by all who are interested in the future of the potato industry.

Blood and Haddock (*1*) in New Hampshire in 1939, quoting Rinear (*10*), 1931, stated that dry and mealy, not soggy, potatoes are preferred by consumers above all others. This is the unanimous conclusion of later investigators as shown by their interest in, and use of, the specific-gravity method for determining cooking quality.

Hincks (*5, 6*) in 1940 reported in Maine that most consumers preferred medium-sized potatoes (between 2½ and 3 inches) and definitely objected to small potatoes. Large potatoes were objectionable because they cooked slowly if left whole, were apt to have hollow heart, and, in the opinion of some consumers, did not have as good flavor as the smaller sized potatoes. Consumer packages should be plainly marked as to size, and the range of size in any one package should be small. The enumerators were of the opinion that small potatoes would sell well if sold at lower prices than those asked for the larger potatoes. Consumers preferred potatoes that will cook white, dry, mealy, and with even texture and good flavor. They objected to potatoes that "cook to pieces," to those that blacken or become soggy on cooking, and to those damaged by cuts and bruises.

Hotchkiss, Wood, and Findlen (*8*) in New York in 1940, in interviewing consumers (homemakers), retailers, and institution buyers in New York State, found that mealiness and whiteness were considered the most desirable qualities in cooked potatoes. Turning black and sogginess caused dissatisfaction, the first being objected to most.

Spangler (*11*) in 1940 stated that in 1939–40 retailers in the Chicago, Ill., area said their customers preferred the red-skinned Colorado McClures and the Nebraska Bliss Triumphs for general cooking purposes and the Idaho Russet Burbanks for baking. Varietal preference of retailers for potatoes was not generally expressed in terms of correct varietal name but in terms of color of skin or State of origin. Such preferences, however, probably were based on consumer demand and the reputation established with retailers by certain States or producing areas for the high quality of their offerings.

Hotchkiss (*7*) in New York reported in 1941 that during investigations on the Rochester, N. Y., and Cleveland, Ohio, markets she found that the kinds of potatoes bought by consumers appear to depend upon (1) the family income; (2) the type or varieties offered by a retailer to his customers, which were probably influenced by their incomes; and (3) the relative difference in the prices of the varieties offered. She stated (*p. 33*) that—

> When both Rural and Green Mountain potatoes were available in the store, and when the relative difference in price was small, more families, regardless of income, bought the higher-priced Green Mountains.

She also found that about 85 percent of the potatoes were peeled before cooking and that most of them were cooked in water.

Wood (*15, p. 44*) in 1943 reported that—

> Institution buyers in 126 institutions in New York City, Rochester, New York, and Cleveland, Ohio . . . preferred "smooth" potatoes (probably meaning that tubers should be well-shaped and free from blemishes), those that would be mealy and white when cooked, and those of even size for serving whole. They wanted better marketing procedures such as the enforcing of present grade standards and the improving of grades (probably meaning that U. S. No. 1 grade should be of higher quality).

Some of the institutions thought it desirable to have containers labeled with the size range, source of supply, variety, grade, and weight, but others thought that labeling might not be successful because of the variability of supplies and doubted whether producers and dealers could "meet and maintain rigid specifications."

Hemphill (*4*) in 1944 reported that Bliss Triumph and Early Ohio potatoes were preferred to all others by North Dakota consumers. Cobbler ranked third. Of the potatoes in retail stores during July 1943, 83 percent had been purchased from local producers, 6 percent from truckers or dealers, 1 percent from itinerant truckers, and 10 percent from wholesalers. Retail grocers were found to be making commendable efforts to sell locally grown potatoes. They stated, however, that they would like to see local producers do a much better job of handling, sorting, grading, cleaning, and storing their potatoes.

In an extensive survey of consumer preferences in private households in cities of 2,500 and over in the United States, the Bureau of Agricultural Economics (*12*) in 1948 reported, as in the other surveys just cited, that (1) most homemakers prefer potatoes that have a smooth skin, a clean surface, very few eyes, and no spots or blemishes; and (2) they prefer that potatoes should cook mealy, should not fall apart in cooking, and should cook evenly and soft throughout. Most homemakers said they had used potato chips; those who had tried canned boiled white potatoes said they liked them because of the convenience.

In a survey of potato preferences among restaurant and hotel buyers in New Orleans and Cincinnati in 1948 (*13, 14*), it was found that the buyers are interested first in quality and type and then in size. They want potatoes that are free from rot, without cuts, cracks, or bruises, and with a smooth skin, regular shape, and shallow eyes. In New Orleans 58 percent of the buyers and in Cincinnati 39 percent bought the long white netted type; in New Orleans 6 percent and in Cincinnati 37 percent bought the round red type; and in New Orleans 26 percent and in Cincinnati 20 percent bought the round white type. There was a decided preference for round potatoes 3 inches in diameter and for long ones weighing 8 to 12 ounces. A majority of the buyers preferred washed potatoes.

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DISEASES

Diseases of potatoes that need to be considered during the handling, storage, and marketing of the crop are of two kinds: (1) Those that originate in the field; and (2) those that originate after harvest, usually gaining entrance at mechanical injuries or following heat injury.

Examples of the first are leak, alternaria tuber rot (early blight), and late blight tuber rot; of the second, bacterial soft rot, fusarium rot, and physiological troubles such as freezing and blackheart. Diseases that originate in the field are often destructive in transit or early in the storage period, whereas those that develop after harvest, with the exception of bacterial soft rot, do not usually cause damage in transit and are not likely to be serious in storage until after a considerable period has elapsed.

The characteristics of the important transit and storage diseases of potatoes are described herein. Methods of control are discussed under each disease. The general statement can also be made that control of storage decay of any kind depends first of all on careful culling before storage to remove injured tubers and those already showing decay and second on the maintenance of a temperature between 38° to 40° F. after the curing period has passed (p. 65).

BACTERIAL SOFT ROT

Bacterial soft rot is an important disease of potatoes in storage and in transit. It progresses rapidly under some conditions and potatoes that appear to be almost free of the disease when loaded have been known to show 50 to 75 percent damage after only 7 days in transit (*33*).[24]

Blackleg, which is often considered a separate disease, is included in the discussion of bacterial soft rot, since it is a soft rot in storage and in transit. The organism causing blackleg was considered by Leach (*75*) and Bonde (*13*) to be the same as *Erwinia carotovora*, but recently Smith (*123*) showed that the two organisms differ physiologically and pathologically.

Although bacterial soft rot of vegetables is often attributed to *Erwinia carotovora* (Jones) Holland alone, soft rot of potatoes is probably caused more often by one or more of the following species of bacteria and possibly by others: *E. atroseptica* (van Hall) Jennison, *E. aroideae* (Townsend) Holland, *Bacillus polymyxa* (Prazmowski) Migula, and *B. mesentericus* Trevisan (*13, 41, 69, 75, 82, 105, 123*). The last-named species is listed as *B. subtilis* (Cohn) Prazmowski in the latest edition of Bergey's Manual of Determinative Bacteriology (*26*).

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[24] Italic numbers in parentheses refer to Literature Cited for Diseases, p. 142.

The rot caused by *Erwinia carotovora, E. atroseptica,* or *E. aroideae* is light cream in the early stages, but later it sometimes becomes brown to black and watery. It has little or no odor. The slimy soft rot that is so often described is probably caused by one of the other species mentioned in the preceding paragraph or by a mixture of several species of bacteria. This latter type of rot is usually accompanied by a foul odor resembling hydrogen sulfide. Any of these pathogens alone or in combination can cause a rapid rot of the inner portion of the potato and leave a hollow shell of unaffected outer tissue.

Bacteria that cause soft rot are normal inhabitants of soil and are especially plentiful where there is an abundance of decaying vegetable matter. As a result, they are present on practically all vegetables and cause decay whenever conditions are favorable for infection and progress of the disease.

The soft rot bacteria can enter the potato through cuts, bruises, skinned places, cracks, or other mechanical injuries. They can also enter through lesions caused by other diseases or through enlarged lenticels. It has been shown that bacterial infection may take place even through normal lenticels during washing operations. Such infection is more likely to occur when the washing is done in tubs or deep vats than when it is done under a spray of fresh water, and the amount of infection is correlated with the depth and length of time the potatoes are submerged (*40, 40a, 115, 120*). Rose and Schomer (*111*), Nielsen (*95*), and Nielsen and Todd (*96*) found that heat-injured potato tissues were more subject to soft rot than normal tissues. Even temperatures not high enough to kill the tissues made them susceptible to rot. The effect of such temperatures is reversible, however, and may be corrected to some extent by subsequently keeping the potatoes at a lower temperature. Heat damage may be expected whenever the potatoes are exposed to the sun for 15 minutes or longer on days when the air temperature is 90° F. or higher. The potatoes absorb the heat rays of the sun and may develop surface temperatures 25° to 40° higher than the surrounding air. Heat damage is likely to occur when the surface temperature is 110° or higher. Heat injury may also occur before the potatoes are dug if they remain in the ground during hot weather after the tops have died (*95, 109*).

In experiments at Beltsville, Md., and Meridian, Miss., the greatest amount of soft rot in potatoes that had been affected by heat occurred in those stored at 90° F., but very little decay occurred at 70°, and practically none at 50° to 60° (*109*).

Moisture is a necessary factor for soft rot infection and development. For this reason the practice of washing potatoes sometimes causes an increase in the amount of this disease (*40, 40a, 115, 120*). This is especially true if the water is not changed frequently, as repeated use of the same wash water soon results in heavy contamination. There are indications in California that chlorinating the water will counteract this condition to some extent. The use of fresh running water may be beneficial, because it reduces the number of soil-inhabiting bacteria on the potatoes. In Florida Ruehle (*115*) found that much of the soft rot in transit could be eliminated by drying the potatoes with warm air after they had been washed. Work in Nebraska by Ramsey and others (*104*), however, showed that it was not necessary to dry the potatoes if they were given adequate refrigeration in transit and had not been subjected to adverse conditions during and after harvest.

Bacterial soft rot is more common in early than in late-crop potatoes, but sometimes it occurs in the latter as a secondary decay following late blight, ring rot, or freezing injury.

The following practices are suggested for the reduction of losses from soft rot:

1. Harvest potatoes carefully so as to avoid mechanical injuries.
2. Avoid heat damage by harvesting promptly after the tops have died if the weather is hot; by picking up and removing potatoes from the field before they are exposed to the heat of the sun; and by shipping or storing at temperatures below 70° F.
3. Either dry or refrigerate potatoes that have been washed.

BLACKHEART

Blackheart is characterized by a gray to black discoloration and death of the internal tissues of the potato. It is caused by an insufficient supply of oxygen. Usually it is necessary to cut the potato to detect blackheart. In advanced stages moist, purple to dark-brown or black areas may be seen at the surface. The internal tissues may be normal in color when cut, but on exposure to air they turn pink, gray, purple, and finally black. The affected tissues are usually at the center of the potato and sharply differentiated from the healthy. They are firm and somewhat leathery. In advanced stages cavities may be formed as the affected tissues become dry.

The temperature at which blackheart develops depends on the oxygen supply and the rate of respiration of the potatoes. Blackheart may develop at 70° F. if the oxygen supply is reduced, but in commercial shipments or storage it is not likely to develop at temperatures much below 90° if the potatoes are given sufficient oxygen. It develops at high temperatures regardless of the oxygen supply because of the inability of the potatoes to absorb oxygen fast enough to supply the rapidly respiring internal tissues. A relation between the development of blackheart and a decrease in enzymatic development has been noted. Blackheart has been attributed to destruction of the enzyme by the high temperatures (*117*). Small actively growing tubers appear to be more resistant to blackheart than large mature ones (*118*).

To avoid blackheart, the temperature in storage and in transit should be below 70° F. and there should be adequate ventilation (*5, 6, 8, 126*).

BROWN ROT, OR SOUTHERN BACTERIAL WILT

Brown rot, caused by *Pseudomonas solanacearum* E. F. Sm., is a common and serious transit disease of early potatoes grown in the Southern States and occurs as far north as Long Island, N. Y. It is not of much importance in storage as these potatoes are usually marketed immediately after harvest.

The external appearance of the disease on the potato may be merely a slight depression at the point of attachment to the stolon, or the disease may appear as grayish-brown patches on the surface of the potato. Sometimes infected potatoes show no external signs of the disease. Internally the disease appears as a brown discoloration and a slight softening of the water-conducting tissues. A yellowish-white slimy mass of the causal bacteria frequently oozes out of the cut vascular bundles. There is no odor at this stage, but later other bacteria gain entrance and reduce the entire center of the potato to a slimy, foul-smelling mass. Usually a thin shell of outer tissues remains intact.

The bacterium that causes the disease is commonly present in soil in warmer areas. The known host range includes over 90 species of cultivated and wild plants (*122*). Brown rot is a serious disease of eggplant, peppers, tomatoes, tobacco, and peanuts as well as of potatoes.

The pathogen gains entrance to the potatoes by way of the stolon of the diseased mother plant. Affected plants may produce both diseased and healthy potatoes. Since some of the diseased tubers do not show external symptoms, they are not thrown out when the potatoes are graded and are likely to rot in transit if the temperature is favorable. The causal organism grows well at 77° to 97° F., but practically stops at about 55° (*88*).

The Green Mountain, Katahdin, and Sebago varieties are resistant to brown rot, whereas the Spaulding Rose, Irish Cobbler, and Triumph varieties are susceptible (*42, 44, 47*).

For control in transit, it is suggested that the potatoes be sorted carefully to eliminate all visibly infected potatoes and that shipments be kept at temperatures below 55° F.

BROWNING

The term "browning" is applied to the brown or black discoloration that occurs on the skinned areas of immature potatoes when they are subjected to dry currents of air. The browning is accompanied by a loss of moisture, which results in withering and shrinking of the affected tissues. Under moist conditions the browned areas become affected with a moist, sticky bacterial growth or are sometimes covered with a mold.

The fact that browning may occur at either low or high temperatures indicates that it is not a form of heat injury as was formerly assumed. Instead, it apparently is associated with too rapid drying of injured tissues, which prevents the prompt formation of wound periderm. It has been shown that browning does not occur if the potatoes are exposed to high humidity and temperatures favorable for wound healing for 12 hours after they are skinned (*3, 99, 109, 110*).

Browning may be reduced to a large degree by protecting the potatoes from rapid drying. This may be accomplished by prompt picking and hauling from the field, by using tightly woven bags, and by covering the loaded truck and the stacks of potatoes at the shed with tarpaulins.

CHEMICAL INJURY

Chemical injury may result from contact with common salt, sodium nitrate, ammonium sulfate, coal tar, and oil products in storage or in transit. It is not likely to occur from contact with lime, gypsum, or other insoluble chemicals. Injury does not take place unless the chemicals are ground into the tissues. It may happen to potatoes that are in contact with the floor or walls of storages or cars that have become impregnated with the injurious chemicals. Chemical injury does not occur so frequently now that most potatoes are shipped in refrigerator cars as it did when boxcars were used (*142*).

CORKY RING SPOT

Corky ring spot disease has recently been found in Florida, where it has caused losses of up to 50 percent of the potatoes in some fields. The disease is characterized by brown, concentric rings and arc-shaped cracks on the surface of the potatoes and by brown, corky blotches in the inside tissues of the affected potatoes. The blotches inside are of various sizes and shapes, but those near the surface appear to form arcs or rings that originate at the discolored surface spots and radiate into the flesh (*46*).

The cause of corky ring spot is unknown, and there are no recommendations for control.

EARLY BLIGHT

Tuber infection by the early blight fungus, *Alternaria solani* (Ell. and G. Martin) Sor., takes place during harvesting operations when potatoes come in contact with diseased leaves, but the symptoms on the tubers do not become visible until several days later (*9, 128*). In 1943 up to 50 percent of the potatoes from one farm in Minnesota were found to be infected with this disease in storage (*127*). Externally, this disease appears as dark-brown or black dry, sunken spots ⅓ to ⅔ inch in diameter. The spots are usually shallow but may be as much as ¼ inch deep. Sometimes they are surrounded by a slightly raised border. The flesh beneath the spots is yellowish and is sharply set off from the healthy tissues by a layer of cork. Because of the cork layer, it is possible to lift out portions of the decayed tissues with the point of a knife. The lesions caused by the early blight fungus differ from those caused by the late blight fungus in that the latter are water-soaked, more reddish, larger, and less definite in outline. Also, the late blight rot spreads irregularly into the flesh instead of being set off by a cork layer and is reddish brown instead of yellow.

The spots caused by the early blight fungus detract from the market appearance of the potatoes. Affected potatoes lose water rapidly and if badly diseased may shrivel, while in storage, to less than half their original size. Early blight also predisposes the potatoes to infection by other rot organisms.

Experiments in Florida showed that infection takes place most readily at 57° to 61° F., but that the lesions enlarge most rapidly at 75° to 77°. The experiments also showed that bruised potatoes were more susceptible than sound ones and that more infections occurred when the potatoes were air-dried and stored under dry conditions than when they were stored in bins under moist conditions. The results of these experiments suggest that humidity and temperature conditions favoring rapid healing as soon as the potatoes are harvested reduce the amount of infection, but that temperatures below 50° are necessary to retard the enlargement of lesions after infection has taken place (*59*).

Tervet (*128*) observed that potatoes grown on light soils were more likely to be severely affected with alternaria rot than those grown on heavy soils.

Bertram (*9*) and Klaus (*72*) in Germany concluded that the early blight fungus did not spread from diseased to healthy potatoes in storage.

The amount of infection can be reduced by careful handling of the potatoes during harvesting to avoid bruising and by keeping the potatoes from coming into contact with infected foliage. In fields of badly infected potatoes the tops should be completely dead before the potatoes are dug. Barrels or bags of potatoes standing in the field should not be covered with vines. High humidity and a storage temperature of 66° to 72° F. immediately after harvesting will favor rapid wound healing (*1*) and reduce the amount of infection. Subsequent storage at temperatures below 50° will retard the enlargement of any lesions that have started (*59*). (See also *54, 105*.)

FREEZING AND CHILLING INJURY

Freezing injury is the cause of considerable loss of potatoes in storage and transit. The severity and type of damage depend on the temperature, length of exposure, and condition of the potatoes.

Tissues that are frozen solid are killed. If they thaw in a humid atmosphere, they are likely to become infected with bacteria and to decay. Such tubers are sometimes called "leakers." However, in a dry atmosphere the frozen potatoes may dry down to a tough, leathery, or dry, chalky mass. Less severely affected potatoes show a pronounced blackening of the vascular ring and adjacent tissues. Also gray, blue, or black sooty blotches may occur anywhere in the tuber, but usually between the vascular ring and the skin. Slight freezing causes a general blackening of the finer vascular elements that extend throughout the potato (*70, 130, 142, 143*).

The danger point for freezing is approximately 29° F. (*144*). The actual freezing point varies with the variety and previous storage temperatures. Potatoes previously stored at 32° have a freezing point about 1° lower than potatoes that have been stored at 50° (*143, 144*). Potatoes may be undercooled considerably below 29° and not freeze, provided ice crystals do not form (*70, 145*). However, any mechanical jar is apt to cause ice crystals to form. For this reason freezing injury is especially apt to occur if undercooled potatoes in storage are moved.

Potatoes exposed at temperatures below 40° F. but not below freezing have a tendency to become undesirably sweet. The normal flavor can be nearly restored by raising the temperature to 60° for a week or more (*105*).

A type of chilling injury known as mahogany browning affects Chippewa and Katahdin potatoes if they are exposed for 20 weeks or longer to temperatures in the neighborhood of 32° F. This type of injury is characterized by the development of reddish-brown irregular-shaped patches of flesh anywhere in the tuber. The color varies in intensity and shades into that of the normal flesh. When the discolored areas are mostly in the outer tissues, they may be mistaken for those caused by late blight. A variation of this type of injury may occur in Green Mountain and Sebago potatoes in the form of a blackish discoloration of the flesh when they are stored for 20 weeks at 30° to 32° (*65, 141*).

To avoid freezing, potatoes should not be exposed to temperatures below 29° to 32° F. in the ground or during harvest, transit, or storage. Potatoes that have been exposed to freezing temperatures should not be disturbed until the temperature has been raised so as to avoid causing ice-crystal formation in those that have undercooled. After several days at the higher temperature they may be sorted to eliminate the "leakers." Varieties susceptible to mahogany browning should be stored at temperatures above 38° (*52, 65, 85, 87*).

FUSARIUM ROTS

Fusarium rots have been reported to be caused in the field by *Fusarium oxysporum* Schlecht., *F. radicicola* Wr., and *F. eumartii* Carpenter; and in storage by *F. caeruleum* (Lib.) Sacc., *F. sambucinum* Fckl., *F. avenaceum* (Fr.) Sacc., *F. sulphureum* Schlecht., and *F. trichothecioides* Wr.

The various fusarium tuber rots are responsible for considerable losses in storage and transit. The one called powdery dry rot often causes losses of 10 to 50 percent of the contents of rail cars (*97*). An average of 5 percent of the potatoes in 34 bins inspected in New York in 1945 were affected with fusarium rots, the amount ranging from a trace to 17 percent in the different bins (*35*). Surveys indicated that black rot caused mostly by *Fusarium sambucinum* is a very important storage disease in Idaho (*10*).

Fusarium tuber rots generally are characterized by sunken, shriveled, or broken areas occurring on the surface of the tuber. These areas may be of the same color as the healthy parts or they may be greenish or brown to black, and on them there may appear masses of whitish, dark, or brightly colored mold. An excellent brief statement, not generally available now, concerning the internal condition and appearance of potatoes affected with fusarium rot, is quoted herewith from a circular by Link and Meier (*77, pp. 3–4*).

> The tissues underlying such discolored and sunken areas may be mushy, leaky, and grayish or light to dark brown, as in one of the Fusarium tuber rots of southern potatoes . . . ; they may be jellylike and light to dark brown or black, as in one type of the jelly end-rot of western potatoes . . . ;

they may be soft and light colored to black, at times containing cavities lined with white or brightly colored mold; they may be dry, corky, and friable and dark brown to black; they may be dry and tough and brown to black, as in black field-rot of western potatoes; or, as in powdery dry-rot, they may be dry and brittle, with cavities separated by dried brownish tissue and starch and lined with whitish and fluffy or powdery molds. . . . Whether only one of these types occurs, or a mixture of several, will depend upon the species responsible for the rot or the conditions under which affected tubers are kept. Fusarium tuber rot is usually dry at low temperatures and wet at high. It never is slimy, even when wet, and never has a bad odor; when accompanied by other fungi or bacteria there may be bad odors from them.

Under transit and storage conditions, powdery dry rot is the most common fusarium rot in western and midwestern potatoes (*116*). This rot may actually vary from dry and powdery to cheesy, or even wet and jellylike, depending on the percentage of moisture present and the type of associated rot-producing organisms that invade the infected tissue (*94*). Stem-end rot, which predominates in long tubers of the Burbank type, and black field rot, which is particularly destructive in tubers of the Rural type, are also western types of fusarium rot. The grayish, leaky, mushy type of fusarium tuber rot is chiefly a southern disease (*116*).

The fungi causing fusarium tuber rots are present in the soil and are able to live there for several years even in the absence of potatoes. They also may be present on the bins and boxes (*50, 119*). Removal of the soil from the potatoes by washing reduced the amount of infection from 20.7 to 3.1 percent and from 10.4 percent to zero in two tests (*119*). Although this reduction was attributed to reducing the amount of inoculum, it may have been the result of more rapid healing brought about by the high humidity resulting from storing wet potatoes. It has been shown that even severe wounds do not become infected by *Fusarium caeruleum* after new periderm is formed (*24*).

Wounding in harvesting or handling is generally considered conducive to infection (*35, 62, 89, 119*). Chilling also was found to predispose potatoes to fusarium rot (*83*).

The temperature relations of the various Fusaria differ but in general it may be said that no growth or germination occurs below 34° F. or above 102°. Growth is slow between 41° to 50°, but the fungus is able to become established and makes some progress at these temperatures (*62, 89, 116*).

Much of the loss in storage may be prevented by careful harvesting and handling, so as to avoid wounding the potatoes. Control in storage consists fundamentally in removing surface moisture from the potatoes as soon as possible after digging and then keeping them dry during at least the first 4 weeks of storage. So long as there is no surface moisture, the humidity should be that most favorable for maintaining the quality of the tubers (generally 85 to 90 percent). A high humidity favors the healing of wounds and helps to reduce moisture loss, which is normally rapid during this early part of the storage period. (See Shrinkage, p. 62.) A temperature of 38° to 40° F. will greatly reduce the percentage of fusarium rot in storage, although it will not entirely check it. This temperature is also necessary to keep the potatoes dormant (See also *4, 105, 133*.)

GREENING

Greening is the result of the development of chlorophyll in potatoes that have been exposed to light. The affected potatoes are unattractive in appearance and have a bitter taste that makes them unpalatable. There are indications that greened potatoes are poisonous to some people because of the presence of the alkaloid solanin. A number of fatalities from eating green potatoes are on record (*60*). Immature potatoes are particularly subject to this trouble. The coloring may be confined to the surface layers, or it may extend to the deeper tissues. The depth of penetration depends on the length of exposure, the temperature, and the variety. Greening takes place more rapidly at room temperature than in a cool place. The Katahdin variety greens more rapidly in the light and fades less in the dark than either the Chippewa or the Green Mountain variety (*53*).

Greening frequently develops in the field on potatoes that are not completely covered with soil. It also develops in storage unless the room is dark. Potatoes on display in retail stores may become green as a result of the light penetrating the open-mesh bags.

It was formerly considered that the green color could be removed easily by keeping the potatoes in the dark for a few weeks. Recent experiments in Maine (*53*) show, however, that over a month in a warm dark storage was required to remove the green color caused by only 2 days' exposure to light and that several months was necessary after longer exposures. When badly greened potatoes are placed in the dark, the green color may be merely replaced by red or brown instead of the normal color.

Losses from greening may be reduced by keeping the potatoes covered with soil while the crop is growing, storing them in a cool dark storage, and not displaying them for a long period in the retail market.

HEAT INJURY

Heat injury is a serious trouble in the early and intermediate potato crops that are harvested during hot weather from April through August. It affects the appearance of the potatoes and also predisposes them to soft rot.

Visible signs of heat injury do not appear until several hours after exposure, and therefore the potatoes may be packed and shipped or stored before it is realized that they have been damaged. Severe heat injury causes the affected areas to become watery and blistered. The affected tissues may lose moisture and become sunken or flat and leathery, or they may become infected with soft rot bacteria and decay. Freshly cut, heat-injured tissues are white to gray, but after exposure to the air they turn brown and then black. Sometimes there are no visible signs of heat injury, but the tissues are conditioned for invasion by soft rot bacteria and decay follows after 2 or 3 days.

Heat injury usually takes place when the potatoes are exposed to the sun in the field after they are dug or while being transported to the packing shed. The injury may occur even when the sun is not bright and the air temperature is not exceedingly high. The reason is that the damage is done by the invisible heat rays of the sun instead of the light rays (*109*). Prolonged exposure results in an accumulation of heat in the tuber so that the temperatures of the exposed parts may be 25° to 40° F. higher than the air temperature (*111*). The thermal death point of potato tissue for 1 hour's exposure is approximately 122° (*95*). Temperatures as high as 135° have been recorded on hot days in potatoes lying on the ground (*104*). Temperatures of 110° to 113° are sufficient to predispose potatoes to soft rot (*95*). Such temperatures are apt to be reached in potatoes exposed to the sun when the air temperature in the shade is 90° or higher (*109*).

During excessively hot weather potatoes may become heat-injured before they are dug if they are allowed to remain in the soil after the tops have died (*95, 109*). The injury in this case is deeper and is characterized by a gray to purple watery break-down of the internal tissues and sometimes by a purplish-black discoloration just under the skin.

To avoid heat injury, potatoes should be picked up within 15 to 30 minutes after they are dug. This is especially important if the air temperature is above 90° F. in the shade (*109, 111*). In hot weather it is a good practice to dig potatoes late in the after-noon and to allow them to cool in the field overnight before they are picked up (*96, 99, 109, 111*). Potatoes that have been exposed to conditions likely to cause heat injury should be held several days before packing to allow time for the injured potatoes to decay so that they can be sorted out. Shipping under refrigera-tion at a temperature of 60° or below will reduce the amount of soft rot damage following heat injury (*109*).

HOLLOW HEART

Potatoes affected with hollow heart have a more or less irregu-larly shaped cavity at the center of the tuber. The cavity is often lined with brownish corky cells, has no external openings, and has no decay associated with it.

This trouble usually occurs in seasons when conditions are favorable for rapid growth of potatoes. It is confined mostly to the large, excessively thick potatoes, but it may occur also in small ones (*76, 134*).

The amount of hollow heart can be reduced by closer spacing in the field, and by planting whole seed, or by seed-piece treat-ment with thiourea to increase the number of stalks and potatoes per hill (*90, 91, 92, 135*). It has been shown that hollow heart can be detected by use of an X-ray machine. It is said that 7,500 pounds can be sorted an hour by one machine (*61*).

INTERNAL BLACK SPOT

Internal black spot has been a serious trouble in Green Mountain potatoes on Long Island, N. Y. (*105, 121, 136, 138*). A similar condition has been reported from western Washington (*25*). Recently it has been found in other varieties and areas. The affected potatoes have roughly circular or oval areas of blackened tissues between the skin and the vascular ring. These spots are ¼ to ¾ inch in diameter. The blackened areas may extend to the surface of the potato, but frequently they do not. The affected area may become sunken as much as ⅛ inch, but sometimes there is no external evidence of black spot.

The trouble appears to be associated to some extent at least with mechanical injury to tissues that have been subjected to pressure bruising in the storage bins. However, it may also occur in potatoes on which pressure bruises are not visible.

Practically no black spot develops in potatoes while they are still in the bin, but it develops after grading and sacking. It has been shown experimentally that the blackening developed at the pressure spots if those areas were struck with a smooth, rounded object, such as the handle of a pocketknife. The discoloration developed in varying degrees after the potatoes were run over a grader. When potatoes with pressure bruises were stored 3 days at 49°, 61°, and 67° F. and then struck on the pressure spots with a knife handle or run over a grader, the greatest amount of black spot developed in those from the lowest temperature and the least amount in those from the highest temperature (*138*).

The limited geographical occurrence of internal black spot suggests that some nutritional conditions predispose the potatoes to blackening following pressure bruises and other mechanical injuries. It has been noted that black spot is especially apt to follow bruising if the potatoes were grown under irrigation, stored in bank storage, or fertilized with a high level of nitrogen or potash (*137*).

INTERNAL BROWN SPOT

Potatoes affected with internal brown spot have dry brown spots or blotches of irregular shape scattered throughout the potato. There are no external indications of the disease, but when it is discovered by cutting a sample of the potatoes, the marketability of the whole lot is affected. Internal brown spot develops in the growing crop and does not progress further in storage or transit.

The cause of internal brown spot has not been determined. It is probably a complex that may be caused by several factors. Among the possible causes that have been suggested are soil acidity in combination with a deficiency of superphosphate (*64, 101*), growing on sandy or gravelly soils, lack of water, and high temperature. In the case of "heat and drought necrosis," which is associated with the last two factors, the discoloration is usually confined to the vascular ring and adjacent tissues (*116*).

Triumph, Pontiac, and Red Warba varieties are more resistant to internal brown spot than Katahdin, Rural New Yorker, Russet Rural, or Harmony Beauty (*2, 23, 74, 100*).

LATE BLIGHT

Late blight tuber rot, caused by *Phytophthora infestans* (Mont.) DBy., is a serious storage disease. Surveys of potatoes in storages in the New England States in the winter of 1943–44 showed that late blight was the most important storage disease. It was found in 75 percent of the storages and was responsible for three-quarters of the average loss of 18 percent that was found. Losses in individual bins ranged from a trace to 50 percent (*30, 34, 35*). Initial infection may take place even before the potatoes are dug, but most of it occurs during the harvesting operations when the potato comes in contact with blight-infected vines, even though the tops may be only slightly infected (*19*). In Maine 48 percent of tuber decay occurred in storage in potatoes that were harvested while the tops were still green, but only 4.5 percent developed in potatoes harvested after the tops had been killed by frost (*15*). Some spread from one potato to another may occur in storage if conditions are favorable for the fungus to develop on the surface of the infected tubers (*78*).

The disease at first appears on the surface of the potatoes as small brownish or purplish spots. These spots enlarge and become darker and slightly sunken. When numerous spots occur, the affected area has a hobnailed appearance. The flesh beneath the spots is reddish brown to a depth of ¼ to ½ inch. Under dry storage conditions the blight-infected tissues are dry and firm, but in a moist storage bacteria become involved and a soft, slimy, foul-smelling rot results. When abundant moisture is present, white fungus growth may develop on the affected parts.

Late blight development in the tubers is retarded by low temperatures. In two storage experiments in Maine the late blight rot was reduced from 44.2 and 41.4 percent when stored at 70° F. to 1.9 and a trace when stored at 36° (*20*). In Germany the minimum, optimum, and maximum temperatures for development of *Phytophthora infestans* on the tubers were found to be 5°, 19° to 20°, and 25° to 26° C., respectively. In resistant varieties a defensive reaction on the part of the tuber sets in between 5° and 11° (*93*).

Control of late blight in the growing crop by means of a proper spray program is the most effective means of eliminating tuber rot. Destroying the cull piles in which large quantities of inoculum are produced also aids in controlling the disease (*17, 18*). Danger of inoculation of the potatoes during harvesting may be reduced by delaying digging until the vines have been killed by frost (*15, 19*), or by treatment with a chemical such as copper sulfate, sulfuric acid, calcium cyanamide, or sodium dinitro-ortho-cresylate (*29, 49, 67, 68, 73, 84, 98, 106, 125, 140*), burning (*73*), and rotobeaters (*67, 68*). There is evidence that vascular discoloration may result under some conditions from the use of various vine killers (p. 141). The occurrence and severity of the discoloration appear to be influenced by the age of the plants, rapidity of killing, and environmental conditions before and after the tops are killed, (*67, 73, 106*). Destruction of the tops when the blight occurs early in the season is not desirable because it is likely to reduce the yield. The greatest amount of tuber rot may be expected when the tops are infected but remain green until digging. The best results from destruction of the tops by artificial means are obtained in such cases about 3 weeks before digging (*49*). Storage under dry conditions at about 40° F. will retard development of the spots and fruiting of the fungus on the surface of the potatoes (*20, 78*). The tubers of varieties resistant to late blight are not necessarily resistant to tuber rot, even though the foliage of those varieties may not be seriously affected by the disease (*22, 108*). The tubers of some of them appear to be even more susceptible to tuber rot than those of some of the nonresistant varieties (*66*).

LEAK

Leak may be found wherever potatoes are grown, but it appears to be of most importance in Idaho and California. It may cause serious losses at harvest, in storage or transit, and on the market.

The first evidence of leak is usually a brownish or somewhat water-soaked discoloration of the skin around wounds or at the point where the stolon was attached. Sometimes the flesh in the affected area is slightly depressed. Internally the affected tissues are grayish or brownish, but they turn darker brown, reddish, or black when exposed to the air. The affected tissues are often separated from the healthy ones by a dark-brown line. The diseased tissues are very watery and, when pressure is applied and the skin breaks, a yellowish or brownish liquid is released. The name "leak" is derived from this characteristic of the disease. Sometimes nearly the entire inside of the potato may rot and leave an outer shell about ¼ inch thick. This stage of the disease is sometimes called "shell rot" (*11*).

Leak may be caused by any of several species of *Pythium* including *P. debaryanum* Hesse and *P. ultimum* Trow. These fungi are abundant in some potato soils and infect the potatoes through wounds caused by mechanical or other means (*11, 63, 71*).

Infection and the development of leak are favored by hot weather and abundant moisture (*27*). The minimum temperature for growth of *Pythium ultimum* is approximately 39° F., the optimum 77° to 87°, and the maximum 104° (*71*).

Losses from leak in storage, in transit, and on the market can be reduced to a large extent by careful harvesting and handling methods to avoid wounding the potatoes and by keeping the potatoes under cool, dry storage conditions (*11, 63, 71*).

NET NECROSIS

Net necrosis, caused by the leaf roll virus, is an internal discoloration of the potatoes that lowers their market value. In a survey of potato storage diseases in Maine in 1943, net necrosis ranged from a trace to 10 percent. In one bin 50 percent of the potatoes were affected (*30*). In the same year net necrosis was found in six out of nine bins of Green Mountain potatoes in New Hampshire. In four of these there was 1 percent or less of net necrosis, but in one there was 36 percent and in the other there was 60 percent (*31*). The discoloration is brown to black and is confined to the phloem tissues. It is usually worse at the stem end, but it may extend nearly to the other end of the potato. It is not confined to the vascular ring. In cross sections the darkened tissues appear as brown to brownish-black spots, but if a thin lengthwise slice is cut they appear as dark streaks or netting. Similar symptoms are seen in potatoes affected with freezing injury and with fusarium wilt or with verticillium wilt. Net necrosis can usually be distinguished from stem-end browning by its lighter color and the fact that it usually penetrates deeper than ½ inch (*57*). It can be distinguished from freezing injury by its more distinct color and by the absence of the irregular gray, blue, or black patches often associated with the latter. Net necrosis can be distinguished from the fusarium or verticillium wilt symptoms by the fact that it affects the phloem whereas the wilts affect the xylem (*56*).

The netted discoloration is a tuber symptom of the leaf roll disease that is exhibited only in the potatoes from plants that become infected during the current season (*58*). Leaf roll is transmitted almost entirely by the feeding of aphids on the potato plants. The discoloration does not appear until some time after harvest and even then may not affect all the potatoes from the newly infected plants. In Maine it has been shown that the development of the necrotic symptoms is influenced by the storage temperatures. It has recently been shown to increase during shipment to market. The maximum amount of net necrosis develops at about 45° to 50° F. and is reached after about 90 days in storage. Little or none occurs at 33° or 70° (*51*).

Leaf roll in the Green Mountain variety may be prevented to a large extent by storing for about 60 days at 70° F. or for 30 to 60 days at 32° to 36° immediately after harvest. It is said that the potatoes may be stored after this conditioning at other temperatures with little development of net necrosis (*51*).

Potato varieties differ in resistance to leaf roll and net necrosis. The Green Mountain variety is very susceptible, whereas Spaulding Rose and Irish Cobbler are somewhat resistant. Although Chippewa, Katahdin, and Sequoia are susceptible to leaf roll, they practically never show net necrosis (*43, 55*).

Control of net necrosis in the growing crop consists primarily in the use of disease-free seed and control of aphids, the insect vectors of the leaf roll virus. In storage, development of net necrosis can be retarded by maintaining temperatures considerably below 50° F. (*51*).

RHIZOCTONIA CANKER (BLACK SCURF, OR SOIL ROT)

The damage caused by *Rhizoctonia solani* Kuehn [25] occurs entirely in the field. The most conspicuous signs of rhizoctonia canker on the potatoes in storage are the black sclerotia that form

[25] Perfect stage: *Corticium vagum* B. and C., or *Pellicularia filamentosum* (Pat.) Rogers.

on the skin. These resemble drops of tar and vary in size from mere dots up to about ⅓ inch in diameter. Some potatoes may be almost completely covered with them. *Rhizoctonia* infection also may cause misshapen potatoes, tuber rot, pitting that resembles insect injury, and russetting that resembles scab (*39, 103, 129*). At high humidities, the sclerotia sometimes start growth and give the potatoes a moldy appearance that affects their sale (*105*).

Avoiding very late harvesting will reduce the number of sclerotia (*38*). High humidity in storage and in transit should be avoided to prevent growth of mold from the sclerotia.

RING ROT

Ring rot, caused by *Corynebacterium sepedonicum* (Spieck. and Kotth.) Skapt. and Burk., is a destructive disease of potatoes in the field. When infected potatoes are stored or shipped the ring rot bacteria, together with secondary soft rot organisms, may cause very severe losses.

The causal bacteria enter the vascular system of the potato from the stolon and cause a rot that is creamy yellow to light brown, crumbly to cheesy in consistency, and odorless. Sometimes the bacteria break through the surface at the eyes and thus provide an opening for the entry of secondary soft rot organisms. These secondary bacteria rapidly disintegrate the center of the tuber and leave a shell of the outer tissues, which is frequently cracked and shows brownish discolored areas.

Some potatoes from ring-rot-affected fields show no external signs of the disease when harvested, but decay after they have been stored. In the Soviet Union it was found that storage rot of potatoes infected with ring rot was worse when the weather was wet at harvest. It was found that the amount of rot could be reduced by drying the potatoes before storage (*7*). Experiments in Florida indicated that the rot developed rapidly at 70° to 95° F., less rapidly at 60° to 65°, and slowly at 37° (*45*).

Experiments in Maine showed that the bacteria could survive from one season to the next on potato sacks that were exposed to outside winter temperatures and inside at temperatures of 30° to 70° F. (*16, 21*).

The best control of this disease is obtained by the use of disease-free seed stock and disinfection of the planting tools, crates, bags, and the storage room (*14*).

Coal-tar disinfectants having a phenol coefficient of 6 have been found effective for disinfecting storage bins, containers, and equipment when used in the proportion of 1 quart to 25 gallons of water (*14*). Other materials that have been recommended for this purpose are copper sulfate (2 pounds to 10 gallons of water), Lysol 1-percent solution or 1 quart to 25 gallons of water, and formaldehyde 1 pint to 15 gallons of water (*124*). If potatoes from fields affected with ring rot are stored, the development of the disease may be retarded by maintaining a low temperature (*45*). Work is being done on the development of disease-resistant varieties (*124*) and one resistant variety, Teton, has been released (*107*).

SCAB

Although scab, caused by *Actinomyces scabies* (Thaxt.) Güssow, is primarily a field disease, severely affected potatoes may be predisposed to rots by secondary organisms in storage (*79, 80, 102*). Also scabby potatoes are undesirable for storage because they lose water and shrink more rapidly than healthy ones (*79*). Surveys in 1943, 1944, and 1945 showed that scab varied from a trace to 100 percent in different lots of potatoes in storage (*31, 32, 131, 132*).

Scab can be recognized by the brown corky roughening on the skin of the potatoes. The scab spots vary in size up to about ½ inch in diameter. On severely affected potatoes the spots may run together and cover a large part of the surface. The scab spots vary in depth, some being raised, some pitted, and others shallow surface blemishes.

The most practical ways to control scab at the present time are to grow potatoes only in soil that is definitely acid (about pH 4.8 to 5.2) and to plant resistant varieties. The development of scab is inhibited at soil reactions below pH 5.2 or above pH 8 (*37, 42, 47, 105*). Results from seed treatment have been contradictory. Seed treatments are more apt to be beneficial if the potatoes are planted in scab-free soil. The Menominee, Ontario, Cayuga, and Seneca varieties are resistant (*12, 43*).

SCLEROTIUM ROT, OR SOUTHERN BLIGHT

Sclerotium rot, caused by *Sclerotium rolfsii* Sacc., is a southern disease. The fungus that causes it attacks a large number of cultivated and wild plants in the South. It is especially severe on southern potatoes that are shipped in May, June, and July. Inspection certificates of potatoes received at New York showed that this disease has been found on potatoes from Florida, North Carolina, South Carolina, and Virginia (*139*).

The tuber rot may be either wet or dry, depending on whether the surrounding air is dry or moist. Potatoes affected with the wet stage are called "melters," because of the liquid released and the nearly complete disintegration of the potato (*48*). In the early stages of the disease the decay is white, mealy, and odorless, but later it becomes yellowish. The cause of the rot may be easily identified in advanced stages of the disease by the presence of the white rather coarse mycelium and the brown mustard-seed-like sclerotia that grow on the surface of the potato. The fungus is present in many of the soils in the South. Tubers may become infected during the growing stage or from contact with sclerotia or mycelium during harvesting operations or in storage. The causal fungus develops most rapidly at 86° to 95° F. The minimum temperature is about 46° and the maximum about 98° to 104°. Growth is slow at temperatures below 68° (*81*).

It has been shown in Tennessee that sclerotium rot is more severe in late-harvested potatoes of the spring crop than in those harvested early. No sclerotium rot developed in storage on potatoes dug June 2, whereas 6, 43, and 70 percent developed on those dug June 17, July 2, and July 17, respectively (*81*).

Methods of control are crop rotation in which cereals and grasses are grown as resistant crops, deep plowing to bury the sclerotia, early harvesting, and storing or shipping at about 46° F.

SILVER SCURF

Silver scurf, caused by *Spondylocladium atrovirens* Harz, may be found on potatoes in most parts of the United States. In storage it causes an excessive drying and shriveling of the affected potatoes. Silver scurf is hardly noticeable when the potatoes are harvested, but it increases rapidly in storage if the temperature and humidity are favorable for the causal fungus.

The disease may affect small localized spots or it may cover a considerable part of the surface of the tuber. The spots at first have a glazed or silvery appearance, which may be overlooked unless the potatoes are washed. Later they turn brown and the outer layers of the skin shed. As a result, evaporation is more rapid from the diseased areas and the tissues below the spots shrivel and become wrinkled.

The optimum temperature for growth of the causal fungus in culture is 75° F. No growth occurred at 37° or 91°. No new lesions were found and the old spots did not enlarge in storage at temperatures below 37° and with less than 90 percent relative humidity.

There are differences in varietal susceptibility. Irish Cobbler, Netted Gem, and Russet Rural are moderately susceptible; Pioneer Rural is fairly resistant; and United States Department of Agriculture seedling No. 44537 is very resistant.

Prompt digging at maturity and storage at below 37° F. and 90 percent relative humidity are recommended for control (*28*).

STEM-END BROWNING

Stem-end browning is a dark-brown to nearly black discoloration of the vascular bundles at the stem end of the potato. The amount that occurs in storage varies with different lots of potatoes. In surveys of stored potatoes in New Hampshire and Vermont in 1943 (*31, 32*), infection up to 20 and 25 percent, respectively, was found. It may be distinguished from net necrosis with a high degree of certainty by the fact that it does not generally penetrate more than ¼ to ½ inch. When it does penetrate further, it is confined to the ring of conducting tissues. In doubtful cases the only proof is to plant the potato and observe the above-ground parts for leaf roll, the leaf symptom associated with net necrosis (*56, 57*).

The cause of stem-end browning is unknown. According to Folsom and Rich (*57*), its development is not related to soil type, insect vectors, organic matter, or availability of nutrients. Stem-end browning does appear to occur more frequently on land where potatoes have been grown for a number of years, with increased amount of fertilizer, and with increased percentage of potash and chlorine in the fertilizer (*114*). There is some evidence that it may be caused by a virus (*112*). Stem-end browning sometimes follows the use of various vine killers (*67, 73, 106*).

According to experiments in Maine, the storage temperature affects the development of stem-end browning, which is worse in potatoes stored for 100 days at 50° F. than at higher or lower temperatures. Preliminary storage for 60 days at 32° to 36° or at 70° inhibits the development of stem-end browning even though the potatoes are stored later at a temperature favorable to it (*51, 86*). Immature potatoes appear to be more susceptible than mature ones (*36*). The Green Mountain and Irish Cobbler varieties are especially susceptible, whereas Katahdin and Chippewa are resistant. Some strains of Green Mountain are more resistant than others, but no differences have been found in different strains of the Irish Cobbler (*113*).

Control consists in growing resistant varieties or strains and storing at temperatures unfavorable for the development of stem-end browning.

VERTICILLIUM WILT

The wilt caused by *Verticillium albo-atrum* Reinke and Berth. occurs principally in the northern potato growing sections since the fungus does not attack plants at relatively high temperatures. Damage from this disease in the growing crop consists of wilting and dying of the plants and a reduction in yield. The fungus does not cause decay of the tubers, but it does cause blackening at the stolon attachment and a distinct browning of the vascular ring of some of the potatoes from infected hills. Not all potatoes from infected hills show these symptoms; so absence of stem-end and vascular discolorations does not necessarily guarantee freedom from verticillium wilt. Also the stem-end and vascular discolorations may be easily confused with those caused by *Fusarium* (*105*).

Control consists of planting disease-free seed and crop rotation.

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INSECT DAMAGE

WIREWORM INJURY

Wireworm injury is caused by the burrowing of the larvae of the snapping, or click, beetles (Elateridae) into the growing tubers. The depth and size of the burrow depend on the length and size of the worm. The holes are round and clean-cut and may be brown and lined with cork. Sometimes they become plugged and surrounded by dead tissue as a result of secondary infections by *Rhizoctonia.*

The injury caused by wireworms takes place in the growing crop, and control measures should therefore be applied in the field. MacLeod and Rawlins (*20*) [27] in New York stated that, since the adult beetles deposit eggs in soil where there is a dense cover crop, one means of control is to keep the ground clear during the period when the eggs are being laid. In 1947 Greenwood (*6*) and Pepper, Wilson, and Campbell (*21*) reported control by applying benzene hexachloride to the soil. Further experimental results and commercial experience, however, have shown that potatoes grown on soil treated with that chemical acquire a bad taste and an odor that become very evident on cooking and render them unpalatable.

FLEA BEETLE INJURY

The damage caused to potato tubers by feeding of flea beetle larvae is characterized by roughened pimply scars, channels in and under the skin, and brown corky slivers that extend 1/8 to 1/4 inch into the tissues at right angles to the surface. The affected tissues are usually so tough and dry that secondary rots, caused by fungi or bacteria, seldom develop.

Five species of flea beetle are known to attack potatoes—the potato flea beetle (*Epitrix cucumeris* (Harr.)), the tuber flea beetle (*E. tuberis* Gent.), the western potato flea beetle (*E. subcrinita* (Lec.)), the eggplant flea beetle (*E. fuscula* Crotch), and the tobacco flea beetle (*E. parvula* (F.)) (*1, 4, 5, 14, 23*). *E. tuberis* causes the most serious tuber damage, but this species is found only in western Nebraska, eastern Colorado, Wyoming, Washington, and Oregon. *E. cucumeris* occasionally damages the tubers in the Eastern States, but its damage is primarily to the foliage. The other species of flea beetle are of little or no importance on potatoes.

Control measures for use on the growing crop are necessary to reduce the losses from flea beetle damage. The injury does not spread or increase in intensity in storage or in transit. Control of flea beetle adults on the foliage reduces the number of larvae

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[27] Italic numbers in parentheses refer to Literature Cited for Insect Damage, p. 152.

that may damage the tubers. Anderson (*1*) in 1942 reported good control in eastern Virginia with a calcium arsenate-bordeaux mixture spray and calcium arsenate-monohydrated copper sulfate-hydrated lime dust. Gyrisko, Jodka, and Rawlins (*7*) in 1945 stated that DDT gave a favorable reduction in flea beetles and other potato insects in western New York and on Long Island and that it had a residual protective effect that lasted at least 10 days. Hill and Tate (*10*) in 1944 reported good control in Nebraska with zinc arsenate spray, cryolite dust, and barium fluosilicate dust. They also advised destroying cull piles and not planting early.

Differences in varietal susceptibility to feeding of the adult beetles on the leaves have been noted. Resistance of the foliage would result in some cases in smaller insect populations in the field and reduced tuber injury. Anderson (*1*) reported Cobbler more susceptible than Sebago and Sequoia. Stevenson (*25*) reported Chippewa, Sebago, and Sequoia only lightly infested and Mesaba and Pontiac moderately infested. Hardenburg and Stevenson (*8*) reported Mohawk to be resistant, and Stevenson (*26*) and Jehle and Stevenson (*13*) stated that Potomac was more resistant than Sebago, but less resistant than Sequoia. Sleesman (*24*) tested 10 species of wild *Solanum* and found that *S. polyadenium, S. chacoense, S. commersonii,* and *S. caldasii* were highly resistant. He suggested that resistance of *S. polyadenium* may be due to the disagreeable odor of an oil or ester on the leaf surfaces and stems. Davis, Landis, and Randall (*4*) reported tuber resistance in the Doe Bay Red variety, which was introduced many years ago from Denmark to the Puget Sound section.

TUBERWORM INJURY

The potato tuberworm (*Gnorimoschema operculella* (Zell.)), which is the larval stage of a moth, is the most important insect pest of stored potatoes. During the growing season the larvae feed in the leaves and stems of the potato plants and are very destructive to the foliage in seasons of low rainfall in some sections of California and the Southern States. Potatoes that are exposed because of inadequate soil covering or cracking of the soil may become infested during the growing period, but the most serious damage occurs to potatoes that are left exposed overnight in the field after digging or are stored in open sheds. The larvae move from the vines to the potatoes left on the ground, and the moths deposit eggs on potatoes left exposed in the field or open shed.

Tuberworms usually enter the potatoes at the eyes and after feeding for a while just under the skin, they tunnel deeper into the flesh and finally riddle the potatoes and make them unmarketable. Sawdustlike heaps of material at the eyes is evidence of the presence of tuberworms (*23*).

The tuberworms overwinter as full-grown larvae or pupae in the soil or in debris in the field, according to Poos and Peters (*22*). Boyd (*2*) in 1945 reported that in New Jersey it overwintered only in the pupal stage. Hovey (*12*) in 1943 reported that only a few full-grown larvae were able to pupate at 5° C. (41° F.) and that only 1 adult emerged from 54 newly formed pupae that were stored for 117 days at 5° C. Also, he found that lowering the temperature from 20° to 15° lengthened the incubation period of the eggs from an average of 8.35 days to 17.8 days.

Mackie (*19*) stated that storage at 38° to 40° F. destroys the worms. Control measures recommended are hilling the potatoes to prevent infestation during the growing period, avoiding exposure of the tubers to the larvae and moths after digging, fumigation in storage, and treating the potatoes and storage containers.

Poos and Peters (*22*) in 1927 recommended keeping the potatoes covered with at least 2 inches of soil. Cannon (*3*) in 1947 advised late hilling with a covering of at least 4 inches of earth. Lloyd (*18*) in 1946 presented data that indicated better control by using a disk for hilling instead of the less efficient scuffler. His data indicated slightly better control by hilling at an intermediate time instead of late.

Kulash (*15*) recommended avoiding infestation at harvest by not leaving the potatoes in the field at night, by not covering them with infested vines, and by storing in an enclosed room or shed.

Mackie (*19*) in 1945 stated that fumigation with methyl bromide was practiced in California, and Walker and Anderson (*27*) in 1944 in Virginia reported excellent results with this material for fumigation of potatoes in storage. Kulash (*15*) in 1947 in North Carolina recommended fumigation with carbon disulfide or methyl bromide. Fumigation with either of these materials must be done with caution, since carbon disulfide is very inflammable and methyl bromide is a very poisonous gas.

Helson (*9*) in 1942 reported that dusting potatoes at time of storage with finely ground magnesite at the rate of 20 pounds to a ton gave satisfactory control and was a suitable substitute for derris. Cannon (*3*) in 1947 reported that this material controlled tuberworm in Australia, but that it was less effective than DDT or derris under conditions of high humidity. Lloyd (*16, 17*), also of Australia, in 1943 and 1944 reported good control with a 5-percent pyridene dust when applied before larval infestation became noticeable. Kaolin showed some promise, but mineral oil used as a repellent was not entirely effective. Walker and Anderson (*28*) in 1944 reported good control of tuberworm on seed potatoes in storage with 2-percent DDT dust, and Hofmaster and Anderson (*11*) in 1948 and Hofmaster (*10a*) in 1949 reported complete control by using burlap bags dipped in xylene solutions containing 1 to 5 percent DDT and by distributing DDT-impregnated streamers and confetti among the stored potatoes.

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NEMATODES

ROOT KNOT NEMATODE

Root knot affects a large number of wild and cultivated plants, including many common vegetables. It occurs on potatoes in nearly all parts of the United States. Although root knot was formerly considered a southern disease, Cunningham (*8*) [28] reported that it has become increasingly important on Long Island, N. Y., since 1931 and Steiner stated that it has been observed in the most northerly States (*11*).

Tubers from affected plants may not show any external signs of root knot. However, if the potato is sliced, the female nematodes, or eelworms, may frequently be seen with the naked eye. They are located between the vascular ring and the surface of the potato and appear as glistening white bodies about the size of a small pinhead. They are surrounded by a clear, watery area in which the cells are devoid of starch. The posterior part of the female is surrounded by a jellylike brownish mass in which the eggs are embedded. Galls, or wartlike protuberances, develop on the surface of the potatoes as a result of cell activity caused by these nematodes. These galls usually remain intact but may rupture late in the season (*8, 11*).

Root knot is caused by a group of species, races, and strains of nematodes still called *Heterodera marioni* (Cornu) Goodey. Eggs and larvae may occur in the host plant, soil, or debris from infected plants. The eggs may hatch in the tuber or root, and the young eelworms may move only a short distance in the host tissue and develop there or they may move out into the soil and enter other roots or tubers. Eggs as well as eelworms may exist in stored potatoes (*8, 9, 11, 14*).

It has been reported that most rapid development takes place when the soil temperature is about 80° F.[29] and that the nematodes are relatively inactive below 50° to 55°. The eelworms are killed by frost, but the eggs resist subfreezing temperatures (*8, 9, 14*). Cunningham (*8*) reported that there are 3 generations on Long Island. In warmer areas 10 to 12 generations may develop in a year (*14*).

The eelworms may be spread from one place to another in infected seed potatoes, in transplants, and in infested soil or debris adhering to such transplants, to shoes of workers, to wheels of farm vehicles and machinery, and to tools (*8, 9*).

The results of experiments by Cunningham (*8*) on Long Island indicated that root knot does not spread in storage and that

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[28] Italic numbers in parentheses refer to Literature Cited for Nematodes, p. 158.

[29] In conversation G. Steiner stated that the soil temperature favoring most rapid development is between 65° and 85° F., depending upon the type of root knot nematode.

infected potatoes keep satisfactorily unless the galls become ruptured and infected with secondary decay organisms.

In tests of three varieties on Long Island, Green Mountain appeared to be the most susceptible, Irish Cobbler the most resistant, and Bliss Triumph intermediate (*8*).

Damage by root knot can be reduced by the use of healthy seed, a 3-year crop rotation, a 3-year summer fallow, soil treatment with chemicals, the use of resistant varieties such as Irish Cobbler, and early harvesting. Grain or grass crops should be used but alfalfa and clover omitted in the crop rotation. Although chemical soil treatments are effective, they are generally considered impractical because of cost (*8, 9, 10, 11, 14*).

POTATO ROT NEMATODE

The potato rot nematode was found on potatoes in Idaho by Blodgett in 1943 (*2, 3, 4*). It has not been found anywhere else in the United States, and vigorous control measures have been instituted in the district in Idaho where it was originally found (*5, 6*). It was found by Baker (*1*) in Prince Edward Island, Canada, in 1945; infected seed potatoes shipped from that district to Long Island were intercepted before they were planted. Potatoes infected with the potato rot nematode have been found from time to time in ship stores from 20 world sources by port inspectors of the United States Bureau of Entomology and Plant Quarantine.[30]

When discovered in Idaho, the nematode was identified by Glen KenKnight, of the University of Idaho, as *Ditylenchus dipsaci* (Kühn) Filipjev, the stem and bulb nematode. This species had been described on potatoes in Germany by Kühn in 1888. Thorne, however, found that the potato rot nematode was different from the stem and bulb nematode and named it *Ditylenchus destructor* (*17*).

The potato rot nematode affects only the tubers, which may be found in various stages of decay when dug. The rot continues to develop in storage. Blodgett (*2*) reported damage in the field ranging up to 75 percent. Thorne (*17*) stated that invasion of the tissues continues in storage and that many potatoes are almost completely destroyed by midwinter. Kreis (*13*) recorded observations of 80 percent loss in storage.

In the early stages small gray or brown spots of decaying tissue develop at the tuber surface. Later the tissues dry out as the lesions enlarge and the skin shrinks. In advanced stages the decaying tissues form a shallow, dark-brown layer just beneath the epidermis and the deeper tissues are bluish gray to brown, granular, and honeycombed. The nematode multiplies in the zone between the decaying and uninjured tissues, and both the adult and egg stages may be found there in abundance (*17*). Since this species of nematode does not form cysts (*11*), it is less difficult to control than some other species (*14*).

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[30] McCubbin, W. A., Steiner, G., and others. THE POTATO ROT NEMATODE, DITYLENCHUS DESTRUCTOR THORNE. U. S. Dept. Agr. [Unnumb. Pub.], 7 pp., illus. 1946. [Processed.]

The potato rot nematode is disseminated by means of infected seed potatoes, by water erosion of soil, and by soil on the feet of men and animals and on implements. Potatoes from affected crops may carry the nematodes even though they show no visible signs of infection. Wollenweber (*18*) reported that even carefully selected seed from infested land quite regularly produced 30 percent visibly rotted tubers.

In Idaho *Ditylenchus destructor* has been found to attack dandelion (*Taraxacum officinale* Weber) in addition to potato tubers (*17*). All varieties of potatoes tested have been found to be susceptible.

The following methods of control have been suggested: 3- to 5-year crop rotations, planting early varieties, clean cultivation, soil fumigation, the use of clean seed, and preventing movement of infested soil (*9, 11, 12, 14*).[31]

GOLDEN NEMATODE

The golden nematode (*Heterodera rostochiensis* Wr.), which causes major losses to the potato crop in the northern potato-growing areas of England and continental Europe, has become established in a localized district of Nassau County, Long Island, N. Y. It was first reported from that district in 1941, but Chitwood and Buhrer (*7*) stated that it probably was introduced about 1930. So far it has not been found anywhere else in the United States.

This nematode does not cause a rot or deformation of the tubers, but it does cause stunting, early dying of the vines, and reduction in yield. The female nematodes may be detected on the freshly dug roots and tubers from infested soils. At first they are white, spherical, glistening, and about the size of a pinhead. Later they turn orange or golden brown and fall off into the soil. The dead body of the female serves as a protective cyst in which the eggs and larvae overwinter (*7, 11*).

The golden nematode is spread by the transfer of infested soil. Care should be taken that such soil is not carried by running water, on the feet of farm workers, on farm implements, on vehicles, or by other means. Potatoes from infested districts should not be used for seed and should not be shipped to districts that are still free of this trouble. The movement of potatoes being grown in the infested district on Long Island has been restricted since discovery of the nematode (*7, 9, 14*).

SCRIBNER'S MEADOW NEMATODE

Scribner's meadow nematode causes small, slightly sunken pimples on the surface of affected potatoes in contrast to the raised warts, or galls, caused by the root knot nematodes. At first the pimples are inconspicuous, but later they become very noticeable because of their depressed borders. The skin over the tip of the pimples usually breaks and a thin layer of brown, dry tissue is

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[31] See footnote 30, p. 156.

exposed. These discolored tissues contain large numbers of the nematodes. The affected tubers wilt and eventually become hard and dry (*11, 15*).

Scribner originally described this trouble on potatoes in Tennessee in 1889. In 1943 Sherbakoff and Stanley (*15*) published Dr. G. Steiner's description of this nematode as a new species, *Pratylenchus scribneri.*

Steiner stated that at least five species of meadow nematodes occur in this country and that they are important factors in root destruction of cultivated and wild plants (*11, 16*). Sometimes the roots appear bearded or resemble a witches'-broom because the attacked plants try to overcome the damage through formation of new lateral roots.

A 2- or 3-year crop rotation, combined with the use of healthy seed, appears to be the most economical means of control (*11*).

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REVIEW PAPERS

Several papers that consist of or contain extensive reviews of potato literature are listed herein (*1–16*) [32] for the convenience of the readers.[33] Kröner and Völksen (*9*), for example, reviewed 784 papers.

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[32] Italic numbers in parentheses refer to Literature Cited for Review Papers.

[33] See also: HARVEST, TRANSPORTATION AND STORAGE COMMITTEE. REVIEW OF RECENT LITERATURE. [Unnumb. Rpt. of Commit., Div. Fruit and Veg. Crops and Dis., U. S. Bur. Plant Indus., Soils, and Agr. Engin.] 9 pp. [1947.] [Processed.]

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CONCLUSION

Literature published on potatoes during the past decade has dealt with a great variety of problems, several of which are discussed in this digest. All of these are important in one way or another. It is no exaggeration to say, however, that one of the most important of these, probably the most important, is the problem of mechanical injury and what to do about it.

Even before the period covered by this digest, Hastings,[34] in 1931, wrote as follows:

> Close association with the inspection of fruits and vegetables, especially potatoes, during the past several years in Minnesota and North Dakota has greatly impressed the writer with the significance of mechanical injury and its effect upon the appearance, quality, condition and grade of white or Irish potatoes. Invariably this injury is a major factor affecting the quality of potato shipments. Very often it is practically the only factor with which shippers have to contend in sorting potatoes to meet a certain grade. Sometimes the injury is so prevalent and so severe that it is impossible for the shipper to attempt to sort the stock to meet any of the better grades. Furthermore, observations prove that this type of injury may be the fundamental cause for deterioration and a lower grade in transit or at destination. When one stops to think of the number of injured and deteriorated potatoes which were thrown out before he examines the actual shipments, he is appalled by the apparent waste and resultant costs of mechanical injury.

Since the time of Hastings' report numerous investigators, mentioned elsewhere in this digest, have worked on the problem. They all found that mechanical injury causes serious loss in the potato crop every year during handling operations in the field, in storage, and on the market. The more recent of these reports tell just about the same story as did that of Hastings in 1931, although progress in reducing injury has undoubtedly been made.

It is no reflection on research already done to say that more is needed in order to determine just where and when most of the injury occurs. But even if more definite and specific information is eventually accumulated, there still remains the problem of putting it into practice. A rather pessimistic view of the possibility of doing this was expressed by Hincks, Spangler, and Sprague,[35] who wrote in 1941:

> In general, the causes of damage are well known. Elimination of these causes is usually dependent upon the individual who handles the potatoes. Educational campaigns would probably have little, if any, effect upon the persons responsible for most of the damage that occurs through rough handling.

It would be a confession of failure for the potato industry to admit that the situation is as hopeless as that statement indicates. But surely, one conclusion stands out as self-evident; namely,

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[34] HASTINGS, R. C. MECHANICAL INJURY TO POTATOES AND ITS ERADICATION IN NORTH DAKOTA. Amer. Potato Jour. 8: 126–132, illus. 1931. (See p. 126.)

[35] HINCKS, M. A., SPANGLER, R. L., and SPRAGUE, G. W. MARKETING MAINE POTATOES. DAMAGE IN SELECTED BAGS AT MAINE SHIPPING POINTS AND IN BOSTON WHOLESALE AND RETAIL MARKETS. [U. S.] Farm Credit Admin., Coop. Res. and Serv. Div. Misc. Rpt. 39, 17 pp. 1941. (In cooperation with [U. S.] Agr. Market. Serv. and Maine Agr. Expt. Sta.; see p. 15.) [Processed.]

that doing research on the problem and then publishing the results are not enough. Intensive and unremitting efforts are necessary at the working level in all important producing areas and on all the larger markets, to impress on those who do the physical handling the fact that potatoes cannot safely be banged around like coal or gravel.

Valuable research on developing new varieties, on cooking quality, on blackening after cooking, and on the control of diseases, besides all the money and labor expended on growing the crop, will yield greater results if economically preventable injury is actually prevented. Although potatoes may not "rate" the degree of careful handling given to dessert varieties of plums or pears, they certainly can be handled more carefully than they are now without their cost to the consumer being raised unjustifiably high.

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