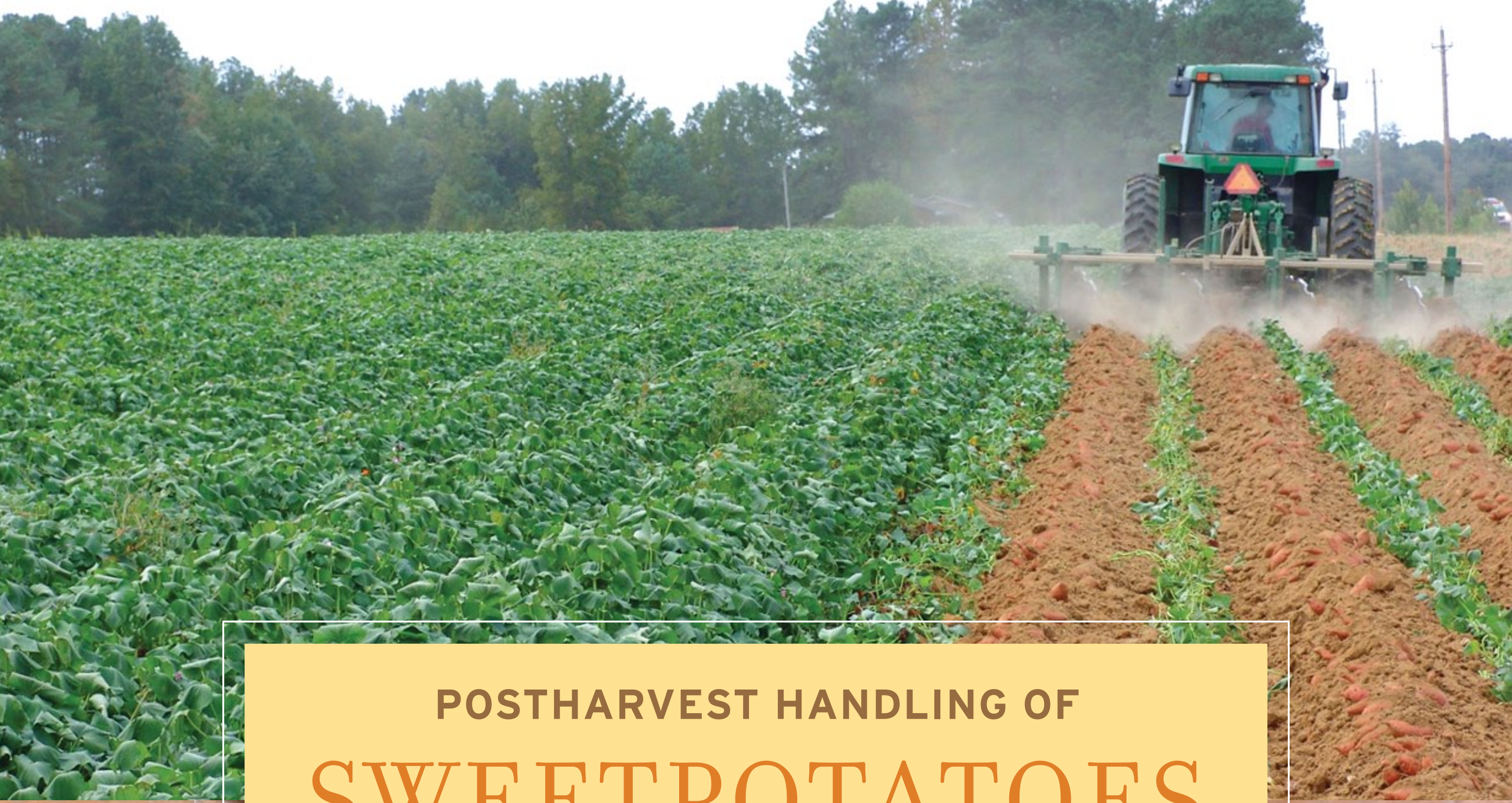
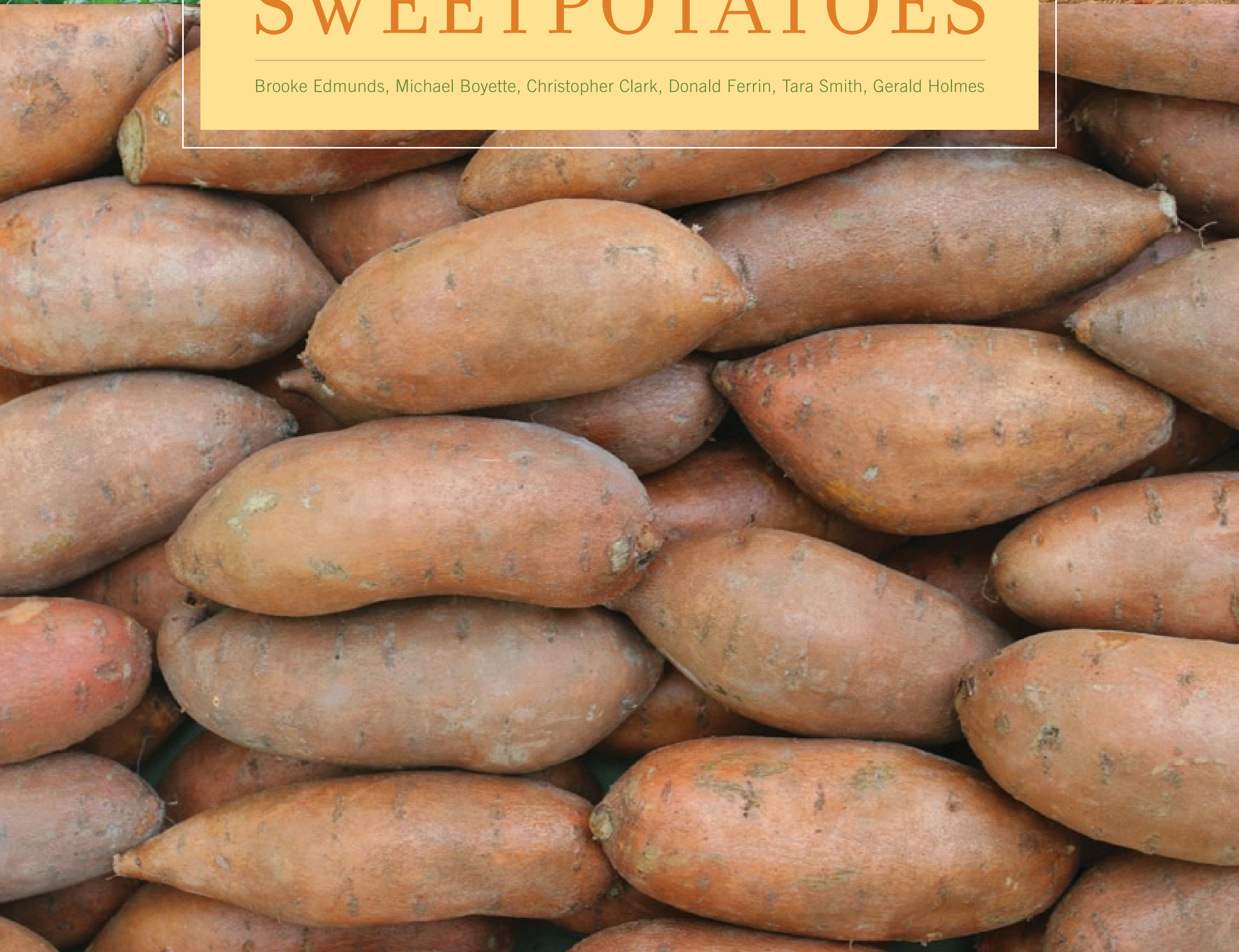


POSTHARVEST HANDLING OF

SWEETPOTATOES

Brooke Edmunds, Michael Boyette, Christopher Clark, Donald Ferrin, Tara Smith, Gerald Holmes




NORTH CAROLINA
SWEET POTATO
U.S. No. 1
50 lbs. net
PRODUCE OF U.S.A.
PACKED AND SHIPPED BY
HAROLD QUEBEDEAUX PRODUCE
Sweetpotatoes/Yam
PACKERS
Selected
LOUISIANA YAMS
M. RICHARD & SON
Classic
North Carolina
SWEET POTATOE
POINTER BRAND
A Pointer on Quality
YAMS / SWEET POTATOES
Quality and Service since 1942
Distributed By SOUTHERN PRODUCE DISTRIBUTORS, INC.
GODWIN PRODUCE CO.
OUR SPECIALTY IS HOUSE CURED YAMS
The Pride of North Carolina
WASHED AND WAXED
40 LBS. NET
PUERTO RICAN TYPE
DUNN, NORTH CAROLINA PHONE
CINNAMON & SUGAR
Sweet Potatoes
YAMS
HEART
TATOES
WASHED
WAXED
CAJAN QUEEN
SWEET POTATOES
YAMS
40 LBS. NET WT.
PRODUCT OF U.S.
TEXAS
ROADHOUSE
Sweet Potatoes
Nashville, NC 27856
SWEET MAGNOLIA
U.S. No. 1
BRAND
Louisiana
SWEET POTATOES
SAMPSON KING
NUTRITIONALLY FRESH®
SWEET POTATOES/YAMS
Distributed by Wayne E. Bailey Produce Co.
Chadbourn, North Carolina 28431 910-654-5163
PURE WINNER
BRAND
U.S. No. 1
SWEET POTATOES
Louisiana Porto Rican
PIERRE'S PRIDE
YAMS
Dri-Pak
BRAND
Old Fashioned — Hand-Packed
NORTH CAROLINA
SWEET POTATOES
We Be Yammin'
cajun style
40 LBS. NET WT.
NICKY
SWEET PO
LIZZY'S
DELIGHTS
Thornhill Farms
SWEET POTATOES
We're just plain good for you!
40 LBS. NET WT.
SHARKEY'S FINEST
sweet potatoes
Cajun
GOLD
Yams
Go for the GOLD
NORTH CAROLINA
Queen Ann
BRAND
WASHED AND WAXED
YAMS
WAYNE E. BAILEY PRODUCE CO.
SWEET POTATOES
Bursting with Beta-Carotene
Pride
40 LBS. NET
NORTH CAROLINA
YAMS
SWEET POTATOES
MORNING GLORY
BRAND
LOUISIANA
PORTO RICAN
SWEET
POTATOES
U.S. No. 1
PELICAN PACKING CO.
WAYNE E. BAILEY
NUTRITIONAL ALL STARS
SWEET POTATOES
the Nutritional Link to Health & Happiness
Cajun Sup
Yam
LOUISIANA
NUGGETS
KILN DRIED
PORTO RICAN
SWEET POTATOES
Sun Beauty
YAMS
BAKER'S CHOICE
Sweet Potatoes
Old Timers
Louisiana Porto Rican Yams
KILN DRIED
CAJUN GOLDEN
"It's Raining on Dez"
LOUISIANA BEAUREGARD YAMS
NORTH
CAROLINA
SWEET POTATOES
NATURALLY
HEALTH
BAYOU MAID
LOUISIANA
PORTO RICAN
SWEET
POTATOES
U.S. No. 1
TATER GATOR
BEAUREGARD
YAMS
40 LBS.
NET WT.
18.1 KG.
NASH'S PRI
NORTH CAROLINA
YAMS
SWEET POTATOES
NASH PRODUCE CO.
NASHVILLE, NC
's Pride
otatoes/Yams
NUTRITIONALLY
Play Boy
Brand
SWEET POTATOES/YAMS
Distributed by Wayne E. Bailey Produce Co.
Chadbourn, North Carolina 28431 910-654-5163
NET WT.
40 LBS. NET
JUMBO
SWEET
POTATOES
DEER MARK
LOUISIANA
PORTO RICAN
SWEET
POTATOES
General
LOUISIA
50 LBS. NET
JOYELLES
BRAND
U.S. No. 1
DOVE
Louisiana
YAMS
Sweet Potatoes
SWEET POTATOES
VICTOR

POSTHARVEST HANDLING OF

SWEETPOTATOES

Brooke A. Edmunds | Graduate Research Assistant, Dept. of Plant Pathology, N.C. State University

Michael D. Boyette | Professor, Dept. of Biological and Agricultural Engineering, N.C. State University

Christopher A. Clark | Professor, Dept. of Plant Pathology and Crop Physiology, Louisiana State University

Donald M. Ferrin | Assistant Professor, Dept. of Plant Pathology and Crop Physiology, Louisiana State University

Tara P. Smith | Assistant Professor, Sweet Potato Research Station, Louisiana State University

Gerald J. Holmes | Associate Professor, Dept. of Plant Pathology, N.C. State University

THE AUTHORS GRATEFULLY ACKNOWLEDGE THE FOLLOWING FOR REVIEW OF THIS BULLETIN: Charles Averre, Professor Emeritus, Dept. of Plant Pathology, N.C. State University; William Branch, Professor Emeritus, Dept. of Biological and Agricultural Engineering, Louisiana State University AgCenter; Abner Hammond, Professor, Dept. of Entomology, Louisiana State University AgCenter; George Kennedy, Professor, Dept. of Entomology, N.C. State University; and Jonathan Schultheis, Professor, Dept. of Horticulture, N.C. State University.

ON THE COVER: (Top) The process of harvesting sweetpotatoes involves digging the roots. Here the soil is turned over using large disks that bring sweetpotato roots to the surface. (Bottom) High quality, fresh-market sweetpotatoes (cultivar Covington) cured, washed and ready for sale.

SWEETPOTATO AS ONE WORD. Throughout this book, sweetpotato is deliberately spelled as one word unless directly quoting a source where it is spelled as two words (i.e., sweet potato). The one-word spelling was officially adopted by the National Sweetpotato Collaborators in 1989. Sweetpotato (*Ipomoea batatas*) must not be confused in the minds of shippers, distributors, warehouse workers, and above all consumers with the equally unique and distinctive potato (*Solanum tuberosum*) or the yam (*Dioscorea* sp.) which are also grown and marketed commercially in the United States.

Table of Contents

Proper Handling Pays

The importance of proper handling of sweetpotatoes, from the farmer's field to the consumer's kitchen, cannot be overemphasized. Studies show that significant postharvest losses occur because of improper handling and other factors. On average in the United States, 20 to 25 percent is lost in sweetpotatoes during curing and storage, another 5 to 15 percent is lost during shipping and retailing, and an additional 10 to 15 percent is lost after sweetpotatoes reach the consumer. In total, poor handling practices may result in the loss of more than half the harvested sweetpotatoes before they reach the consumer's table.

Providing consumers with an acceptable product (Figure 1) demands attention to the unique postharvest requirements of sweetpotatoes. This publication has been prepared to acquaint growers, packers, and shippers with the most current information and recommendations for proper postharvest handling of sweetpotatoes. It incorporates new information on good agricultural practices (GAPs) and packing line sanitation and configurations, and the results of an in-depth packing line survey. Also included are plans and operating recommendations for a moderate-sized sweetpotato curing and storage facility with negative horizontal ventilation (NHV). Photographs of common postharvest diseases, abiotic damage not caused by disease organisms, and insects are in Appendix 1.

Figure 1. Proper postharvest handling is required to produce quality sweetpotatoes for retail markets. (PHOTO BY G.HOLMES)

Figure 2. Freshly harvested roots exude latex when cut. (PHOTO BY G. HOLMES)

Figure 3. No latex exudation when cut: a symptom of chilling injury. (PHOTO BY T. SMITH)

Figure 4. Proper cutting of slips is done above the soil line to avoid contact of the knife blade with soil. A contaminated blade may transfer disease organisms from the soil to the cut ends of slips. (PHOTO BY G. HOLMES)

Growing for Improved Postharvest Quality

Successful storage starts with high-quality roots. Events occurring during the growing season may later negatively affect postharvest quality. Some factors such as weather are impossible to control, whereas others (such as fertilization) can be manipulated by a grower to ensure that a quality product goes into storage.

The weather during the growing season, especially just before and during harvest, has a major effect on postharvest quality. An extended drought followed by heavy rain frequently accelerates growth, which often produces roots with thin, delicate skin that are prone to growth cracks (Figure 53). Besides being unappealing to the customer, these cracks provide infection sites for soilborne pathogens. Additionally, heavy rains that saturate soil for more than a few hours can cause root asphyxiation. Water-saturated soil allows carbon dioxide to accumulate in the roots, a condition that may also be accompanied by a depletion of oxygen. Asphyxiation can happen at any time, but it is more likely to occur during warm periods, especially if the vines have been removed before harvest. Sweetpotatoes that have been asphyxiated may appear healthy for several days or weeks, but if injury was severe, the roots will die and begin decomposing in storage. The first indication of a problem may include the lack of exuding latex from the vascular ring of a cut sweetpotato (Figures 2 and 3). The smell of alcohol, yeast or "decay," increased numbers of fruit flies, and secondary diseases such as bacterial or fungal infections also appear during storage of asphyxiated sweetpotatoes.

Nitrogen fertilization timing and rates affect postharvest quality. While the final studies are not in yet, good cultural practices dictate the use of nitrogen fertilizers early and sparingly. Increasing yield with additional nitrogen fertilizer may result in an abundance of large, misshaped roots. Research on calcium fertilizers has also produced variable results. Some studies show a beneficial effect on skin quality and appearance, while most show no effect on quality.

Field practices control some postharvest diseases. Fusarium root rot, Fusarium surface rot, and black rot are just three diseases that start as infections in the field but develop symptoms in storage. Growers can reduce losses from these diseases by avoiding fields with a known history of disease and by using slips (plant cuttings used as transplants) that have been cut instead of pulled, which avoids transferring disease from the plant bed into the field (Figure 4). Proper curing is also essential to controlling many diseases and is discussed in the curing section on page 11.

Harvesting for Quality

Sweetpotatoes have thin, delicate skin that is easily damaged by cuts and abrasions (Figure 5). Rough handling during harvest can contribute significantly to postharvest losses. These losses result from shrinkage (weight loss), inferior appearance of the roots, and diseases that enter through damaged skin. Plowing and hand harvesting or harvesting with a mechanical digger will give satisfactory results if done carefully. Most growers harvest into either 20-bushel or 40-bushel "double" wooden bins, although some 20-bushel plastic bins are used. (See page 44 for more details on pallet bin dimensions and capacity.) Workers should not throw or step on the roots in the bins (Figure 6). Pallet bins should never be overfilled, as this prevents proper bin stacking. Improper stacking will injure the roots, not just on top, but throughout the bin (Figure 7). Overfilling can also

Figure 5. Skinning due to abrasions incurred during postharvest handling. (PHOTO BY G. HOLMES)

Figure 6. Gentle handling during harvesting operations is critical to maintaining quality and reducing decay. (PHOTO BY G. HOLMES)

Figure 7. Bins are often slightly overfilled initially so that as roots settle, the bin's holding capacity remains maximized. However, if sufficient settling does not occur, overfilled bins will lead to tremendous injury when stacked. (PHOTO BY G. HOLMES)

Figure 8. Sunscald (A) with deer feeding injury (B); undamaged root skin under the soil line (C). (PHOTO BY G. HOLMES)

Figure 9. Surface pitting caused by chilling injury. (PHOTO BY G. HOLMES)

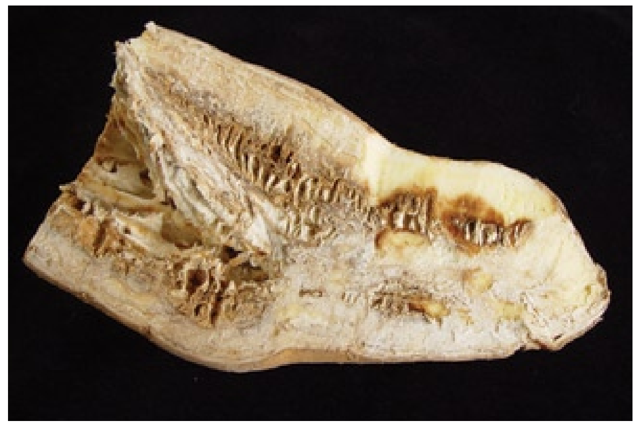


Figure 10. Internal voids caused by dry matter loss. (PHOTO BY G. HOLMES)

Figure 11. Secondary *Penicillium* mold invasion following chilling injury. (PHOTO BY G. HOLMES)

cause stability problems when stacking. Likewise, transport over rough roads or excess movement at the curing and storage facility can result in additional damage. Although prompt and proper curing can help heal injuries, an injured sweetpotato will never regain its original appearance.

After roots are dug, they should be promptly loaded and moved to the storage facility. Otherwise, there is a risk of injury by sunscald or chilling, depending on environmental conditions. Sunscald (Figure 8), a physiological condition that causes a darkening or death of the skin, may result after as few as 30 minutes of exposure to bright sunlight. If sweetpotatoes are allowed to remain in bright sun for several hours, either before they are picked up or after they are placed in the pallet bin, they are almost sure to develop sunscald. Sunscald is unattractive and can be a site for postharvest decay. Some cultivars of sweetpotatoes are more susceptible to sunscald than others, and it is more conspicuous on light or flesh-colored cultivars.

Chilling injury becomes a concern during late-season harvests. Although sweetpotatoes freeze at about 30°F (1°C) and are immediately ruined, they are injured at temperatures below 50°F (10°C). The extent of the chilling injury is a function of both the temperature and length of exposure. For example, one hour at 40°F (4°C) may produce the same level of injury as five hours at 45°F (7°C). Chilling injury is also cumulative; one short episode below 50°F (10°C) may not produce any noticeable injury, whereas many short episodes may cause significant injury. Unharvested sweetpotatoes may not be harmed by a frost, depending on the temperature of the soil surrounding the roots. Harvest as soon as possible after frost has killed the vines to ensure that no injury occurs. Never leave harvested sweetpotatoes in the field overnight, as cooling may cause substantial injury. Damage caused by chilling may not appear for many weeks—or even several months—after the chilling occurs.

Chilling injury is expressed in many ways and can be difficult to diagnose. The most common symptoms are surface pitting, greatly accelerated respiratory activity (dry matter loss), and an increase in susceptibility to decay (especially blue mold caused by *Penicillium* spp. See Figures 9 through 11). Other common symptoms include internal breakdown and voids, hardcore, failure to sprout, reduced culinary character (color, texture, taste, and aroma), and discoloration (darkening) of flesh when exposed to air. If chilling was severe, the roots may not exude latex when cut (Figures 2 and 3), or die and begin to decompose in storage.

The Curing and Storage Facility

A properly built storage facility maintains the temperature and humidity required for curing and long-term storage of sweetpotatoes. "Common storage" in areas without temperature control or assuming that the ambient cool winter temperatures are adequate will not maintain sweetpotato quality. The most effective type of storage facility uses negative horizontal ventilation (NHV).

The NHV system uses a slight negative pressure to pull the ventilation air horizontally past the pallet bins. Fans mounted internally along the top of a plenum wall on one end of the room create the negative pressure. Air first enters the mass of sweetpotatoes at the end of the room opposite the plenum wall, through ducts formed by the forklift slots at the bottom of the pallet bins. The air then moves horizontally through the mass of sweetpotatoes toward openings in the plenum wall. Once in the plenum, the air rises and passes through the fans and back out into the room, where it moves horizontally in the opposite direction back over the top of the stacked bins (Figures 12 and 13).

Figure 13. Loading pallet bins of sweetpotatoes into a new negative horizontal ventilation (NHV) facility. (PHOTO BY CCU INC.)

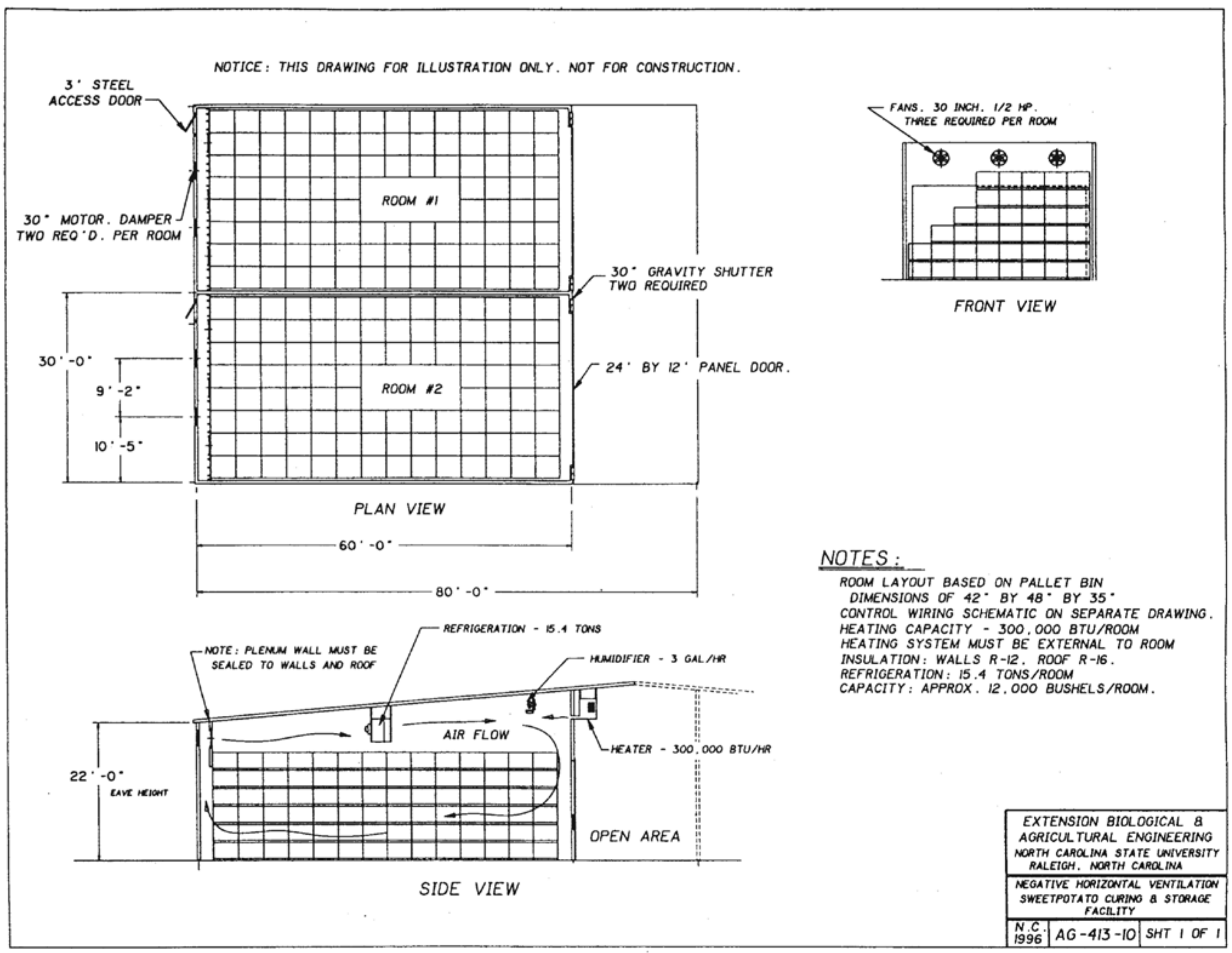


Figure 12. Construction diagram for negative horizontal ventilation storage facility. (ILLUSTRATION BY M. BOYETTE)

The NHV system allows good air mixing, so there is little internal variation in temperature or humidity throughout the room. Further, because the air is in motion and is passing through the mass of sweetpotatoes (no root is more than one-half the depth of a pallet bin—approximately 25 inches (63.5 cm)—from a moving stream of air), there is opportunity for heat transfer. Good heat transfer is important for warming the sweetpotatoes at the beginning of the curing cycle, cooling them at the end, and for removing the heat of respiration throughout the storage period.

A series of motorized dampers is located on the exterior wall across the plenum from the fans. While these dampers remain closed, only internal air is circulated through the pallet bins. These dampers are opened when outside air is required for ventilation or cooling. Air is pulled into these openings because of the slight negative pressure the fans create in the plenum. The size and number of these dampers are determined by the capacity of the room. When correctly designed, approximately one-third of the air passing through the fans will be pulled from outside, with the remainder of the air recirculated from the stack of pallet bins. The air displaced by the incoming air exits the room through gravity shutters located near floor level at the end of the room opposite the plenum.

The NHV system offers a number of improvements to sweetpotato curing and storage facilities:

- Air moves efficiently and consistently through the large mass of sweetpotatoes, providing ventilation and heat transfer to minimize both in-building variations and fluctuations because of changes in outside temperature and humidity. Warming sweetpotatoes at the beginning of curing, cooling at the end, removing heat, and warming seed sweetpotatoes for pre-sprouting before bedding are greatly enhanced by NHV's efficient heat transfer.
- Because the air passes through the mass of sweetpotatoes horizontally, the NHV system does not use floor trenches. The floors may be the standard four inches of welded wire mesh or fiberglass-reinforced concrete over a packed grade. This feature substantially reduces the cost of construction and allows NHV systems to be installed in many existing structures.
- Economical standard pole-type or steel column and girder buildings may be used without expensive custom modifications or the need for excessively wide spans.
- The system can accommodate a large variety of room sizes. Individual rooms have been built as small as 20 by 50 feet (6.1 by 15.2 m), with 6,000-bushel capacity, to as large as 120 by 100 feet (36.6 by 30.5 m) with 96,000-bushel capacity. This flexibility is particularly attractive in the larger facilities with lower per-unit construction and operating costs. Larger rooms may make slightly more efficient use of space than smaller rooms but can result in undercured or overcured roots if not filled on a timely basis. Smaller rooms, however, are more quickly emptied and taken out of service.
- The NHV system makes very efficient use of floor space. For the system to operate properly, the pallet bins must be placed tightly together, in straight rows, with as little space between bins as possible. The system has worked well with bins stacked six, seven, and even eight high, but it works best if all the bins are stacked to the same height. It is also better if all the pallet bins are nearly the same size and of the same construction, as this facilitates proper stacking and minimizes air leakage between bins. Some air will inevitably short circuit between the bins, both in the horizontal and vertical direction, which is why the fans are sized to accommodate this leakage.
- Because the cost of outfitting a building with NHV is modest, there is no advantage to having separate rooms for curing and storage. This makes better use of space and eliminates the need to move the sweetpotatoes at the end of curing—an operation that is time consuming, expensive, and invariably results in damage to the roots.
- Eliminating substantial variations in temperature and humidity inside the room allows for more precise and sophisticated controls that help maintain quality and reduce energy usage. Although many NHV facilities are successfully managed by electro-mechanical controllers (thermostats, relays, timers), the full benefit of NHV technology is realized by using programmable logic controllers (PLCs). These industrial, computer-like devices may be programmed not only to control the temperature and humidity but also to monitor and limit energy use, collect data, sound alarms, and provide security.
- The ventilation fans mounted in the roof of traditional sweetpotato storage facilities are often a source of leaks and other maintenance problems. In an NHV facility, air inlets and outlets are mounted on the sides of the building, which makes them much easier to install and maintain and less likely to leak.
- Various sprays are effective against insect pests. Until recently, however, it was difficult to consistently distribute the material throughout the mass of sweetpotatoes. Even in facilities with automatic insecticide dispersal systems, complete coverage is difficult. The uniform air movement in NHV facilities effectively distributes insecticides throughout the room for maximum coverage.

For more information on specific construction guidelines for the NHV system, see Appendix 3.

Curing for Quality

A portion of the annual sweetpotato crop is still marketed as “green,” although the practice is fading from favor. Green roots are washed, graded, and packed within a few hours or days of harvest and shipped immediately to buyers without curing. Uncured sweetpotatoes generally lack the visual appeal, shelf life, and culinary character of cured roots.

Most sweetpotato growers and packers have invested in modern curing facilities and consider proper curing an indispensable first step in a process that allows the industry to provide a year-round supply of high-quality sweetpotatoes. Successful curing requires roots to be held at a temperature of 85°F (29°C) and a relative humidity of 85 to 90 percent with proper ventilation for three to five days immediately after harvest. (The duration varies depending on the root pulp temperature at harvest. The greater the difference between root pulp temperature and 85°F (29°C), the longer it will take to cure. See page 47 for more information.) A delay of as few as 12 hours between harvest and curing has been shown to be detrimental to successful curing.

Sweetpotatoes remain metabolically active after harvest. They respire, converting starch to sugars that are metabolized to release carbon dioxide and water vapor. Sufficient movement of air (ventilation) during curing is essential and helps dry roots and any adhering soil, provides proper oxygen and carbon dioxide exchange, and is necessary for good heat transfer during curing. As little as one-half cubic foot of outside air per bushel per day is sufficient for proper ventilation. However, sweetpotatoes injured by rough handling, exposed to chilling, or harvested from waterlogged soil may require as much as 5 to 10 cubic feet of outside air per bushel per day.

The humidity during curing should be as high as possible (85 to 90 percent) but not to the point where water may be seen on the walls, floors, bins, or especially the sweetpotatoes. All properly designed curing facilities should have correctly sized humidification equipment and controls. The cost of this equipment is easily recovered in reduced weight loss and better root quality. Curing rooms should be properly insulated to conserve energy and reduce condensation. (See Appendix 3 for a discussion of insulation materials.)

BENEFITS OF CURING:

1. Curing enhances culinary characteristics (eating quality). A sweetpotato’s culinary characteristics are a combination of color, texture, taste, aroma, and fiber content. Much of the culinary character of an individual sweetpotato depends on the cultivar and, to a smaller extent, on cultural practices during the growing season. Some of the most important culinary characteristics, however, are the result of chemical changes that occur as a result of curing. Proper curing has been shown to increase the sensation of moistness and sweetness, enhance the aroma, and decrease starch content while increasing sugars.

2. Curing aids in wound healing and reduces losses due to shrinkage and disease. When roots are wounded, the exposed cells will quickly dry and die. Sweetpotatoes will naturally exude sticky latex from injuries, particularly at the ends of the sweetpotato (Figure 14). This material may dry in a few hours and appear to close the wound, but it actually provides little protection from decay organisms or weight loss. Only proper curing can result in “true” wound healing. Under curing conditions, the sweetpotato will deposit a layer of material under the dead cells in the wounded area. This barrier further reduces moisture loss and impedes microbial invasion of the tissue. In the final stage of this process, a second layer similar to undamaged skin is deposited under the wound in a process known as *suberization*.

Figure 14. Latex stains on roots. (PHOTO BY B. EDMUNDS)

3. Curing sets the skin. Freshly harvested sweetpotatoes have thin, delicate skin that is easily broken, scraped, or otherwise removed (Figure 5). Some cultivars may be washed and graded without serious injury if it is carefully done within 24 to 48 hours of harvest. However, most cultivars require curing to “set the skin” because the skin quickly becomes too loose to permit safe handling. Proper curing after harvest results in skin that sets within four to six weeks. The exact time required for skin set varies considerably across cultivars. The factors influencing skin set, such as growing conditions, are not well understood and are the subject of ongoing research.

If roots must be shipped soon after harvest, the time required for skin set may be shortened somewhat by proper curing at standard conditions followed by several weeks at proper storage temperatures but at less than 85 percent relative humidity with good air ventilation (as much as 30 to 50 cubic feet of ventilation per day per bushel may be required in this circumstance). This treatment may allow roots to be shipped sooner but will result in increased weight loss, so it is important to move this product quickly to market. For longer storage periods, follow the curing period with normal storage conditions—55°F (13°C), 85–90 percent relative humidity, and adequate ventilation.

PROBLEMS ASSOCIATED WITH IMPROPER CURING:

Inadequate and excessive curing can shorten shelf life, increase sprouting during storage, and result in excessive weight loss. Normal weight loss should not exceed 5 to 8 percent of the freshly harvested weight.

Improper ventilation during curing can result in an extremely low oxygen/high carbon dioxide environment. Exposure to this environment for short periods has been shown to reduce the effectiveness of curing, shorten storage life, and alter the taste of the sweetpotatoes, but this problem is unlikely to occur in a properly operated modern facility.

Curing at improper temperatures or humidity can reduce quality during storage. Research has shown that curing sweetpotatoes at temperatures below 75°F (24°C) increases weight loss and decreases storage life. Low humidity also results in inadequate healing of wounds.

Curing that continues for too long can result in widespread sprouting (Figure 15). It is not unusual to see short (less than one-fourth inch) sprout buds on a few roots toward the end of curing; however, widespread sprouting results in rapid weight loss. The best way to minimize weight loss from overcuring is not to exceed the recommended three to five days of curing and to reduce the temperature to 55 to 60°F (13°C) as quickly as possible. Maintaining the correct relative humidity (85 to 90 percent) during storage is also critical.

Storing for Quality

The next step in the production of quality sweetpotatoes is storage in the proper environment. The primary goal of storage is to maintain root quality and ensure an adequate supply throughout the year by minimizing both physiological disorders and disease development. Current experience shows that high-quality roots that are properly cured and held, undisturbed, under proper storage conditions—55°F (13°C), 85 to 90 percent relative humidity, with adequate ventilation—remain marketable for as long as 13 months.

These storage conditions were first determined in the 1920s with cultivars grown at that time, and recent research has shown that these conditions are still valid for modern commercial cultivars. It is important to maintain the temperature as close as possible to 55°F (13°C). Minor fluctuations of three or four degrees are expected, but avoid fluctuations of more than five degrees. Fluctuations can occur when roots are stored in common storage or in a room without temperature regulation. Fluctuations of more than five degrees will lead to premature breakdown of the sweetpotato and excessive weight loss.

Higher relative humidity (greater than 85 percent) would be entirely suitable for sweetpotato storage. However, from a practical standpoint, very high humidity (90 to 95 percent) is difficult to maintain consistently and to measure accurately. Additionally, very high humidity will cause condensation to form on the building walls or roof, causing maintenance problems and the wetting of bins and roots, which promotes decay. Improper room insulation can also contribute to condensation problems.

PROBLEMS ASSOCIATED WITH IMPROPER STORAGE CONDITIONS:

Improper storage conditions can increase the development of physiological disorders and diseases. Physiological disorders are the result of stresses related to excessive light, heat, cold, and moisture, or the mix of surrounding gases such as oxygen, carbon dioxide, and various pollutants. Some disorders can be caused by mechanical damage, and all are abiotic in origin (not caused by disease organisms) and cannot be controlled by postharvest pesticides. However, many postharvest disorders compromise the sweetpotato's natural defenses, which in turn increases susceptibility to infectious postharvest diseases. In some cases, physiological disorders may even mimic infectious diseases. Common physiological problems resulting from improper storage conditions include excessive dry matter loss, sprouting, pithiness, hardcore, chilling injury, and moisture loss (Figures 9 through 11).

Dry matter loss and pithiness. Sweetpotatoes lose dry matter through natural respiration. Respiration is a chemical process necessary for all living tissue whereby starches and sugars (dry matter) are oxidized to carbon dioxide and water vapor with the liberation of heat. The heat generated by an individual sweetpotato is negligible, but the combined output of thousands of bushels in a storage facility can raise the temperature of sweetpotatoes one-fourth to one-third degree per day. This heat must be continually removed from

Figure 15. Sprouting due to poor curing or storage conditions. Note that sprouts generally originate from the proximal end of the root (i.e., the end closest to the plant). (PHOTO BY G. HOLMES)

the facility, or the temperature will rise above acceptable levels in a short time. A storage facility must have provisions for cooling with outside air or a refrigeration system.

Although not apparent externally, significant dry matter loss may result in pithiness with the formation of many small voids (Figure 10). Pithiness is very common in sweetpotatoes held for long periods in poorly controlled storage facilities.

Sprouting in storage. Another effect of elevated storage temperatures is sprouting (Figure 15). At temperatures above 60°F (16°C), sweetpotatoes will sprout. The length of time required for sprouting depends on the temperature. It may take a month or more for sprouts to show at 65°F (18°C), but at 75°F (24°C) and warmer, sprouts can develop in a few weeks. Sprouting is always accompanied by rapid respiration and weight loss. Chemical sprout inhibitors are not used in sweetpotatoes because proper temperature control inhibits sprouting. USDA standards (see Appendix 2) list sprouts over three-fourths of an inch long as defects. Sprouts can be manually removed from roots during the packing process.

Chilling injury. Chilling injury is rare in modern storage facilities, but it can occur if roots are kept in common areas during the winter months. Storage below 50°F (10°C) can result in chilling injury that may not be evident until several weeks have passed (Figures 9 through 11).

Excessive shrinkage. If the humidity is low, sweetpotatoes will lose weight as moisture evaporates from the surface of roots. This results in weight loss and may cause shriveling of the skin, especially at root ends (Figure 16). Although some moisture loss is practically unavoidable during curing and storage, excessive water loss may be avoided by maintaining high relative humidity during storage.

Figure 16. Weight loss is increased by skinned areas and leads to shriveling. (PHOTO BY B. EDMUNDS)

TABLE 1. Typical components and sequence of components in medium and large sweetpotato packing lines.

Medium (Low Volume) Packing Line	Large (High Volume) Packing Line
dump tank	dump tank
wash/brush	wash/brush
eliminator	eliminator
grading	grading
fungicide application	**wash/brush***
sizer	fungicide application
grading	sizer 1-expanding pitch type
box fill	first grading
	wax/brush*
	sizer 2-electronic*
	final grading*
	box fill

*Bold text indicates items that differ from medium packing lines.

Disease development in storage. By far, postharvest diseases account for the greatest loss in stored sweetpotatoes. In extreme instances, decay losses can run nearly 100 percent. The occurrence of postharvest diseases tends to vary from year to year. Outbreaks occur when pathogens are given an opportunity to proliferate. Many of the diseases that affect sweetpotatoes in storage are first established in the field or on planting material such as scurf (Figure 51). Other postharvest disease organisms are wind- or soil-borne as spores and are essentially ubiquitous (such as Rhizopus soft rot).

Postharvest diseases may be caused by fungi, bacteria, or viruses, although fungi are more common in sweetpotatoes. Most viruses do not cause serious postharvest diseases, although symptoms from field infections may be first noticed after harvest (as with russet crack) or may develop in storage (internal cork). Similarly, root knot nematodes infect roots in the field, and the resulting cracking may be noticed during grading and packing (Figures 54 and 55).

Control depends on understanding disease-causing organisms, the conditions that promote their occurrence, and the factors that affect their capacity to cause losses. Additionally, following approved cultural practices in the field can significantly reduce many of these diseases. Sweetpotatoes should be inspected as they are harvested. Leave roots with indications of established disease (lesions) or obvious defects such as growth cracks or excessive skinning in the field. Gentle handling and minimization of environmental stresses can substantially reduce the level of postharvest disease. The management of specific diseases is discussed in Appendix 1.

Packing for Quality

The packing of sweetpotatoes is an industrial operation that should be dedicated to delivering the highest quality product to the consumer. The current market demands uniformity in appearance in both color and size (see cover photo bottom), which necessitates long and complicated packing lines. Unfortunately, long packing lines can increase the opportunity for skinning, bruises, cuts, and broken ends that detract from appearance and increase the possibility for disease development.

In general, good packing-line design strikes a balance between gentle, yet efficient, handling of the sweetpotatoes. Indications of the need to alter an existing packing line include high labor and energy costs, bottlenecks, congestion, worker complaints, accidents, and product damage such as excessive skinning, excessive loss to disease, and large piles of broken ends on the floor below problem areas.

An industry survey of sweetpotato packinghouses in North Carolina and Louisiana from 2004 to 2006 revealed similarities among layouts and associated trouble spots (Tables 1 through 5). Table 1 describes the typical components and layouts for mid- and large-size packing lines seen in both states. An instrumented impact-recording device (SmartSpud, Sensor Wireless, Canada) was used on packing lines in both states. This device measures the force of impacts (measured as a unit of force called a *g*; 1 g = 9.81

Figure 17. Instrumented impact recording device used to measure impacts on packing lines. Right: fresh sweetpotato; middle: molded urethane casing with accelerometer inside; left: handheld computer with antenna for receiving signal from accelerometer and recording impacts. (PHOTO BY B. EDMUNDS)

Figure 18. Dumping roots using a forklift-mounted bin rotator device. (PHOTO BY G. HOLMES)

Figure 19. Dumping roots using an automatic bin rotator. (PHOTO BY G. HOLMES)

Figure 20. Dump tank with metal bib to sift out soil. (PHOTO BY G. HOLMES)

Figure 21. In a submerged dump, the entire storage bin is placed in the dump tank, and roots float out. (PHOTO BY G. HOLMES)

meters/second squared) with higher numbers indicating areas or drops on packinglines where potentially damaging impacts are occurring. The original device used by researchers was called an *instrumented sphere* because of its shape, and a major improvement has been the development of a urethane or silicon casing that mimics the dimensions of the commodity being tested. The North Carolina State University engineering department fabricated a casing by making a mold of an actual sweetpotato (U.S. No. 1 grade, Figure 17). This casing allows for measurements that reproduce impacts received by sweetpotatoes on a packing line. Impacts occurring at specific points on the packing line will be discussed further and are summarized in Tables 2 and 4.

Dump Tank. Sweetpotatoes are generally dumped into a tank of water (dump tank) either by a bin rotation device on a forklift (Figure 18) or an automatic bin rotator (Figure 19). Because harvested roots go directly into storage without washing, sweetpotatoes always have significant amounts of soil adhered to the surface, even when harvested from dry, sandy soil. Some dump tanks have a bib of small metal bars that sift the loose soil out as the roots tumble into the dump tank (Figure 20). The bib prevents some of the soil from entering the water, but the impact of the roots on the bars is high and is also a major source of mechanical injury. Skinning is particularly severe because dry roots skin much easier than wet roots. Because the severity of damage is directly related to the distance of the fall, automatic bin rotation equipment (which shortens the fall distance) is preferred to bin rotators on forklifts. A better option is an automatic bin rotator with a lid, which gradually releases the roots into the dump tank and minimizes root-to-root impacts. The best option for minimizing root injury is the "submerged dump" (Figure 21). This requires specialized equipment that completely submerges the entire bin into a water tank, allowing the roots to float out and virtually eliminating root-to-root impacts. Submerged dumps have yet to be adopted in the Southeast mainly due to the expense associated with the equipment and the transition to plastic storage bins. (Wooden bins quickly break down when wet and are poorly suited for this type of dump.)

Figure 22. High-volume water rinse is used to clean roots. (PHOTO BY B. EDMUNDS)

Figure 23. Eliminator on a packing line. Roots smaller than 1.5 in (3.8 cm) in diameter fall through the bars. (PHOTO BY G. HOLMES)

Figure 24. Proper lighting and height for grading table allows workers to adequately see and reach cull roots. (PHOTO BY G. HOLMES)

The dump operator can have a major influence on impacts. Operators must be able to see into the dump tank so that they can carefully monitor the dumping operation. Sweetpotatoes should not be dumped into an overfilled tank, which causes excessive impacts.

Unloading sweetpotatoes into the dump tank generates a large amount of dust. In addition to creating problems for workers and machinery, this dust usually contains decay-causing spores that are a ready source of contamination for nearby sweetpotatoes. For these reasons, it has become customary to partition or wall off the dump tank from the rest of the packing line. Additionally, ventilation fans should be installed near the dump tank to draw the dust outside the building and away from the rest of the line. Fans also help keep dust away from forklift and dump operators.

Dump tanks vary in size but may hold several thousand gallons of water. A portion of this water is flushed regularly, along with the heavier soil, through a large, air-operated slide or butterfly valve located on the bottom of the tank. The air cylinder may be switched on manually or activated by a simple float switch and timer circuit. Many newer dump tanks also have automatic monitors that adjust the water level as needed.

To reduce decay, some packers treat the dump tank water with antimicrobial agents. Sodium hypochlorite (liquid bleach) is commonly used. Unfortunately, bleach is quickly deactivated by large amounts of soil in dump tanks and must be recharged at regular intervals (dependent on the amount of soil entering the dump tank). The gases released from treated dump tanks can irritate the skin and eyes of workers and corrode metal surfaces. Very high concentrations of bleach in dump tanks may also lead to root bleaching. Other treatments that have been used with limited success include ozonation and copper ionization. Although these treatments may kill pathogens in relatively clean water, suspended soil particles diminish their efficacy, making them impractical on packing lines. Several studies have shown that sanitizers are not effective for controlling Rhizopus soft rot.

Washing. Most sweetpotato packing lines use a water rinse step to remove clinging soil. Waterfall/curtains and normal- or high-pressure spray washers may be used (Figure 22). High-pressure washers have become popular because of the difficulty of removing darker soils from some sweetpotato cultivars. Water at pressures as high as 250 pounds per square inch (psi) is directed by spray nozzles at the surface of sweetpotatoes as they travel over rotating brushes.

The dump tank and spray washer can use several thousand gallons of water per hour. Even if a well or other source can supply this amount of water, packing line operators should consider disposal: The less water a packing line uses, the less that needs disposal. For this reason, many sweetpotato packing lines have screens and tanks to collect the water from the wash step and use it to supply the dump tank. This simple plumbing arrangement can reduce water use (and disposal) by two-thirds or more.

Impacts are generally low during washing because most packing lines wash over a brush bed. Some brush beds are immediately preceded by a metal incline, which itself can be a source of high impacts.

Figure 25. A dip tank can be used to apply fungicides (PHOTO BY G. HOLMES)

Figure 26. Fungicides may also be applied by using a waterfall/curtain. (PHOTO BY G. HOLMES)

Figure 27. Spray application over a brush bed is a common method of applying fungicides. (PHOTO BY G. HOLMES)

Eliminator. Most packing lines have one eliminator. (Less than five percent have two.) The eliminator consists of a bed of parallel metal rollers normally set 1.5 inches (3.8 cm) apart (Figure 23). The eliminator quickly removes trash and small unmarketable roots. It is important that the roller spacing does not get dented or bent, as this will increase the spacing and cause marketable roots to be discarded. Impacts can be severe if sweetpotatoes fall directly onto the rollers, rather than rolling down an incline onto the eliminator, because the rollers are supported by the chain guides.

Instrumented device readings averaged 8.8 g and ranged from a low of 0 g where the sweetpotatoes rolled down a gentle incline (total drop of 5 inches) to a high of 30.7 g in a case where the sweetpotatoes fell about 16 inches directly onto the eliminator rollers.

Grading. After washing and elimination of trash, sweetpotatoes move onto a table for hand sorting and removal of decayed or otherwise unmarketable roots. The tables are generally made of PVC rollers and should be easily accessible by workers from both sides (Figure 24). Adequate lighting is important, so that defects can be seen easily. Table height should also allow workers to reach roots in the middle of the table comfortably. Workers who directly handle roots should wear gloves to protect roots from fingernail scratches and human pathogens. Gloves will also protect workers from fungicides or other chemicals used on the packing line.

Impacts on the grading line vary, depending on height of the drop and whether there was an incline or padding. For example, one packing line had a drop height of only 3.5 inches, and the impacts were all below the threshold recorded by the instrumented device. On the other extreme, another packing line had roots dropping 12 inches directly onto the rollers, which produced a much higher impact (23.5 g).

Fungicide and other decay control treatments. Although every effort should be made to prevent mechanical injury to sweetpotatoes during packing, it is impossible to avoid all injuries. Decay-producing organisms, especially those that cause soft rot (such as *Rhizopus stolonifer*), enter through injuries. Bruised or crushed tissue offers a particularly favorable place for decay to develop. For this reason, most sweetpotatoes not destined for canneries or further processing are treated with an approved fungicide.

TABLE 2. Average number of drops and turns, cumulative impacts, and length of packing lines, based on 24 Louisiana and 12 North Carolina packing lines.

	Average	Maximum	Minimum
Number of drops	10	19	5
Number of turns	3	8	0
Cumulative impacts (g)*	118	302	31
Length of line (ft)	102	277	37
Speed of line (ft/min)	24	59	7

*Cumulative impacts measured on all drops and turns on a packing line. Average of five runs with the impact recording device.

Figure 28. Roots falling out of an expanding pitch roller (EPR) sizer usually land on the root end. (PHOTO BY G. HOLMES)

Figure 29. Overlapping roots (shown inside yellow circle) on an electronic sizer leads to placement on the return loop of the packing line. (PHOTO BY G. HOLMES)

Fungicide may be applied either by dipping the roots in a tank of chemical suspension (Figure 25), by using a waterfall/curtain application (Figure 26), or by spraying the fungicide either alone or mixed in a wax solution as the sweetpotatoes pass over a brush roller conveyor (Figure 27). Regardless of treatment method, roots must be completely covered with the fungicide suspension. No treatment is 100 percent effective. Even properly treated roots may develop significant decay. For specific recommendations on the use of fungicides, refer to the manufacturer's label instructions, state Extension manuals (such as *North Carolina Agricultural Chemicals Manual* or *Louisiana Plant Disease Management Guide*), or contact your local Extension center for guidelines in your state.

Sizing. Sorting sweetpotatoes into uniform sizes is a key function of packing. The U.S. sweetpotato grade standards for both fresh market and canning were updated in 2005 and are found in Appendix 2. Most mid-size sweetpotato packing lines employ expanding pitch roller (EPR) sizers. These sizers allow the roots to move along on a conveyor of rotating and ever-widening rollers. The smaller roots are the first to fall between adjacent rollers and are deposited on a belt moving perpendicular to the direction of the rollers (Figure 28). Larger roots are carried further before they are deposited to a different section of the belt. EPR sizers segregate sweetpotatoes only by diameter. Sweetpotatoes with the same diameter but different lengths will be placed in the same category. Unless there are large variations in root lengths (usually a function of cultivar and growing conditions), EPR sizers satisfy most commercial U.S. grade requirements.

As there is an increasing demand for more uniformity both in diameter and length, high-volume packers have invested in electronic sizers that optically scan both length and diameter and segregate sweetpotatoes into precise grades. If overlap (Figure 29), abnormal shape, or color prevents the sizer from categorizing a root properly, it will travel to the end of the sizer and go through a "return loop" to be resized. As much as 30 percent of roots have been observed going through this return loop. With this in mind, consideration must be given to the drop heights and speed of the conveyors on these return loops, because skinning

TABLE 3. Average decay control product use and application methods, averaged over 22 Louisiana and 21 North Carolina packing lines.

	Percent of Packing Houses	
	Louisiana	North Carolina
DECAY CONTROL PRODUCT USED		
Dicloran (Botran)	77-91*	81
Other (peracetic acid, bacteria-based biological control)	5-18*	9.5
None	5-9*	9.5
APPLICATION METHOD		
Spray	50	32.5
Curtain	0	4.5
Dip	45	42
In wax	0	21

* Several packing lines used different products one time to another.

Figure 30. Box fill can occur off the end of a conveyor. (PHOTO BY T. SMITH)

Figure 31. Automatic box fillers are integrated into electronic sizing equipment. (PHOTO BY G. HOLMES)

and bruising can be significant. Furthermore, a significant portion of roots may pass through a return loop more than once. Many high-volume packers employ both an expanding pitch sizer and an electronic sizer to size roots efficiently into the correct grade.

Impacts depend on the height of the drop, whether there is an incline onto the sizer, and whether there is padding. Impact measurements were quite low on lines where the sweetpotatoes rolled down a gradually padded incline onto the sizer, and were higher on a few lines where there was a high drop directly onto sizer bars.

Box fill. Boxes (40 and 14 lb) can be filled by hand in small operations (Figure 30). Mid-size and large packing lines generally fill boxes by allowing the roots to fall off a conveyor into the box or by using an automated box fill system (Figure 31). Automated systems are mainly used with electronic sizers. These devices are able to control the speed of roots entering the box, may have a hydraulic tilt mechanism that automatically lowers the box as it fills, and will release boxes when they have filled to the designated weight.

Most box fills are a similar height, so any variation in impact measurement (Table 4) is related to how full the box was at the time of measurement. Roots dropping into an empty box will experience larger impacts than those dropping into an almost full box. In the survey, higher impacts were found with automatic box fillers, which may be due to the greater height of the drop or the speed of the conveyor filling the boxes. Impacts from specialized packing (plastic or net bagging machines) were also measured and can be high if large-distance drops are present.

Reducing Packing Damage

Mechanical damage to sweetpotatoes during handling may include cuts, abrasions, and bruises, depending on the physics and configuration of the surfaces involved. A survey of 46 Louisiana and North Carolina sweetpotato packing lines from 2004 to 2006 provided valuable insight into ways to limit damage during packing. This study concluded that significant differences exist among various packing line configurations and even within the same line operated at different capacities and speeds.

Other significant findings indicate that most damage to roots occurs from impacts between roots and the various surfaces of the packing line. This suggests that cushioning these surfaces or otherwise reducing impacts may significantly reduce mechanical damage to the roots. Common "make do" padding materials, such as carpet and upholstery foam, perform poorly when compared to specially engineered padding materials but are, nevertheless, much better than bare metal surfaces. Use a good-quality cushioning material on all impact surfaces. The best material for cushioning is one that absorbs the energy from the falling root, so obtain samples from the manufacturer and test energy absorbency by dropping a root onto the samples. A material that has less bounce is a better material for padding sweetpotato packing lines because the roots won't rebound and hit another packing line surface. The ideal cushioning material should also have a tough surface that resists wear and doesn't absorb water and dirt. Padding material should be easy to wash during packing line cleanings. Carpet materials fail in this regard because they absorb water and soil and are difficult to clean.

Keep packing lines as level as is practical. Packing lines that continually raise and lower the roots impart potential energy that results in mechanical damage. For example, when sweetpotatoes are elevated by a belted conveyor or other means, potential energy is imparted, which is proportional to the height raised. When sweetpotatoes are allowed to fall or roll back to the lower level, the potential energy is changed into kinetic energy (motion), which must be absorbed by the roots or some impact surface.

Figure 32. Install velocity-reducing flaps to slow root speed over packingline drops. (PHOTO BY G. HOLMES)

Figure 33A-C. Avoid very steep drops onto unpadded hard surfaces. (PHOTOS BY G. HOLMES)

When sweetpotatoes must be lowered from one level to another, do so gently by using generous quantities of energy-absorbing blankets, strips (Figure 32), or padded surfaces. Long, inclined surfaces will reduce velocity better than near-vertical falls. Conveyor belts have minimal energy-absorbing ability. When sweetpotatoes are allowed to drop onto a belt supported by sheet metal or rollers (for example, under a sizer), the level of bruising is nearly the same as if the belt were not there. If possible, remove the supports to allow the belt to be suspended, providing an energy-absorbing impact surface.

Synchronize packing and grading line components to prevent abrupt changes in velocity or direction of the produce. Carefully engineer cross conveyors to include curved and padded transitions that allow a gradual change in direction and velocity. Operate packing lines no faster than necessary to reduce root damage and wear on the components.

Recommendations to reduce damage on packing lines

- Dump roots slowly into water (not onto roots) in the dump tank.
- Use high-quality padding on all impact surfaces.
- Use long inclines to reduce drop heights between components (Figure 33A through C).
- Reduce the number of drops and turns (Figure 34).
- Reduce the overall length of the packing line.
- Remove belt supports (if feasible) to reduce impact.
- Use deceleration flaps and blankets to reduce the speed over drops.
- Instruct workers to handle roots with care, and monitor handling frequently.
- Avoid abrupt changes in direction and speed of belts. Add padding if turns are unavoidable.
- Reduce packing line speed.

Figure 34. Packing line turn without padding. Note worn paint where roots make contact with metal guides. (PHOTO BY B. EDMUNDS)

TABLE 4. Impact measurements associated with common drops on sweetpotato packing lines, averaged over 23 Louisiana and 12 North Carolina packing lines.*

Components/Transfer Point	Average Cumulative Impact (g)	Maximum	Minimum	Number Surveyed
DUMP				
By hand	6.8	7.1	5.1	1
Onto bars (dry dump)	13.0	17.3	8.7	2
Into tank w/ metal lid	13.0	22.9	5.4	3
Directly into tank	12.8	36.1	0	29
MISCELLANEOUS				
Onto eliminator (metal bars)	8.8	30.7	0	27
Onto grading line (PVC bars)	8.3	29.2	0	40
Onto brushes	8.2	35.9	0	58
Onto conveyors (plate supported)	9.6	35.4	0	34
SIZERS				
Onto EPR** sizer	17.7	30.6	4.5	29
Out of EPR sizer (onto conveyor)	14.1	34.2	4.6	29
Onto drop-roller sizer	19.2	25.7	10.1	1
Out of drop-roller sizer (onto conveyor)	5.8	13.3	0	1
Electronic sizer	21.6	53.8	4.6	5
BOX FILL				
By hand or falling off conveyor	12.4	39.5	0	30
Automated box filler	30.3	72.5	4.2	6

*Average of five passes with the instrumented impact recording device
**EPR=expanding pitch rollers

Packing Line Cleaning and Sanitation

No matter how careful the operation, decay-producing organisms enter the packinghouse with the sweetpotatoes and will quickly contaminate all working surfaces. These organisms can remain viable for many months on storage bins, tank walls, sorting belts, rollers, and brushes. It is possible for surfaces to remain contaminated from one packing session to the next, or in the case of storage bins, from one year to the next.

Some pathogens that cause significant postharvest diseases of sweetpotato, such as *Rhizopus*, are common everywhere, and it is not possible to eliminate them completely. However, the amount of contamination is often important in determining whether disease develops. Thus, reducing the amount of contamination is the general aim of cleaning and sanitation efforts.

Reducing the introduction of pathogens onto the packing line. On most sweetpotato packing lines, roots are dumped into a tank of water and then fed onto the rest of the line. This process often spreads disease-causing microorganisms. Thus, reducing the amount of disease that develops in storage will reduce the number of diseased roots that enter the dump tank and contaminate the packing line. The following are a few important considerations for reducing disease development in storage:

TABLE 5. Percent of packing lines that use a technique or have each type of component, based on 25 Louisiana and 21 North Carolina packing lines.

	Percent of Packing Houses	
	Louisiana	North Carolina
DUMP		
By hand	0	9.5
Onto bars then into dump tank	0-8*	9.5
Directly into dump tank	84-92*	81
Onto rollers (dry dump)	8	0
MISCELLANEOUS COMPONENTS		
Eliminator	56	75
Waxer	0	57
Drying fans	0	43
SIZERS		
No sizing equipment	12	9.5
1-2 EPR** sizers only	84	62
Electronic sizer only	0	19
Drop-roller sizer only	4	0
Both EPR sizer and electronic sizer	0	9.5
BOX FILLERS		
Automatic box fill equipment	0	28.5
Box fill from off end of conveyor	96-100***	62
Box fill by hand picking	0-4***	9.5

* Two packing lines have movable sets of rollers that are used only when roots are muddy; otherwise, roots are dumped directly into the dump tank.
**EPR=Expanding pitch rollers
*** One line hand picks sometimes and lets them fall from end of conveyor other times.

- **Extreme field conditions at harvest:** Extreme environmental conditions at harvest can increase disease development in storage. Very dry soil increases skinning of the roots, a problem in itself, and can also favor Fusarium root rot. The other extreme, flooded soils, can contribute to the complex condition of souring that leads to simultaneous increases in many diseases, including Rhizopus soft rot, bacterial soft rot, Fusarium root rot, and sour rot. Flooding also results in mud adhering to the sweetpotatoes and being carried into storage. Anything that can be done to avoid extremely dry or wet conditions at harvest will reduce problems in storage.
- **Sanitation of storage bins:** Bins that can hold in excess of 20 bushels of sweetpotatoes are likely to have at least a few roots that develop disease during a long storage period. Assume that they are all contaminated after use. Cleaning and sanitizing the bins after each use should be a regular practice. Spotts and Cervantes (1994) studied disinfestation of wood and plastic surfaces used in bins for storing pears. They found that steam was the most effective in reducing populations of fungi that infect pears. Chlorine compounds, sodium orthophenylphenate (SOPP), and quaternary ammonium compounds were also effective but were less consistent than steam. Most of these agents were similarly effective on wood and plastic except sodium hypochlorite, which was less effective on wood. Leaving the bins outside in the summer, where the surfaces that contact sweetpotatoes are exposed to direct sunlight, may also help reduce microbial contamination.
- **Reducing disease development in storage:** Following the recommendations for proper curing and storage of roots remains one of the most effective ways of reducing diseases in storage. See the "Curing for Quality" and "Storing for Quality" sections for specific guidelines.

CLEANING VS. SANITATION

CLEANING: the removal of debris from packing line surfaces using physical methods such as high-pressure water sprays or a detergent.

SANITATION: the reduction of the number of microorganisms on packing line surfaces to levels that do not cause disease problems.

A single root affected with Rhizopus soft rot can produce millions of fungal spores. Likewise, a single root affected with bacterial soft rot can release millions of bacterial cells. Since both Rhizopus soft rot and bacterial soft rot can completely rot a sweetpotato in a few days, it makes sense to remove all roots that fall off the packing line from the packing area at the end of each day. Otherwise, they will quickly become a source of inoculum that can infect healthy roots.

Cleaning and Sanitation. No matter how rigorous your disease-control efforts are, some diseased roots will go into the packing operation, and there will be a need to clean and

TABLE 6. Guidelines for mixing chlorine solutions*

Desired ppm of Free Chlorine	Pints of 5.25% NaOCl Solution per 100 Gal. of Water	Pints of 12.75% NaOCl Solution per 100 Gal. of Water	Ounces of 65% Ca (OCl)2 per 100 Gal. of Water
50	0.8	0.3	1.0
75	1.1	0.5	1.5
100	1.5	0.6	2.1
125	1.9	0.8	2.6
150	2.3	0.9	3.1
175	2.7	1.1	3.6
200	3.0	1.3	4.1

*From "Chlorine Use In Produce Packing Lines" Document HS-761 Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, and used with the permission of the authors.

sanitize the packing line. Regardless of what surface is being sanitized or what agent is used for sanitizing, it will be more effective if the surface is cleaned first. Some microorganisms form biofilms (a microscopic layer of bacteria) that are particularly difficult to remove. Removal of biofilms requires detergent and pressure, either from scrubbing or from a pressure washer. In order to properly sanitize surfaces, the following sequence should be followed:

Rinse → Clean → Rinse → Sanitize

Nonporous and exposed surfaces may be relatively easy to clean and sanitize, but other components of the packing line may require special attention. Of particular concern are the brush beds. Small bits of debris and tissue broken from sweetpotato roots may become lodged at the base of the brush bristles and support the growth of microorganisms. High-pressure hoses or a pressure spray will flush debris out of the brushes.

There are no uniform standards in the sweetpotato industry for sanitizing packing lines, and the effect of sanitation on postpacking disease development is not known. Some packers have relied on chlorine, primarily sodium or calcium hypochlorite, without understanding the factors that influence its efficacy. In water, the most commonly used forms of chlorine that are used for sanitizing (sodium hypochlorite, calcium hypochlorite, or chlorine gas) all form hypochlorous acid. Hypochlorous acid is the component that kills microorganisms and is referred to as *available* or *active* chlorine. At high pH, hypochlorous acid dissociates to form a hypochlorite ion, which is not effective as a sanitizer, and chlorine solutions with a pH above 8 are not effective in killing pathogens. Below pH 6, chlorine solutions are highly corrosive, and the activity is rapidly lost due to volatility of elemental chlorine. The volatile chlorine can also irritate workers. Thus, in order to have an effective sanitizing solution, it is necessary to measure both chlorine content and pH and maintain the pH between 6.5 and 7.5.

Organic matter inactivates hypochlorous acid and reduces the amount of available chlorine. Even though the chlorine combined with the organic matter is inactivated, it is still measured by "total chlorine" test kits. This makes it difficult to maintain an effective chlorine solution in a dump tank where large volumes of soil and organic material enter. Chlorine must be added frequently to replace the chlorine lost. For produce harvested above ground, checking and replenishing the chlorine supply at least once an hour is often recommended. But a root crop introduces much more soil into the system, so the chlorine must be replenished more frequently. Generally, chlorine should be maintained at 100 to 150 parts per million (ppm) *active* chlorine with pH maintained between 6.5 and 7.5. Thus, chlorine test kits that measure active or available chlorine should be used. You may need to dilute the source product in distilled water for proper readings. Commercial systems that automatically monitor and adjust pH and chlorine are likely to be more effective in maintaining effective sanitizing conditions. Always follow the label directions for any product used.

Water temperature and water quality can also affect the efficacy of chlorine. For example, chlorine solutions are more effective at higher temperatures, but the chlorine is lost faster. Registered formulations of chlorinators for use on produce contain either 5.25 percent or 12.75 percent sodium hypochlorite (NaOCl), or 65 percent calcium hypochlorite [Ca(OCl)2]. To estimate the amount of these formulations to use in making chlorine solutions with various concentrations of free chlorine, use Table 6. Current research does not suggest that chlorine can be used for disease control. It should only be considered a sanitizer of water and equipment. Also, check current guidelines, as some products may not be acceptable by certain markets.

One additional problem with these chlorine products is that they produce trihalomethanes when they react with organic matter. These compounds are carcinogens and pose a potential health risk. Chlorine dioxide gas circumvents this problem because it does not react with organic matter to form trihalomethanes. Chlorine dioxide is also active over a wider range of conditions than other forms of chlorine and is an effective sanitizer. However, its use is not without problems, as the gas must be generated on site. When used indoors, adequate ventilation is essential because some of the gas can come out of solution.

As indicated earlier, there has been little research on sanitizing sweetpotato packing lines. However, several classes of chemical sanitizing agents have been considered for other perishable produce. There are many factors to consider when choosing a sanitizer, in addition to whether it will effectively reduce the number of pathogens. Many sweetpotato packers have experience with the corrosive nature of chlorine, and several have had to rebuild their packing lines because of this problem. Table 7 compares the properties of some of the classes of chemical sanitizers.

General recommendations for packinghouse sanitation: Fresh sanitizing solutions should be prepared and used daily. For sanitizing wash water, it is recommended that active (not total) chlorine levels be kept between 100 to 150 ppm, and the water pH should be kept between 6.5 to 7.5. The wash water should be replaced as often as possible during the day, or at least when it becomes obviously dirty. The frequency that wash water is replaced depends on the soil load, packing line configuration, and regulations regarding disposal, and it is specific to each packing line. Storage bins and packing line components should be cleaned and sanitized after each use, and sweetpotato roots and debris should be removed from the packinghouse floor daily.

Product Safety and Certification Programs

At the time of publication, no cases of foodborne illness associated with consumption of unprocessed sweetpotatoes have been reported in the U.S. In our rapidly changing environment, with increasing concerns for food safety, standards in addition to those listed may be required by different certifying organizations or markets.

Food safety has always been a concern and an important issue related to both domestic and international food supplies. In the 1990s, through the U.S. Produce Safety Initiative, the focus increased to ensure the safety of the nation's food supply, whether grown domestically or internationally. As a result, the U.S. Food and Drug Administration (FDA) developed guidelines for the produce industry with an overall goal of minimizing microbial food safety hazards. Those guidelines, known as Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP), have become increasingly important in the produce industry.

Growers use GAP and GMP extensively to improve and ensure the safety of their produce. Growers also are reducing risks to fresh fruits and vegetables with comprehensive education and traning programs on farms. GAP guidelines are primarily associated with production field practices, whereas GMP guidelines are aimed at storage and packing facilities.

As a first step in the certification process, all sweetpotato producers should register with the FDA, after which they will be issued a federal identification number. Producers can access the FDA's GAP and GMP guidelines online at http://www.cfsan.fda.gov/~dms/prodguid.html.

Producers who use the FDA guidelines are not only protecting the health of consumers, but are also reducing their financial risk. Participating producers are audited,

TABLE 7. Comparison of the chemical and physical properties in commonly used sanitizers.*

	Chlorine	Iodophors	Quaternary Ammonium Compounds	Acid Anionic	Fatty Acid	Peroxyacetic Acid
Corrosiveness	yes	slightly	no	slightly	slightly	slightly
Irritating to skin	yes	no	no	slightly	slightly	no
Effective at neutral pH	yes	depends on type	in most cases	no	no	yes
Effective at acid pH	yes, but unstable	yes	in some cases	yes, below 3.0 to 3.5	yes, below 3.5 to 4.0	yes
Effective at alkaline pH	yes, but less than at neutral pH	no	in most cases	no	no	less effective
Affected by organic material	yes	moderately	moderately	moderately	partially	partially
Affected by water hardness	no	slightly	yes	slightly	slightly	slightly
Residual antimicrobial activity	none	moderate	yes	yes	yes	none
Cost	low	high	moderate	moderate	moderate	moderate
Incompatibilities	acid solutions, phenols, amines	highly alkaline detergents	anionic wetting agents, soaps, and acids	cationic surfactants and alkaline detergents	cationic surfactants and alkaline detergents	reducing agents, metal ions, strong alkalies
Stability of use solution	dissipates rapidly	dissipates slowly	stable	stable	stable	dissipates slowly
Maximum level permitted by FDA without rinse	200 ppm	25 ppm	200 ppm	varied	varied	100 to 200 ppm
Water temperature sensitivity	none	high	moderate	moderate	moderate	none
Foam level	none	low	moderate	low to moderate	low	none
Phosphate	none	high	none	high	moderate	none
Soil load tolerance	none	low	high	low	low	low

*Comparisons made at approved "no rinse" use levels. *Adapted from B.R. Cords and G.R. Dychdala (1993) and R.H. Schmidt (2003), and used with the permission of the authors.*

inspected, and validated by an independent third party. These companies provide a checklist to growers that they will use to complete the auditing and inspection processes associated with certification.

Producers, packers, and shippers must comply with 70 percent of the guidelines to pass certification. Certain conditions are mandatory and can result in certification failure if they are detected. Examples include the determination of an immediate food safety risk, a violation of the U.S. Environmental Protection Agency (EPA) or state pesticide regulations, and failure to test or treat water sources. Two critical components of GAP and GMP involve educating employees and maintaining facilities. Producers should stress personal hygiene and ensure that all employees are provided a copy of safety guidelines. Employees working in a packing facility should not wear jewelry or body adornments, and they should also wear hairnets. It is also extremely important that sanitary facilities be provided to employees to promote personal hygiene and sanitary activity, such as frequent hand washing. Communication and cooperation between a producer and his or her production and packing employees is essential for GAP and GMP guideline compliance.

There is increasing interest in exporting sweetpotatoes produced in the U.S. to other countries, especially to Europe and the United Kingdom. At the same time, there have been rapid changes in laws, regulations, and attitudes of consumers and all levels of the produce-marketing industries regarding produce quality and pesticide residues. GlobalGAP is a third-party certification program with guidelines and standards that are used widely by fruit and vegetable producers and shippers in Europe and around the world for the voluntary certification of good agricultural practices. Specific information can be obtained from the GlobalGap Web site (http://www.globalgap.org/).

Packaging and Shipping for Quality

PACKAGING FOR QUALITY:

Proper packaging is an important step in the journey from packer to consumer. Packing and packaging materials constitute a significant cost to the sweetpotato industry; therefore, it is important that packers and shippers have a clear understanding of the different packaging options and their limitations. A significant percentage of produce buyer and consumer complaints may be traced to inferior container design or inappropriate container selection and use. A properly designed sweetpotato container will contain, protect, and identify the sweetpotatoes, satisfying everyone from grower to consumer.

The container must enclose the sweetpotatoes in convenient units for handling and distribution. Sweetpotatoes are now marketed in a variety of packages, depending on the requirements of the market (Table 8, Figures 35 A through F). Although the most common shipping size is the 40-pound carton, in recent years, the trend has been toward smaller packages designed to be carried home by the consumer.

All packaging containers must protect the sweetpotatoes from mechanical damage and environmental conditions during handling and distribution. Torn, dented, or collapsed packages usually indicate lack of care in handling. Sweetpotato containers must be sturdy to resist damage during packaging, storage, and transportation to market. Because almost all sweetpotato packages are palletized, the container must have sufficient stacking strength to resist crushing in a high-humidity environment. Although the cost of packaging materials has escalated in recent years, inferior quality, lightweight containers that are easily damaged by handling or moisture are no longer tolerated by packers or buyers.

The package must also identify and provide useful information about the contents. It is customary (and may be required in some cases) to provide information such as produce name, brand, size, grade, cultivar, net weight, count, fungicide treatment, grower, shipper, and country of origin. It is also becoming more common to include nutritional information, recipes, and other useful information directed specifically at the consumer.

The federal government now requires that records be kept on all sweetpotatoes packed. Currently a "one step forward, one step back" approach is being enforced. This means that packers must keep track of the source of the roots as well as the shipping destination. Traceability is the ability to follow a piece of produce from the grower through consumption. Traceability of individual containers and pallets of produce in general is a system undergoing improvements. Current guidelines on the implementation of produce identification and traceability can be found on the Produce Marketing Association's Web site (www.pma.com).

SHIPPING FOR QUALITY:

It is estimated that as much as 5 percent of packed sweetpotatoes are lost annually during transportation to market. Much of the loss is a direct result of mishandling during shipment. To reduce losses, shippers, truckers, and receivers should be well acquainted with the specific handling requirements of sweetpotatoes.

Packaged and palletized sweetpotatoes awaiting shipment should be refrigerated at 55°F (13°C) and 85 percent relative humidity immediately after packing. This storage area should be separate from the area where unwashed roots are stored and, ideally, near the loading dock.

Exercise care when storing or shipping sweetpotatoes with other commodities. Packed sweetpotatoes usually are shipped to domestic and Canadian markets in tractor-trailers, which may be loaded with other commodities. The two main concerns when cross-loading are compatibility between ethylene sensitivities and required storage temperatures. Ethylene is a naturally occurring, odorless, colorless gas produced by many fruits and vegetables, but it can also be produced by faulty heating units and combustion engines. In sweetpotato, ethylene damage is difficult to diagnose but can cause internal darkening and pithy areas. Sweetpotatoes are low emitters of ethylene when stored and handled properly, but they may produce higher levels of ethylene when wounded, infected, or subjected to chilling injury. Sweetpotatoes are considered to be sensitive to the ethylene produced by other commodities and machinery, so avoid shipping in mixed loads with ethylene-producing commodities. Most ethylene-producing commodities are shipped at much lower temperatures than sweetpotatoes; however, avoid mixing loads with bananas, mangoes, papa-

TABLE 8. Types of packaging for sweetpotatoes

Corrugated Fiberboard	The most common container material. Available in many different styles and weights. Relatively low in cost and easy to print with customized labels. Most 40-pound boxes are one-piece, regular slotted containers (RSC) and two-piece, full telescoping containers (FTC). The RSC is the most popular because it is simple and economical. However, the RSC has relatively low stacking strength and therefore is most often used with produce (for example, sweetpotatoes) that can carry part of the stacking load. The FTC is used when greater stacking strength and resistance to bulging are required. Smaller size cartons (14 lb) are also used, especially for overseas markets. Almost all corrugated fiberboard containers are shipped to the packer flat and require hand or machine assembly onsite. (Figure 35A)
Plastic Bags	A newer, low-cost material for consumer-sized packaging. Film bags are clear, allowing for easy inspection of the contents. They readily accept high-quality graphics and are available in a wide range of thicknesses, grades, and gas permeability. Decay is a risk if a low-oxygen and high-moisture environment develops within the bags, which is more likely to occur with extended storage time or if the bags are stacked. Specialized bagging equipment is required. (Figure 35B)
Shrink Wrap	One of the newer trends in packaging is shrink-wrapping of individual roots, which can reduce moisture loss, reduce mechanical damage during shipping, and provide a good surface for stick-on labels. Roots can be shrink-wrapped in a foam tray of two or three. Some consumers prefer individually wrapped roots for microwave cooking. Only healthy roots should be shrink-wrapped, and film that allows for root respiration must be used. Otherwise, disease problems, particularly Fusarium root rots, can develop. (Figures 35C-D)
Net Bags	Net bags bundle roots into convenient consumer-sized packages. Although they cannot offer the modified-atmosphere possibilities of plastic, they are preferred by many consumers, and good air movement limits the chance of disease development. Specialized bagging equipment is required. (Figure 35E)
Bulk Bins	Large double- or triple-wall corrugated pallet bins are used as one-way pallet bins to ship in bulk form to processors and retailers. Container cost per pound of produce is as little as one-fourth that of 40-pound containers, and some bulk containers may be collapsed and reused. (Figure 35F)

Figure 35. Examples of packaging: corrugated fiberboard (A) (PHOTO BY B. EDMUNDS); plastic bags (B) (PHOTO BY G. HOLMES); tray shrink wrapping (C) (PHOTO BY G. HOLMES); individual root shrink wrapping (D) (PHOTO BY G. HOLMES); net bags (E) (PHOTO BY G. HOLMES); bulk bins (F) (PHOTO BY T. SMITH)

yas, and other tropical fruits that are also held at 55°F (13°C). Also make certain that the refrigeration unit is functioning properly and that no engine exhaust is entering the trailer.

Compatible shipping temperature is the main concern with sweetpotatoes. Many commodities are shipped at temperatures near freezing, which can severely damage sweetpotatoes. Be sure to inform shippers of the temperature requirements (Figure 36). Roots may be chilled if the trailer thermostat is set too low to accommodate other commodities or during long trips in cold weather.

Export-market shipping involves onsite packing of marine containers with pallets or bulk bins (Figure 37). Shipping time by boat to European markets can range from 8 to 14 days, plus the distribution time on either end of the trip. Marine containers for sweetpotatoes are usually not modified-atmosphere environments, but most containers do have temperature control along with vents to provide air exchange. Research on optimal conditions for overseas shipping of sweetpotatoes is minimal. The best source of general information is a publication from the University of California, "Marine Container Transport of Chilled Perishable Produce" (Thompson et al., 2000). This publication states that sweetpotatoes are considered to have low respiration during shipment, so the recommended air-exchange rate is 15 $feet^3$ per minute (25 $meter^3$ per hour) for a 40-foot marine container to maintain proper carbon dioxide levels. Container temperature should be maintained at 55°F (13°C). All containers have vents that are left open at a specified setting during transport to ensure fresh air exchange. However, this makes controlling relative humidity difficult. Vent settings vary among container manufacturers, so it is important to set vents by airflow rates in $feet^3$ per minute or $meter^3$ per hour, because "percent opening" recommendations may not be reproducible between container manufacturers. Packers should install temperature-recording devices to verify that proper temperatures were maintained during shipping.

MARKET LIFE OF PACKED SWEETPOTATOES:

Market life begins when roots are removed from bulk storage bins. Market life includes washing, packing, and distribution to market, and it concludes at the point of consumer purchase. Temperature and relative humidity often vary greatly at different steps as the roots move from storage to consumer. Market life is maximized when roots are handled gently and temperature and relative humidity are maintained at 55°F (13°C) and 85 percent, respectively. Under these conditions, market life is typically two to three weeks. (Market life should not be confused with storage life, which can be up to 13 months under proper conditions.)

Many factors influence the market life of sweetpotatoes. The cultivar, pre-harvest growing conditions, curing conditions (or lack thereof), storage temperature, relative humidity, atmospheric oxygen/carbon dioxide composition, amount of mechanical injury during packing, wash water sanitation, type of packaging, and air flow and temperature during transport and distribution to market are among the most important factors influencing market life.

Weight loss due to mechanical injuries received during packing is a major cause of quality reduction in the retail market. Weight loss results in shriveled or pithy roots. It can be high, particularly during transit or in supermarket display areas where relative humidity is generally low. For example, recent research with cultivar Beauregard showed weight loss of washed roots in the range of 5 to 10 percent after a four-week period under simulated retail market conditions (about 70°F and 70 percent relative humidity). Consumers prefer sweetpotatoes that have lost less than 5 percent during transit and retail marketing, and that requires proper temperature and humidity control.

It is not possible to make an all-inclusive statement that defines the market life of any commodity. Market life can vary greatly from one lot of product to another for numerous diverse causes. Ultimately, the market subjectively determines the point at which sweetpotato quality becomes unfit for consumption.

Figure 36. Temperature and air exchange controls for shipping container.
(PHOTO BY G. HOLMES)

Key References

Chemical control

Louisiana Insect Pest Management Guide. Available online: www.lsuagcenter.com/en/communications/publications/Publications+Catalog/Crops+and+Livestock/Insect+and+Disease+Control/management_guides/Insect+Pest+Management+Guide.htm

Louisiana Plant Disease Management Guide. Available online: http://www.lsuagcenter.com/en/crops_livestock/crops/Integrated_Pest_Management/Publications/Plant+Disease+Control+Guide.htm

North Carolina Agricultural Chemicals Manual. Available online: http://ipm.ncsu.edu/agchem/agchem.html

Vegetable Crop Handbook for the Southeastern U.S. Available online: http://www.sripmc.org/

Diseases, abiotic injury and insect damage

Ahn, J. K., W.W. Collins, and D.M. Pharr. 1980. Influence of preharvest temperature and flooding on sweet potato roots in storage. *HortScience* 15:261–263.

Chang, L.A. and S.J. Kays. 1981. Effect of low oxygen storage on sweet potato roots. *Journal of the American Society of Horticultural Science* 106(4):481–483.

Clark, C.A and J.W. Moyer. 1988. *Compendium of Sweet Potato Diseases.* St. Paul: APS Press.

Corey, K.A., W.W. Collins, and D.M. Pharr. 1982. Effect of duration of soil saturation on ethanol concentration and storage loss of sweet potato roots. *Journal of the American Society of Horticultural Science* 107(2):195–198.

Kays, S. J., A.S. Bhagsari, and D.H. Picha. 1992. "Physiology and chemistry." In *Fifty Years of Cooperative Sweetpotato Research, 1939–1989*, ed. A. Jones and J.C. Bouwkamp. So. Coop. Ser., Bull. No. 369.

Kushman, L.J. and D.T. Pope. 1972. *Causes of Pithiness in Sweetpotatoes*. Tech Bulletin No. 207. Raleigh, NC: North Carolina Agricultural Experiment Station and USDA-ARS.

Picha, D.H. 1987. Chilling injury, respiration, and sugar changes in sweet potatoes stored at low temperatures. *Journal of the American Society of Horticultural Science* 112(3):497-502.

Sanitation

Rangarajan, A., E. A. Bihnr, R. B. Gravani, D. L. Scott, and M.P. Pritts. 2000. *Food safety begins on the farm: A grower's guide*. Available online: www.gaps.cornell.edu/FSBFEng.html

Ritenour, M.A., S.A. Sargent, and J.A. Bartz. 2002. *Chlorine use in produce packing lines*. Document HS-761, Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Available online: http://edis.ifas.ufl.edu/CH160

Schmidt, R. H. 2003. *Basic elements of equipment cleaning and sanitizing in food processing and handling operations*. Document FS14, Food Science and Human Nutrition Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Available online: edis.ifas.ufl.edu/FS077

Spotts, R.A., and L.A. Cervantes. 1994. Contamination of harvest bins with pear decay fungi and evaluation of disinfestants on plastic and wood bin material. *Acta Hort*. 367:419-425.

Suslow, T. 1997. *Postharvest Chlorination: Basic Properties and Key Points for Disinfection*. University of California, Division of Natural Resources, Publication 8003. Available online: anrcatalog.ucdavis.edu/pdf/8003.pdf

U.S. Food and Drug Administration. 1998. *Guide to minimize microbial food safety hazards for fruits and vegetables*. Available online: http://www.foodsafety.gov/~acrobat/prodguid.pdf

Packaging and Traceability

Anonymous. *Fresh produce traceability: a guide to implementation*. Joint publication of the Produce Marketing Association and the Canadian Produce Marketing Association. October 2006. Available online: www.pma.com

Shipping

Thompson, J.F., Brecht, P.E., Hinsch, T. and Kader, A.A. 2000. *Marine container transport of chilled perishable produce*. University of California, Agriculture and Natural Resources. Publication 21595.

Figure 37. Marine containers are utilized to transport bulk bins and pallets to overseas export markets. (PHOTO BY G. HOLMES)

Appendix 1.

Guide to Common Postharvest Diseases, Abiotic Damage, and Insects

DISEASES THAT DEVELOP IN STORAGE

Bacterial root rot, caused by *Dickeya didantii (Pectobacterium (Erwinia) chrysanthemi)*, can occasionally cause heavy losses in storage or after packing. Infection results in mostly internal, very wet, soft rot that usually occurs during warm humid conditions (Figure 38). Occasionally, bacterial soft rot has developed after sweetpotatoes coming from the field were wetted to help set the skin, or when pallets were wrapped too heavily in plastic for stability during shipping, depriving them of adequate gas exchange. Bacterial soft rot can be internal and without symptom in roots, developing only under the proper conditions. The disease is managed by using planting stocks that are free of disease, avoiding wounding during harvest and handling, using clean water on packing lines, and preventing high carbon dioxide/low oxygen environments with high temperatures.

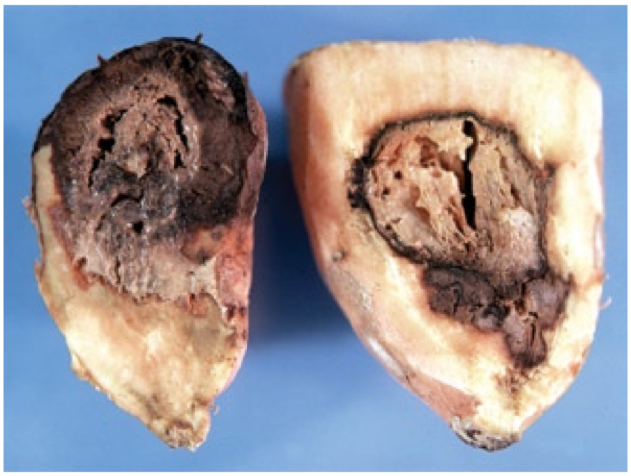


Figure 38. Bacterial root rot causes a soft, dark rot. (PHOTO BY C. AVERRE)

Black rot infections caused by the fungus *Ceratocystis fimbriata* occur in the field. However, the disease can be spread during harvest from diseased to healthy roots. The presence of even small black rot lesions in the crop during harvest may lead to large losses in storage (Figure 39 A and B). If a small amount of black rot is present at harvest, the lesions will expand in storage. Black rot was once the most important postharvest disease of sweetpotato, but using disease-free seed roots, cutting slips above the soil line, and rotating crops have dramatically reduced its occurrence.

Fusarium surface rot and Fusarium root rot decay caused by *Fusarium* is commonly seen in storage. There are two species of *Fusarium* that cause two distinct symptoms on roots. Fusarium root rot, caused by *Fusarium solani*, is a decay that extends into the flesh of the root. Externally, lesions are dark tan and often have a distinct ring pattern of light and dark brown bands (Figure 40). The rot is firm, dry, and dark brown, with internal cavities often filled with white mycelium of the fungus (Figure 41). Fusarium surface rot, caused by *Fusarium oxysporum*, has surface lesions that do not extend into the flesh. They are generally circular, light to dark brown, firm, and dry. Both diseases can be managed by minimizing injuries during harvesting and handling, harvesting when soil moisture is optimal, curing promptly after harvest, and using cultivars resistant to Fusarium root rot. Fusarium surface and root rots develop slowly and, therefore, are not considered a post-packing disease because there is insufficient time for the diseases to develop between packing and consumption.

Java black rot, caused by the fungus *Lasiodiplodia theobromae*, is occasionally found during storage. This disease is easily identified by its distinct symptoms. Symptoms usually begin at the root end as a firm, moist decay that turns color from pale yellow, to brown, to black (Figure 42).

Figure 39. Black rot caused by *Ceratocystis fimbriata*. (A and B) (PHOTOS BY G. HOLMES)

As the disease progresses, hard black masses called "stroma" break through the surface of the root (Figure 43). With time, these masses will break down to release powdery spores. The fungus enters through a wounded area and can be controlled with good packinghouse sanitation and with prompt curing at the proper temperature and humidity to heal wounds. Java black rot is more common in tropical areas of the world.

Rhizopus soft rot, caused by the fungus *Rhizopus stolonifer*, is the most common disease of stored and packed sweetpotatoes. After the fungus enters the tissues through wounds, it can cause a soft, wet decay of the entire root within three days. Rhizopus soft rot is characterized by white, whiskery fungal growth and prolific dusty black spores on the surface of infected roots (Figure 44). Wet soil and low temperature at harvest cause sweetpotatoes to be especially susceptible, and symptoms appear soon after storage. Rhizopus soft rot is most likely to occur after packing, because infections occur through wounds.

Figure 42. Internal symptoms of Java black rot include a clearly demarcated, firm, dark rot. (PHOTO BY B. EDMUNDS)

Figure 40. Fusarium surface rot is characterized by sunken, scalloped-edge rings on the root surface. (PHOTO BY G. HOLMES)

Figure 43. External symptoms of Java black rot are hard black "stroma" protruding out of the sweetpotato skin. (PHOTO BY G. HOLMES)

Figure 41. Fusarium root rot shows internal decay with characteristic cavities that may contain white fungal growth. (PHOTO BY G. HOLMES)

Figure 44. Rhizopus soft rot is characterized by a wet, soft rot and whiskery fungal growth covered with powdery black spores. (PHOTO BY G. HOLMES)

Rhizopus soft rot can be managed by properly curing roots to heal wounds incurred during harvest and by avoiding damage on packing lines. Most packers apply fungicide on the packing line. Less susceptible cultivars are available; however, none show complete resistance. For specific fungicide recommendations, refer to the latest edition of the *North Carolina Agricultural Chemicals Manual, Louisiana Plant Disease Management Guide*, or contact your local Extension center for guidelines in your state.

Figure 45. Circular spot is caused by the fungus *Sclerotium rolfsii*. Lesions are unusually circular. and the center of the spot typically cracks. (PHOTO BY G. HOLMES)

Figure 46. Geotrichum sour rot can occur in the field or in storage. It is favored by conditions of low oxygen and high temperature. The disease has a distinctly sour smell. (PHOTO BY G. HOLMES)

DISEASES THAT OCCUR IN THE FIELD AND ARE ALSO SEEN IN STORAGE AND PACKING

Circular spot is caused by the soilborne fungus *Sclerotium rolfsii*, which also causes sclerotial blight in plant beds. The circular, brown, shallow spots (Figure 45) develop on roots just before harvest but do not develop further after harvest unless there is free moisture on the roots during curing. Usually, the roots heal during storage, and the spots begin to peel away from the root.

Geotrichum sour rot begins in the field when flooding occurs and continues to develop in storage. A wet, soft rot develops that has a distinctive fruity-alcohol odor. Tufts of white mycelia develop on the outside of the root (Figure 46). Sour rot can also occur postharvest when roots are exposed to high temperatures and low oxygen environments.

Mottle necrosis is caused by at least two species of the soilborne fungus *Pythium*. Although it occasionally causes significant losses, it is not considered a common disease. External symptoms consist of slightly sunken, brown spots with irregular margins. When affected roots are sliced, a marbled decay is revealed (Figure 47). Avoid cool, wet conditions near harvest, and practice crop rotation.

Soil rot or pox is caused by a soilborne filamentous bacterium (*Streptomyces ipomoea*). Soil rot causes dark corky lesions that are usually indented (Figures 48 and 49). The type of symptom produced depends largely on the timing of infection with respect to root development. Infections occurring prior to root enlargement are more likely to constrict

Figure 47. Mottle necrosis is caused by *Pythium* spp. and produces a distinctive marbled necrosis of the root pith. (PHOTO BY G. HOLMES)

Figure 48. Constrictions can be caused by early season infection with soil rot/pox. (PHOTO BY G. HOLMES)

and disfigure the root, but do not develop further in storage. Growing resistant varieties can greatly reduce the incidence of soil rot or pox. Lowering soil pH through applications of sulfur can reduce disease problems.

Figure 49. Soil rot symptoms also include circular, sunken, dark scabby lesions. (PHOTO BY G. HOLMES)

Figure 50. Russet crack is caused by a virus; slight constrictions and parallel cracking are characteristic symptoms of the disease. (PHOTO BY G. HOLMES)

Russet crack is a disease caused by a strain of the sweet potato feathery mottle virus (SPFMV). In the field, brown bands develop on the skin and extend laterally around parts of the root. Within these brown bands there are usually shallow cracks that run perpendicular to the bands (Figure 50). The symptoms do not change in storage and are often missed until the roots are washed. Russet crack can be managed by a good seed program that utilizes virus-tested, Certified, or Foundation seed.

Scurf, caused by the fungus *Monilochaetes infuscans*, is a common sweetpotato disease that is transmitted primarily by infected planting stock, but it also may persist in soil for 1 to 2 years. Scurf is a disease of the skin (Figure 51). However, roots that are heavily infected with scurf may shrink more rapidly than normal roots. Research has shown that scurf does not spread to other roots during storage. Small, insignificant, infected areas may enlarge, especially in the presence of humidity higher than 90 percent.

Scurf can be managed by using scurf-free planting stock, treating seed with fungicide, avoiding problem fields, rotating land used for plant beds each year and, most importantly, cutting plants above the soil line instead of pulling to reduce the spread from seed plants (Figure 4). Scurf-infected roots should not be used for seed or disposed of in a field where sweetpotatoes will be planted later. USDA Standards (Appendix 2) list scurf covering more than 15 percent of the root surface as a defect.

Slime molds occasionally develop on the surface of sweetpotatoes. Little is known about the conditions that favor slime mold development on storage roots. Although they look superficial (Figure 52), it is difficult to wash slime mold off sweetpotatoes without permanently damaging the skin of the root.

Figure 51. Scurf only affects the root skin; it does not penetrate into the root flesh. USDA standards allow for 15 percent of the root surface to be covered with scurf. (PHOTO BY G. HOLMES)

Figure 52. Slime mold damage to root skin. (PHOTO BY C. CLARK)

ABIOTIC DAMAGE

Chilling Injury is rare, but it can occur if roots are kept in common storage areas during the winter months (or during transit if temperatures are too low). Storage below 55°F (13°C) can result in chilling injury that may not be evident for several weeks. The roots may appear normal, but the flesh will be spongy and watery. When chilled roots are cooked, the central area of the root may remain hard. Chilled roots are often colonized secondarily by *Penicillium* species (Figures 9 through 11).

Growth Cracks are generally caused by uneven growing conditions, usually when drought is followed by heavy rain (Figure 53). These cracks often serve as infection courts for secondary pathogens. Cracking may also be caused by root-knot nematode (Figure 54). Cracks caused by root growth and those caused by nematodes can be distinguished by the presence of nematodes near the surface of the root (Figure 55).

Mutations/Chimeras in flesh color are common in sweetpotatoes (Figures 56 A and B). Sprouts emerging from the mutated flesh color will produce roots of the same flesh color. A good seed program that uses Foundation or Certified seed that has been selected for freedom from mutations can minimize this problem.

Figure 53. Cracking and galling caused by rapid expansion of roots during a period of high soil moisture on cultivar Beauregard. (PHOTO BY G. HOLMES)

Figure 54. Cracking and galling caused by root knot nematode infection on cultivar Beauregard. (PHOTO BY G. HOLMES)

Figure 55. Nematode damage in sweetpotato root. Small dark spots with light centers reveal the locations of female nematode. (PHOTO BY G. HOLMES)

Pithiness usually is a result of poor storage conditions (such as inadequate temperature or humidity control) and is characterized by white spongy flesh that may contain spaces or cavities and by roots that weigh much less than normal (Figure 10).

Skinning is common during rough handling at harvest and packing (Figure 5). Skinning injuries can be healed through the curing process, although the original appearance will never be regained.

INSECTS

In addition to diseases, potential harm from insects in stored sweetpotatoes is of significant economic concern. Among the insects found in sweetpotato storage facilities are fruit flies, soldier flies, corn earworm, beet armyworm, fall armyworm, southern armyworm, and the sweetpotato weevil. Specific recommendations for control of insects using chemicals are found in the *North Carolina Agricultural Chemicals Manual* and the *Louisiana Insect Pest*

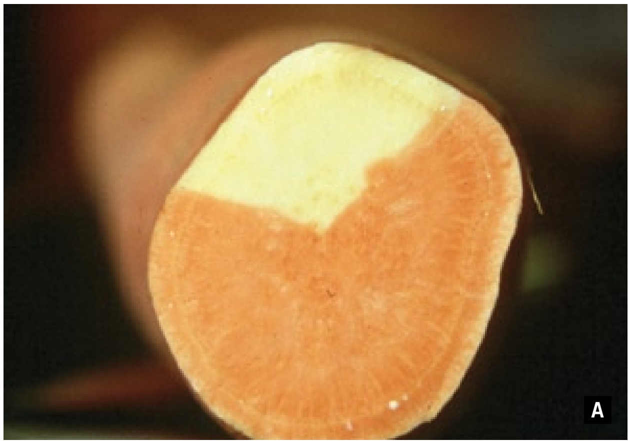


Figure 56. Chimera in orange flesh cultivar (A) (PHOTO BY C. CLARK) and purple flesh cultivar. (B) (PHOTO BY G. HOLMES)

Figure 57. Fruit flies are a common nuisance pest in storage. (PHOTO BY M. WESTBY)

Figure 58. Soldier flies are an occasional pest of stored sweetpotatoes. (PHOTO BY B. DREES)

Management Guide, or you can contact your local Extension center for recommendations.

Fruit flies (*Drosophila* spp.) (Figure 57), also known as vinegar flies, pomace flies, sour flies, banana flies, or drunkards, are very common and are usually considered nuisance pests. They quickly breed into tremendous numbers, but they do not directly attack healthy roots. They lay their eggs and reproduce in diseased, soured, or mechanically damaged sweetpotatoes. Their presence in great numbers is a sure indication of a significant decay problem. Conditions that favor fruit flies are high temperatures, coupled with large quantities of sour, diseased, and mechanically bruised sweetpotatoes. Storing only the best quality, undamaged roots and maintaining that quality are the primary means of avoiding fruit flies. An insecticide spray may be justified when extremely high populations are present.

Soldier flies (*Hermetia illucens*) (Figure 58) are most often seen in the form of scavenging, thick-skinned, flattened larvae. Much like fruit flies, they favor warm, wet storage conditions with decaying roots. Other insects such as earworms and armyworms, which feed on the foliage and exposed sweetpotatoes in the field, are at times carried into storage facilities during harvesting operations. There, they continue to feed and cause large holes in roots. Managing

Figure 59. External damage caused by sweetpotato weevil feeding includes small puncture wounds. (PHOTO BY J. MURRAY)

these insects in the field prior to harvest will help avoid introducing worms into storage areas.

Sweetpotato weevil (*Cylas formicarius,Fab.*) (Figures 59 through 61) can be a serious pest of stored sweetpotatoes once it is established. Although they are not considered a problem in the majority of sweetpotato commercial production areas in the U.S., weevils can become a serious pest of stored sweetpotatoes in the South if not properly monitored and managed. Regulatory mandates differ, and growers should become familiar with their local regulations.

Prevention is the key to successful weevil management. Avoid bringing in sweetpotatoes or containers from areas where weevils are known to be a serious problem. Always insist on weevil-free roots when purchasing seed or roots for storage, and inspect shipments upon arrival to verify place of origin and proper tagging. If a threat of weevils exists, sex pheromone traps (Figure 62) that are specific to sweetpotato weevils can be used to monitor plant beds, storage areas, and production fields. If sweetpotato weevils are discovered outside the quarantine area, promptly alert regulatory officials. Certain insecticides are available and labeled for use in the field and in storage facilities. Contact your local Extension agent for more information on the potential risk of and management options available for the sweetpotato weevil in your area.

Figure 60. Internal damage caused by sweetpotato weevil feeding. (PHOTO BY A. HAMMOND)

Figure 61. Adult sweetpotato weevil. (PHOTO BY DIVISION OF PLANT INDUSTRY ARCHIVE, FLORIDA DEPARTMENT OF AGRICULTURE AND CONSUMER SERVICES, BUGWOOD.ORG)

Figure 62. Pheromone traps for sweetpotato weevil are required in infested areas. (PHOTO BY G. HOLMES)

Appendix 2.

U.S. Standards for Grades of Sweetpotatoes

Summarized from the *U.S. standards for grades of sweetpotatoes*. Published by the USDA Agriculture Marketing Service and effective April 21, 2005. For complete information on grade standards, see http://www.ams.usda.gov/

GRADES

U.S. Extra No. 1.
U.S. No. 1.
U.S. No. 1 Petite.
U.S. Commercial.
U.S. No. 2.

TOLERANCES

U.S. Extra No. 1, U.S. No. 1 and U.S. No. 1 Petite grades. 10 percent of the sweetpotatoes in any lot may fail to meet the requirements of these grades, but not more than one-half of this amount, or 5 percent, shall be allowed for sweetpotatoes which are seriously damaged, including therein not more than 2 percent for sweetpotatoes affected by soft rot or wet breakdown.

U.S. Commercial. 25 percent of the sweetpotatoes in any lot may fail to meet the requirements of this grade, but not more than one-fifth of this amount, or 5 percent, shall be allowed for sweetpotatoes which are seriously damaged, including therein not more than 2 percent for sweetpotatoes affected by soft rot or wet breakdown.

U.S. No. 2. 10 percent of the sweetpotatoes in any lot may fail to meet the requirements of this grade, including therein not more than 2 percent for sweetpotatoes affected by soft rot or wet breakdown.

Off-size. 10 percent of the sweetpotatoes in any lot may fail to meet any specified size, but not more than one-half of this amount, or 5 percent, shall be allowed for sweetpotatoes which are below the minimum diameter and minimum length specified.

DEFINITIONS

Similar varietal characteristics: sweetpotatoes have the same character of flesh and practically the same skin color. For example, dry type shall not be mixed with semi-moist or moist type.

Firm: not more than slightly flabby or shriveled.

Smooth: the sweetpotato is free from veining or other defects causing roughness which more than slightly detract from the appearance of the individual sweetpotato or the general appearance of the lot.

Fairly clean: the individual sweetpotato is not caked with dirt and that dirt or other foreign matter does not materially detract from the general appearance of the lot.

Fairly well shaped: the sweetpotatoes are not so curved, crooked, constricted or otherwise misshapen as to materially detract from the appearance of the individual sweetpotato or the general appearance of the lot.

Damage: any defect which materially detracts from the appearance, or the edible or shipping quality of the sweetpotato or which cannot be removed without a loss of more than 5 percent of the total weight of the sweetpotato including peel covering the defective area. Specific defects:
(a) Sprouts over three-fourths inch in length
(b) Growth cracks which detract materially from appearance
(c) Scurf covering more than 15 percent of the surface
(d) Pox (Soil Rot) when detracting from appearance
(e) Wireworm, grass root or similar injury when any hole in a sweetpotato ranging in size from 6 to 8 ounces is more than three-fourths inch long or when the aggregate length of all holes is more than 1¼ inches, or correspondingly shorter or longer holes in smaller or larger sweetpotatoes.

Length: the dimension of the sweetpotato, measured in a straight line between points at or near each end of the sweetpotato where it is at least three-eighths inch in diameter.

Diameter: the greatest dimension of the sweetpotato, measured at right angles to the longitudinal axis.

One type: sweetpotatoes have the same character of flesh, and do not show an extreme range in skin color. For example, dry type shall not be mixed with semi-moist, or moist type, and deep red or purple skin color shall not be mixed with yellow or reddish copper skin color.

Fairly smooth: the sweetpotato is free from veining or other defects causing roughness which detract from appearance.

Serious damage: any defect which seriously detracts from the appearance or edible or shipping quality or which cannot be removed without a loss of more than 10 percent of the total weight of the sweetpotato including peel covering the defective area. The following specific defects shall be considered as serious damage:
(a) Dirt or other foreign matter when the individual sweetpotato is badly caked with dirt, or when seriously detracting from the appearance of the lot;
(b) Growth cracks when unhealed or when seriously detracting from the appearance of the individual sweetpotato or general appearance of the lot;
(c) Pox (Soil Rot) when seriously detracting from the appearance of the individual sweetpotato; and,
(d) Wireworm, grass root or similar injury when any hole in a

TABLE 9. Size requirements for U.S. sweetpotato grades

Grade	Length (in.)		Diameter (in.)		Weight (oz.)
	Min.	Max.	Min.	Max.	Max.
U.S. Extra No.1	3	9	1 3/4	3 1/4	18
U.S. No. 1 & US Commercial	3	9	1 3/4	3 1/2	20
U.S. No. 1 Petite	3	7	1 1/2	2 1/4	-
U.S. No. 2	1 1/2	-	-	-	36

TABLE 10. Appearance requirements for U.S. sweetpotato grades

U.S. Extra No. 1	US No.1 U.S. No. 1 Petite	U.S. Commercial	U.S. No. 2
Firm	Firm	Firm	Firm
Smooth	Fairly smooth	Fairly smooth	No serious damage
Fairly clean	Fairly clean	Fairly clean	Not dirty
Fairly well shaped	Fairly well shaped	Fairly well shaped	No shape requirement
Similar varietal characteristics	One type	One type	One type
Free of damage*	Free of damage*	Free of serious damage*	Free of serious damage*
Free of chilling injury, internal breakdown and dry rot	Free of chilling injury, internal breakdown and dry rot	Free of chilling injury, internal breakdown and dry rot	Free of chilling injury, internal breakdown and dry rot
<2% soft rot	<2% soft rot	<2% soft rot	<2% soft rot

*See definitions above for description of damage and serious damage

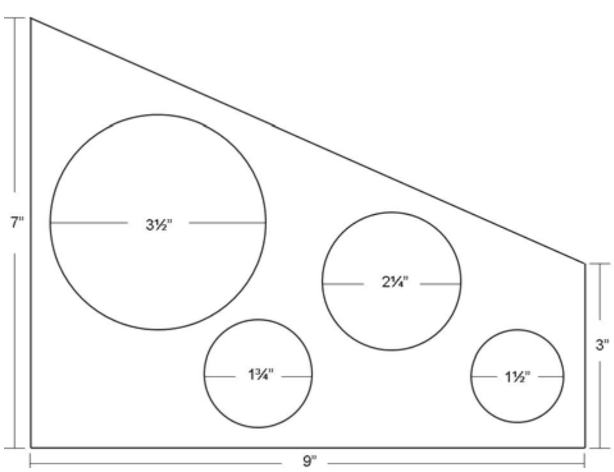


Figure 63. A grading board can be used in the field and on the packing line to manually grade roots. (ILLUSTRATION BY B. EDMUNDS)

sweetpotato ranging in size from 6 to 8 ounces, is more than 1¼ inches long, or when the aggregate length of all holes is more than 2 inches, or correspondingly shorter or longer holes in smaller or larger sweetpotatoes.

A grading board (Figure 63) can be used by growers, graders and packers to determine size classification. A grading board can be made from plywood, metal, Masonite, or plastic. Unless otherwise specified, sweetpotatoes that go through the large hole (left) but not through the small hole (right) and are between three and nine inches in length meet the requirements for U.S. No. 1 size. Additional holes can be made for sizing other grades.

Appendix 3.

Construction Guidelines for Negative Horizontal Ventilation (NHV) Curing and Storage Facilities

Revised from *The Postharvest Handling of Sweetpotatoes: with construction guidelines for negative horizontal ventilation curing and storage facilities.* M.D. Boyette, E.A. Estes, A.R. Rubin, and K.A. Sorenson. 1997. North Carolina Extension Service publication AG-413-10-B

In the 1970s, the Southeast sweetpotato industry began to evolve as a reliable source of good-quality sweetpotatoes, not only in the fall and early winter, but essentially year-round. A growing concern about the quality of stored sweetpotatoes, combined with a move toward larger and more mechanized operations, eventually prompted a re-examination of then-current curing and storage facility design. In Europe, a design known as the "letter-box," or negative horizontal ventilation (NHV) system, had long been employed for ventilation of (Irish) potato storage facilities. During the 1980s, a variation of this design produced excellent results in California and other regions for forced-air cooling of fruit and vegetables in pallet bins.

In the NHV system, the ventilation air is generally pulled horizontally past the pallet bins by a slight negative pressure. The negative pressure is created by fans mounted internally along the top of a plenum wall on one end of the room (Figure 12). The NHV system mixes the air, which results in little internal variation in temperature or humidity throughout the room. Further, because the air is in motion and passing through the mass of sweetpotatoes (no root is more than one-half the depth of a pallet bin from a moving stream of air), there is opportunity for heat transfer. Good heat transfer is important for warming the sweetpotatoes at the beginning of the curing cycle, or cooling at the end, and for the removal of heat generated by respiration throughout the storage period.

A sweetpotato curing and storage facility is an investment in quality maintenance. In general, the longer the storage time, the more sophisticated the facility and hence, the more expensive. Postharvest facilities, unlike many other types of large capital expenditures (such as tractors and harvesters), are frequently subject to alterations and additions. It is a major mistake to assume that any building design is "final." Economic conditions, marketing opportunities, and many other forces tend to alter the requirements of these structures. Very few of these buildings remain as they were built for more than a few years. A facility with excessive and unused capacity makes little economic sense. However, planning for future expansion or alteration should begin with site selection. After a facility is built, all future expansions must necessarily "work around" that facility. A great many problems can be avoided with proper planning.

The following important points should be seriously considered during the planning process:

Function. The first step in planning is to determine the primary function of the facility. Will the facility be used only for curing and storing sweetpotatoes? Do immediate or long-term plans include provisions for a packing line and possible cold storage? Will the facility be used for other types of produce or for other purposes (for example, equipment storage or storage of other crops or supplies) during the off-season? Will activities at the facility be mostly seasonal, or will there be workers at the facility year-round? A useful and efficient facility can be built only when all the needs and functions have been thoroughly explored.

Location. The chain from sweetpotato field to the consumer's table is essentially an exercise in material handling. Visualizing the movement of sweetpotatoes to the facility, through the facility, and away from the facility as a flow of material can significantly simplify the planning process. Land is expensive. Situating an 8,000-square-foot sweetpotato facility in the middle of a 10-acre field may seem a waste of valuable land. However, there are hundreds of postharvest facilities on sites that effectively eliminate any future expansion, even though the facility was originally conveniently located. There are no good guidelines to follow in projecting what future requirements might be, although it is often recommended that a site should have room for a facility to be doubled in size twice. The outlines of a generous expansion program should be included on the original site plan.

As you begin planning, it is a good idea to become familiar with any zoning regulations, local ordinances, or land-use plans that are applicable to the site. You should also become familiar with any laws or regulations pertaining to construction, electrical systems, worker health or safety, the proper use and storage of pesticides, and the proper handling and storage of food products. Although building contractors should be familiar with the laws governing construction, do not assume they are familiar with laws governing the use of the facility.

Before any construction activity, the owners or operators of a sweetpotato facility are urged to complete a comprehensive site evaluation to ensure that wetlands or other sensitive areas will not be affected by the proposed activity. Most county planning departments maintain a comprehensive list of rules and regulations that may impact small businesses and industries. Early contact with regulatory agencies is recommended to ensure that the construction and use of the facility are in compliance with all applicable rules and regulations and that all necessary permits are acquired.

A level, elevated site with good natural drainage is ideal. Standing water is not only a nuisance, but it contributes to the early failure of floors, foundation walls, and column footings. Further, pumping water from loading docks—especially pumping wastewater from packing lines—can be expensive. Avoid sites too near property lines, creeks (and designated wetlands), and railroad, highway, or power rights-of-way. It is also prudent to avoid residential areas whenever possible. Although highway accessibility is essential both for the movement of sweetpotatoes and for those working in the facility, try to maintain a reasonable setback. Allow for adequate parking and truck turnaround space, provide room for future expansion, and avoid potential problems should the highway be altered or widened.

Power. All except the smallest sweetpotato curing and storage facilities should have access to three-phase power. Access may be problematic in some rural areas, but the amount of power required for fans, pumps, and refrigeration systems makes access to three-phase essential in most cases. Although the cost of three-phase power may be considerably less than single phase, connection fees may be quite high. However, the cost of running three-phase equipment may be considerably less than single phase. For example, a five-horsepower, three-phase electric motor may cost about the same as a one-horsepower, single-phase electric motor. Some electrical equipment, such as refrigeration systems with a capacity greater than 10 tons, may require three-phase power. Power stand-by charges or minimum monthly charges may be levied if power is not disconnected in the off-season, so check details with your utility company.

Water. Some water is required for all sweetpotato curing and storage facilities. For facilities intended for curing and storage only, 8 to 12 gallons per minute may be adequate for humidifiers, drinking, bathrooms, and miscellaneous cleaning. However, for facilities with packing lines, the water requirements may range from 1,000 gallons per hour for a small line to more than 3,000 gallons per hour for a large line. If well water is to be the source, follow local permit requirements. Back-flow protection should be incorporated into any well's construction design.

Waste disposal. For a curing and storage facility that may include a packing line, you should closely examine proper waste disposal options. All such facilities must have means for proper management and disposal of both domestic and industrial process waste and may also require one or more regulatory permits, depending on state regulations.

Potential sites that are otherwise suitable may be rejected because they do not provide for the proper disposal of wastewater. Land application of the wastewater, through spray irrigation or other means, should be explored first. The guidelines for this option may require an assessment by a qualified irrigation engineer, depending on the state. This is definitely the best option for most operations. A second alternative is to discharge to a municipal wastewater treatment system, which may have industrial pretreatment requirements of its own.

A final option is to discharge wastewater into the surface waters (stream, canal, drainage ditch, road ditch, and so on). If you are classified as an industrial operation, (you pack any sweetpotatoes other than your own), you may also be required to obtain a wastewater discharge permit. You should try to avoid this step if at all possible. These permits are issued only after all options for land application or reuse are evaluated. Permits to discharge to surface waters are issued only after the surface water and flow regime has been modeled and discharge limits are established. This is a long and often costly process, resulting in only a temporary permit that is subject to review.

In addition to permits for wastewater management, additional permits may be required for managing the solid waste. The solid waste generated in a sweetpotato packing facility, such as culls, mud, sand, and plastic and paper packaging materials, must be disposed of in a permitted landfill or through some permitted on-site composting facility. The quality of the composted materials must be monitored and can be determined through testing by state regulatory agencies for a small fee. Detailed information on composting methods and equipment may be obtained from your county Cooperative Extension center. Land application or livestock feeding of cull potatoes may also be an option.

Capacity. Many of the details of a sweetpotato curing and storage facility are ultimately determined by the required capacity. The capacity requirements are not always so simple as the sum of your anticipated production, plus the amount you might be willing to store for others. The practices of segregating the roots from different growers, from different fields, of different grades or different varieties, and arranging them for easy access, can all have a significant effect on the working capacity of an individual facility. It makes no economic sense to build more capacity than can be efficiently utilized. A measure of excess capacity may be a wise investment when it will be needed to accommodate higher than normal yields or to provide adequate space to store sweetpotatoes from other sources. Remember that the cost per square foot decreases and energy efficiency increases with increasing facility size.

Curing, unlike storage, is a process that involves a definite period of time. Curing for too short or too long a time can have negative effects on the quality of the roots. For this reason, the size of the individual rooms in an NHV facility is customarily limited to no more than two days' harvest. Two days' harvest for some growers may be as few as 5,000 bushels, while for others it may be as many as 30,000 bushels. The typical capacity of an individual room in an NHV facility is about 15,000 bushels. Larger rooms may make slightly more efficient use of space than smaller rooms, but they can result in undercured or overcured roots if not filled on a timely basis. Smaller rooms, however, are more quickly emptied and taken out of service.

Although there have been some notable efforts in the handling and storage of sweetpotatoes in bulk, almost 100 percent of the domestic sweetpotato crop is still harvested into, cured, and stored in pallet bins. Although there are published standards for pallet bins (ASAE 337.1, American Plywood Association and the National Wooden Pallet and Container Association), the construction and dimensions of the bins have evolved through voluntary agreements between the manufacturers and the sweetpotato industry. In the Southeast, most pallet bins built since about 1985 for sweetpotatoes have generally measured 42 inches wide, 47 inches deep (in the direction of the fork slots), and 35 inches high. The level, full capacity of these bins is slightly more than 20 bushels. In practice, however, to prevent crushing and skinning the roots, the bins are not filled to capacity, but are assumed to hold 18 bushels. The gross weight of a full bin at harvest is approximately 1,250 pounds. In recent years, some growers have moved to double-pallet bins for increased efficiency. These double bins (84 inches wide, 47 deep, and 35 inches high) are designed to exactly replace two single bins but require heavier forklifts and specialized bin rotation equipment.

Pallet bins are designed to be stacked one on top of the other to make efficient use of floor space. It is customary to stack bins at least six high ($17^1/_2$ feet). This allows only $2^1/_2$ feet of head space around the walls in buildings with 20-foot eave height. This should be considered a minimum in NHV facilities. Ample head space is necessary above the stack for proper air movement. Some recently built facilities have 22-, 24-, or even 30-foot eave heights. A 30-foot eave height allows pallet bins to be stacked eight high (23.3 feet). All stacked pallet bins should be perfectly aligned and in good condition. The collapse of one lower pallet bin can cause a stack—or even an entire row—to fall over, with catastrophic results.

As mentioned, the total capacity of a sweetpotato curing and storage facility depends on production plus some prudent excess, whereas the capacity of individual rooms is usually limited to two days' harvest. Most sweetpotato curing and storage facilities consist of several individual rooms. Use the following formulas and guidelines to determine the actual dimensions of these rooms:

C = (1.2)(L)(W)(N) *Where:*
C = room capacity in bushels, normally limited to two days' harvest
L = length of the room in feet
W = width of room in feet
N = number of bins in stack, (for example, if the bins are stacked six high, N = 6)

The length of the room (dimension parallel to the direction of air flow) is normally limited to 100 feet because of the difficulty of the fans to consistently move the air greater distances. Although there are no such limits on the width of the room, good planning suggests the selection of room widths that utilize standard building components (beams, girders, and bar joists) and limit the length of unsupported roof spans. It is also a good idea to select widths that match well with the combined width of the pallet bins, plus about two feet to take care of gaps between bins and clearance along both walls. Support columns in the middle of a room are a major inconvenience, a possible safety hazard, and should be avoided when possible.

Example: A room eight bins wide would require a room width of: W = (8)(42) + 24 = 360 inches = 30 feet. Assuming a room capacity of 12,000 bushels with pallet bins stacked six high, the formula above would yield a calculated length of: 12,000 = (1.2)(L)(30)(6) L= 55.6 feet.

When the width of the plenum is added, the total length of the room approaches 60 feet. Therefore, the capacity of a single room for an NHV facility with inside dimensions of 30 feet wide by 60 feet long, with bins stacked six high, is approximately 12,000 bushels. Table 11 provides estimated capacities for rooms of various dimensions.

If the pallet bins are carefully stacked near the door, almost all the floor space inside the room may be used. Often the pallets in the last row or pair of rows must be turned sideways (the forklift slots are perpendicular to the flow of air in the room) to allow the forklift maneuvering room. This arrangement will present no air movement problems, provided a free space of 6 inches to 1 foot is maintained around these bins.

Rarely will a curing and storage room be built without some type of paved (and often covered) staging area for unloading and loading trucks. Carefully consider this aspect of the facility design. Such areas are seldom considered in initial designs but often become a central alleyway of an expanded facility. This area is important to the overall functioning of the facility because convenient access to each room from a central location is essential for ease of material handling. Access aisles and alleyways should be at least 16 feet wide to allow for safe operation of loaded forklifts. When loading docks are part of the design, they should be conveniently located to keep the trips short from truck to storage.

CONSTRUCTION POINTS AND EQUIPMENT SELECTION

Building type. Many types of building construction have proved satisfactory for sweetpotato curing and storage facilities. Insulated concrete-block, curtain-wall buildings with bar joist roof supports were once popular with growers. Because of the labor costs, block construction has been almost replaced by engineered post-frame buildings or all steel buildings of various designs. These modern buildings are durable, functional, economical, and can be custom designed and constructed in a fraction of the time it took to build the older masonry buildings.

Foundation and floor. Although the cost of the foundation is relatively small, the foundation directly or indirectly affects the performance of all other parts of the building. The foundation distributes the weight of the building and its contents over an area sufficient to prevent excessive and uneven settling. A well-drained solid grade is essential to an acceptable foundation.

All sweetpotato curing and storage facilities are constructed on a slab floor of at least 4 inches of wire-mesh-reinforced concrete over a well-compacted grade. The floor should be capable of supporting at least three times the rated capacity of the forklift. Five to 8 inches of reinforced concrete may be necessary where loads are unusually heavy, such as around loading docks. The floor should be as smooth and level as possible. Even a slight unevenness of 1/4 inch between the two front wheels of the forklift may result in a 3-inch side movement of the pallet bin 16 feet off the floor (Figure 64). Because the recommended sweetpotato storage temperature is near the deep soil temperature in most growing areas of the U.S., under-floor insulation is not necessary. It is wise, however, to include a vapor barrier under the slab.

Insulation. Thermal energy flows naturally from warm objects to cold ones. All material, even good heat conductors like metals, offers some resistance to the flow of heat. Insulation, however, is any material that offers high resistance to the flow of energy. Hundreds of different

Figure 64. Extended forklift. (PHOTO BY T. SMITH)

materials have been used at one time or another for thermal insulation. The characteristics of the insulation materials differ considerably. Suitability for the particular application, as well as cost, should be the deciding factors in choosing a material. Thermal resistance (R-factor) should be considered in addition to durability and the labor required to install the material. Some common insulation materials such as fiberglass bats are not recommended for sweetpotato curing and storage facilities because they perform poorly in a high-humidity environment and often harbor rodents and birds.

A measure of an insulation's resistance to the movement of heat is its R-value. The R (for resistance) number is always associated with a thickness: the higher the R-value, the higher the resistance and the better the insulating properties of the material. The R-value can be given in terms of a 1-inch-thick layer or in terms of the total thickness of the material. The R-values of some common building materials are shown in Table 12.

The most popular insulation material now used in new sweetpotato curing and storage facilities is sprayed-on expanded polyurethane foam. Properly applied, this material has an R-factor of approximately 7 per inch, although this value may decrease somewhat with age. It is durable, moisture resistant, and effectively seals cracks and small openings. Its most important characteristic, however, is that it may be applied very rapidly with comparatively little labor. But this material is extremely flammable immediately after application and gives off a toxic smoke when burned. Some local fire codes or insurance companies may require a fire-resistant coating on this material. Fire-protective coating may provide some moisture resistance that is not permanent in urethane, causing the foam's R-factor to decline with age.

Rigid boards of foil or plastic-backed polyisocyranuate foam have been occasionally used for insulating sweetpotato facilities. This material varies in thicknesses (1/2 inch to 3 inches) and in size (4 by 8 feet to as large as 8 by 30 feet). Certain formulations of this material may have R-factors as high as 8 per inch. In the past, similar materials have delaminated and otherwise performed poorly in the high humidity of a sweetpotato facility. This material also requires considerable installation labor. The main objection to this material in an NHV facility in the past was the difficulty in sealing the joints between boards and at roof and floor level. Because NHV facilities operate at slightly reduced or elevated air pressures, failure to adequately seal all openings to the outside can substantially reduce the performance of the system. Newer materials, joint sealing methods, and installation procedures have all but eliminated many of these objections.

Both sprayed-on expanded polyurethane and polyisocyranuate board materials are made of closed cell foams. Closed cell foams act as vapor barriers by retarding the movement of moisture out of the building. A good vapor barrier is desirable to maintain the humidity inside the facility, thereby preventing excessive evaporation and weight loss of the sweetpotatoes. Under high-humidity conditions, sufficient insulation will help prevent moisture from condensing on the walls and roof. When the relative humidity inside the building approaches saturation, moisture will begin to condense on any surface that is below the temperature of the air. Condensation is more likely to occur in the top of the building, is most prevalent at night, and indicates insufficient insulation rather than excessive humidity.

In the sweetpotato growing areas in the Southeast, the total R-factor should be a minimum of 12 for walls and a minimum of 16 for roofs. Roofs require greater insulation because their surfaces are more directly exposed to sunlight during the day and radiation cooling at night.

Doors. The door is another important part of the sweetpotato facility. The larger the door, the better the access to the room and the easier pallet bins may be moved in and out. However, well-designed doors can be expensive. Their price is roughly based on their total area, not width. For example, a 16-foot wide by 16-foot tall sliding or garage door may cost up to four times as much as an 8-foot door. Although small doors are less expensive, few sweetpotato facilities are built with doorways less than 12 feet wide. Doorways should exceed the height of a loaded forklift (about 10 to 11 feet). Improperly designed or maintained doors can waste large quantities of energy. Doors should have as much insulation as the walls and should always provide a good air seal when closed.

Plastic strip curtains are effective in reducing the energy loss when large doors must remain open for long periods. Because the doors of sweetpotato rooms are usually opened only when filling and unfilling, plastic strip curtains are probably not a good investment. Small access doors are a good investment, however, because they allow for inspection of the room and its contents without the bother and energy loss of opening the large access door (Figure 65).

Heating system. Those familiar with the heating requirements of the old trench floor system of curing are sometimes surprised at how much lower the heating requirement is for the NHV system. In general, the heating systems selected for the trench floor facilities were based not on the required heat capacity, but on the fan or air-moving capacity of the heating unit. It is not unusual to see a 12,000-bushel, trench-floor curing room with a heating system capacity of 1 million Btu per hour or more. The actual heating requirement for an NHV room of the same capacity with the recommended minimum insulation is about 300,000 Btu per hour. Because in the NHV system, the fans that move the air about the room are separate from the heating system, the heating system may be rightly based on the heat requirement and not the fan capacity.

Sweetpotatoes delivered to the curing and storage facility usually arrive at a temperature near that of the outside air. Early in the harvest season, this may be near 85°F (30°C), the recommended curing temperature. On cold days late in the harvest season, however, the arriving roots may be significantly cooler. The amount of heat required to warm the sweetpotatoes to the recommended curing temperature depends on their pulp temperature at arrival, the quantity and rate delivered, and the rate of warm up. Generally, sufficient heat should be provided in the curing room to raise the temperature to 85°F (30°C) within *48 hours*. This is an important point. In the past, heating systems were designed to raise the temperature of the roots as much as 40°F in 24 hours. This rate of heat input is excessive for two reasons. First, it often causes drying and other physiological problems associated with high temperatures in localized areas near the heater, even in facilities equipped with NHV systems. The fans simply cannot move the heated air away from the heater fast enough to prevent localized overheating. Second, there is some evidence that abrupt changes in temperature (from cool to warm or vice-versa) may negatively affect sweetpotato metabolism, decreasing quality and shelf life.

Excessively high curing temperatures contribute to excessive weight loss, sprouting, and other possible damage. Although 85°F (30°C) is the recommended curing temperature, it is prudent to stop or slow the input of heat well before that temperature is reached to prevent overshooting the target temperature. Excursions to 90°F (32°C) or even 100°F (38°C) are common problems that occur because of the production of respiration heat at high temperatures. For this reason, it is recommended that the curing thermostat be set no higher than 80°F to allow the pulp temperature to "coast" to 85°F (30°C).

Heating system load calculations are based primarily on two factors. The major factor is the heat required to raise the temperature of the sweetpotatoes from the ambient

Figure 65. Small access doors to storage rooms limit excessive temperature fluctuations that occur when checking root quality or room conditions. (PHOTO BY G. HOLMES)

Operating experience with well-constructed NHV facilities in eastern North Carolina has shown that heating systems sized at 25 Btu per hour per bushel of capacity are adequate.

temperature to 85°F (30°C) at the beginning of the curing cycle. In a properly insulated building, this typically represents 90 to 95 percent of the total load. The rest of the load is composed of heat lost by conduction through the walls and heat lost with ventilation air.

The room from the previous example (30 feet wide by 60 feet long, 12,000 bushel capacity), insulated to R-12 in the walls and R-16 in the roof, would require a heater output of approximately 300,000 Btu per hour. About 94 percent of this total (282,000 Btu per hour) is needed to raise the sweetpotatoes to curing temperature in 48 hours. Only 6 percent of that capacity (18,000 Btu per hour) is needed to offset the conduction and ventilation losses on cold days.

As this example shows, in a properly insulated and operated curing facility, most of the heat load is used to raise the temperature of the sweetpotatoes. Only a small percentage of the heat load is used to offset infiltration losses. Even in very cold weather, heaters are seldom operated because heat from respiration of the sweetpotatoes generally maintains the correct storage temperature. For this reason, it is possible to accurately estimate the required heating system output based solely on the capacity of the facility, provided it is adequately insulated and properly operated. Operating experience with well-constructed NHV facilities in eastern North Carolina has shown that heating systems sized at *25 Btu per hour per bushel of capacity* are adequate. Curing and storage facilities with as little as 10 Btu per hour per bushel have been successfully operated, but in cool weather may take four days or more to raise the curing temperature to 85°F (30°C).

Many different types of oil or gas heaters have been used successfully in sweetpotato curing and storage facilities. Most recently built NHV facilities have used unvented LP or natural gas heaters of the type used in animal confinement buildings or some greenhouses. These unvented gas heaters are simple, relatively inexpensive, and economical to operate. No matter what type of heater is used, it is important that the combustion air for the heater not come from inside the room. Unvented gas heaters in particular can quickly deplete the oxygen inside the room, which results in poor combustion, the production of carbon monoxide, and a potentially deadly situation. Ethylene is a by-product of heaters and can negatively affect sweetpotato quality. Heaters should always be mounted outside the room in some convenient location. Above and to the side of the roll-up or sliding door at the end of the room opposite the plenum wall has proven satisfactory. A duct can be put through the wall from the heater so the hot air enters the room above the stack of pallet bins. The heaters can also be located at the opposite end of the building and ducted into the plenum. Ideally, the thermostat used to control the heater should be located away from the heater in a position that has good air movement and allows easy access (but not directly on an exterior wall if possible).

Refrigeration system. The refrigeration system removes excess heat from the sweetpotato facility. It is possible to store sweetpotatoes for extended periods in both conventional and NHV facilities during cool weather without refrigeration. However, refrigeration allows the timely removal of heat at the end of the curing cycle, which eliminates excessive sprouting and weight loss. Additionally, refrigeration allows for much more precise control of the temperature during storage in warm weather and is essential for successful sweetpotato storage during late spring and summer. In late-season storage situations, the cost of refrigeration generally pays for itself in two years or less by reduced weight loss and increased quality maintenance.

Heat can be thought of as a form of energy that always flows "downhill" from warm objects to cool objects. For example, heat will flow from a warm sweetpotato to the cool surrounding air. A refrigeration system is functionally like a pump that pumps heat "uphill" from cool to warm objects. With a refrigeration system, it is possible to remove heat from a sweetpotato storage room at 65°F (18°C) to the outside air, which may be at 90°F (32°C).

A refrigeration system consists of three major parts: a motor/refrigerant compressor set, condenser coils, and evaporator (cooling) coils. These parts are connected by piping to form a closed loop. Sealed inside the piping is a liquid or vapor refrigerant. The motor/compressor acts as a pump that circulates the refrigerant through the system. Both the compressor and condenser coils are heat transfer devices and have fans to help move heat from the coils to or from the surrounding air. The evaporator coils are always located inside the room and are designed to transfer heat from the air to the refrigerant. The condenser coils are always located outside the refrigerated room and are designed to transfer heat from the refrigerant to the surrounding air. The refrigeration system is controlled by a cooling thermostat. Like the heating thermostat, the cooling thermostat should be conveniently located, but not be directly in the air stream from the cooling coils or on an exterior wall.

The cooling coils of the refrigeration system must be cooler than the air inside the room if the air is to be cooled. The larger the temperature difference, the greater the rate of heat transfer and the smaller and less expensive the cooling coils for a given capacity. However, the colder the coil surface, the more water vapor from the air will condense on the coils. As water condenses on the coils, it gives up heat at the rate of approximately 1,000 Btu per pint. The cooling energy used to remove this latent heat is wasted because it contributes nothing to cooling the room. In addition to wasting refrigeration capacity and electrical power, excessive condensation on the cooling coils should be minimized because it reduces the relative humidity of the room.

To minimize condensation and maintain the optimum curing and storage humidity inside the facility, it is good practice to select a cooling coil that minimizes the temperature difference between the air and coil surfaces by selecting a larger coil. The temperature difference between the air and the coil surfaces (known in the industry as "delta T") should be limited to 12 degrees or less to help maintain a relative humidity of 85 percent. Unfortunately, not all refrigeration contractors are aware of the special humidity requirements of sweetpotato storage facilities. In selecting a cooling coil, be sure to specify a 12-degree maximum delta T. The cooling coils of a refrigeration system are normally equipped with fans that blow or pull air past the heat transfer surfaces. It is advantageous to position the cooling coils inside the room in a way that allows the fans to move air in the same direction as the NHV fans in the plenum wall as shown in Figure 12. Allowing the cooling coils fans to move air across the room perpendicular to the direction of air from the NHV system, or even worse, opposite of that from the NHV fans, will disrupt the air flow patterns, and the result is poor performance of the NHV system.

Similar to the heating system, the refrigeration load calculations are based on two factors. The main factor is the refrigeration capacity required to remove the heat from the roots at the end of the curing cycle. In determining this part of the load, timely removal of heat to reduce weight loss must be balanced with the cost of the system. The longer the time allowed to reduce the temperature from 85°F (30°C) to 58°F (15°C), the smaller the refrigeration load and hence, the smaller and less costly the system. Experience has shown that a cool-down period of 96 hours (four days) strikes a good balance between quality maintenance and cost. In a well-insulated and operated NHV facility, this cool-down generally represents approximately 90 percent of the total required refrigeration load. Similar to heating, the other factor representing the remaining 10 percent is the refrigeration capacity required to overcome the conduction losses through the walls and roof and the ventilation losses.

Using the previous example—a 30-by-60-foot, 12,000-bushel capacity room—the facility would require a refrigeration capacity of approximately 185,000 Btu per hour (15.4 refrigeration tons). More than 90 percent of this amount is needed to lower the temperature at the end of curing. The other 10 percent is needed to offset the heat gained through conduction and ventilation. As with the heating system calculations, it is possible to accurately estimate the refrigeration system capacity required based solely on the capacity of the facility, provided it is adequately insulated and properly operated. Again, operating experience with well-constructed NHV facilities has shown that about 1.3 tons of refrigeration per 1,000 bushels of capacity is adequate.

Again, operating experience with well-constructed NHV facilities has shown that about 1.3 tons of refrigeration per 1,000 bushels of capacity is adequate.

Humidification equipment. For successful curing and storage of sweetpotatoes, maintaining the proper humidity should be considered almost as important as maintaining the proper temperature. In NHV facilities that are cooled with outside air only, low humidity and the resulting weight loss can be a serious problem without humidity control. Some water vapor is continually given up by sweetpotatoes, either by evaporation or by respiration. Under normal curing and storage conditions, however, this is not enough to maintain the humidity at 85 percent. To maintain optimum humidity, some provisions must be made to add additional water to the air. Traditional recommendations to wet the walls or floors are ineffective. The water must be evaporated directly into the air stream to raise the humidity quickly and uniformly throughout the room. A well-designed humidifier is the only way to efficiently accomplish this.

Many good humidifiers are available that are suitable for a sweetpotato curing and storage facility. Most consist of an electrically driven, high-speed fan and atomizer that produces a fine mist. Ideally, this mist is quickly evaporated, picked up by the circulating air, and distributed throughout the room. Properly adjusted, humidifiers in a sweetpotato facility will not moisten the floor, the sweetpotatoes, or any other surface. The purpose of humidification is to fill the sweetpotato facility with water vapor, not a fog of water droplets. For this reason, those humidifiers designed primarily for greenhouses should be avoided, because they often produce relatively large droplets that settle out of the air stream before they evaporate.

The selected humidifier should have a rated capacity of approximately one gallon per hour per 5,000 bushels of facility storage capacity. The rated capacity of the humidifier is indicative of its performance in low humidity. As the humidity in the facility increases to ideal levels, some of the water droplets may not completely evaporate and drip onto the floor or other surfaces. Additionally, water sources often contain lime or other chemicals that form deposits on nozzles, fan blades, and other parts of the humidifier. The

...the total fan capacity of the NHV facility must equal approximately 2 cfm per bushel based on a fan static pressure differential of 0.10 inches of water.

deposits can adversely affect the performance of the unit and should be removed during periodic maintenance. For this reason, humidifiers should be positioned conveniently for ease of servicing. Because the evaporation of moisture cools the air, it is advisable to mount the humidifier near the heat duct to help warm the air cooled by evaporation and further accelerate the evaporation of water droplets.

What cannot be measured, cannot be controlled. Humidity can be measured by hand using an inexpensive device called a sling psychrometer, using wet bulb and a

Figure 66. A sling psychrometer is used to manually measure humidity. (PHOTO BY G. HOLMES)

dry bulb air temperature with a constant air speed passing over the thermometer (Figure 66). Other devices also can be incorporated into automated systems. They measure humidity electronically or by the shrinking or swelling of specially treated materials. A humidistat, which is an adjustable humidity sensor that activates a switch, should always be used to control the humidifier. Manual control of the humidifier by a simple on/off switch will invariably result in poor humidity maintenance. The humidistat should be properly positioned for best results. It should not be located too near the humidifier nor directly in the air stream from the cooling coils or heater.

Ventilation equipment. The fans mounted in the plenum wall are the essential elements of the NHV system. Along with the dampers and louvers, the fans regulate the movement of air inside the facility. Guidelines for the proper selection of this equipment are based on research and practical field experience in a variety of NHV facilities. The horizontal movement of air not only promotes uniform conditions of temperature and humidity throughout the mass of sweetpotatoes, but more important, it provides a means for heat transfer by forced convection. This forced convection allows the temperature of the sweetpotatoes to be raised uniformly at the beginning of curing and lowered at the end. It also allows for the timely removal of respiration heat and the maintenance of uniform conditions of temperature and humidity throughout the room.

Experimental data for heat transfer between the sweetpotatoes and the air forms the basis on which the required fan capacity is determined. If each of the pallet bins were exactly the same size and fitted perfectly together so that air leakage between bins was eliminated, approximately one cubic foot per minute (cfm) per bushel would be more than enough air to effect good heat transfer. Experimental evidence has shown, however, that about half the air passing through the fans leaks into the plenum through gaps between the pallet bins. Therefore, to yield satisfactory results, the total fan capacity of the NHV facility must equal approximately 2 cfm per bushel based on a fan static pressure differential of 0.10 inches of water. Fan manufacturers normally supply charts giving volume flow rate as a function of static pressure.

Correct fan selection is essential to the proper operation of an NHV facility. Industrial ventilation axial flow fans similar to those shown in Figure 13 are offered in many different combinations of blade diameter, motor horsepower, and fan capacity. In general, where two fans of different blade diameter and horsepower have similar capacity, the one with the larger blade diameter is more energy efficient. Although it is possible that only one fan could provide sufficient capacity, experience has shown that multiple fans spaced 10 to 12 feet apart along the plenum wall will distribute air more uniformly. All the fans in a room must be operated simultaneously. If some fans are allowed to operate while others are switched off or otherwise inoperable, air will be drawn backwards into the plenum through the nonoperating fans. This will significantly reduce air movement through the sweetpotatoes, waste energy, and compromise environmental control. Always promptly repair inoperable fans.

When the fans are used to simply circulate the air inside the room, the motorized dampers across the plenum from the fans remain closed. When outside air is required, the dampers are opened. When correctly sized, the total damper area should equal approximately two-thirds of the total fan area. The total area of the gravity shutters at the end of the room opposite the plenum should equal the total area of the motorized dampers.

Using the example facility of a 30-by 60-foot, 12,000-bushel capacity room, the total required fan capacity would be approximately 2(12,000) = 24,000 cfm. Assuming that three fans spaced approximately 10 feet apart along the plenum wall would be sufficient, each fan would need a capacity of about 8,000 cfm at 0.10 inches of static pressure. From typical manufacturers' specifications, three 30-inch

TABLE 11. Estimated capacities (in bushels) for rooms of various dimensions, with pallet bins stacked six high.

	Width in Feet (Number of Bins)								
Length (ft)	30 (8)	34 (9)	37 (10)	40 (11)	44 (12)	48 (13)	52 (14)	56 (15)	60 (16)
40	7,776	8,820	9,576	10,332	11,376	12,420	13,464	14,508	15,560
45	8,856	10,044	10,908	11,772	12,960	14,148	15,336	16,524	17,720
50	9,936	11,268	12,240	13,212	14,544	15,876	17,208	18,540	19,880
55	11,016	12,492	13,572	14,652	16,128	17,604	19,080	20,556	22,040
60	12,096	13,716	14,904	16,092	17,712	19,332	20,952	22,572	24,200
65	13,176	14,940	16,236	17,532	19,296	21,060	22,824	24,588	26,360
70	14,256	16,164	17,568	18,972	20,880	22,788	24,696	26,604	28,520
75	15,336	17,388	18,900	20,412	22,464	24,516	26,568	28,620	30,680
80	16,416	18,612	20,232	21,852	24,048	26,244	28,440	30,636	32,840
85	17,496	19,836	21,564	23,292	25,632	27,972	30,312	32,652	35,000
90	18,576	21,060	22,896	24,732	27,216	29,700	32,184	34,668	37,160
95	19,656	22,284	24,228	26,172	28,800	31,428	34,056	36,684	39,320
100	20,736	23,508	25,560	27,612	30,384	33,156	35,928	38,700	41,480

Note: for rooms with bins stacked seven or eight high, multiply the numbers in the table by 1.17 or 1.33 respectively

TABLE 12. Insulation R-values for common building materials

Material	Full Thickness R-value
fiberglass batt insulation, 3-1/2 inches thick	13
fiberglass batt insulation, 5-1/2 inches thick	19
loose fill cellulose, per inch	3.5
loose fill glass wool, per inch	3.0
vermiculite, per inch	2.2
expanded polystyrene (blue board), per inch	5.5
foil-backed polyisocyranuate, per inch	8.0
aged expanded sprayed in place polyurethane, per inch	6.3
sprayed in place urea formaldehyde, per inch	5.0
solid concrete, per inch	0.08
eight-inch concrete block	1.1
eight-inch concrete block with vermiculite fill	5.0
pine or fir lumber, per inch	1.2
metal siding	<0.01
3/8 inch plywood	0.5
1/2 inch plywood	0.7

diameter, one-half horsepower fans should be sufficient. Based on the fan sizes, two 30-inch motorized dampers and two 30-inch gravity shutters would also be required per room.

Controls. Proper sweetpotato curing and long-term storage requires precise control temperature, humidity, and ventilation. The level of environmental control cannot exceed the precision of the control system. The electrical controls of the heater, refrigeration system, ventilation system, and humidifier form the brain of the NHV facility. Although there are many different possible designs for this equipment, each design essentially consists of sensors and associated switching equipment. There have been two broad categories of control systems utilized in NHV facilities.

Electromechanical controls consisting of thermostats, humidistats, timers, and associated relays are wired into a central panel box. All the necessary parts and wiring can be obtained from most electrical supply dealers, and the system can be built and serviced by most licensed electricians Generally, a separate system is built to control each room. Electromechanical control systems could be designed to control several rooms, but the cost of long runs of control wiring makes this option economically unfeasible. These controls, if correctly installed, are simple and reliable. With the addition of several remote thermostats and indicator lights, the control panel may be mounted just outside the room to provide the status of the room and equipment at a glance.

Programmable Logic Controllers (PLCs), Figure 67, are industrial computers that have also been used to successfully control NHV facilities. These sophisticated devices operate the control equipment (such as heaters and humidistats) through relays in the same manner as the electromechanical controls. However, unlike the electromechanical controls, PLCs can be programmed to make various energy-saving decisions about the operation of fans, heaters, and refrigeration equipment. They also may be programmed to collect data, provide security, and sound alarms or activate automatic telephone dialing devices in emergency situations. One PLC-based system can easily control many rooms and, therefore, may be the least costly alternative for multi-room facilities. Field data suggest that PLC based systems can provide significantly more overall energy efficiency than electro-mechanical systems.

Although many parts of a PLC-based control system can be installed and serviced by a licensed electrician, the actual hardware selection and programming must be done by an experienced professional. These devices have a proven track record of reliable service in many different industries. Additionally, like many types of computer equipment, the power and versatility continue to increase as the price decreases.

Figure 67. Programmable logic controller (PLC) for an eight-room negative horizontal ventilation (NHV) facility. (PHOTO BY CCU INC.)

NORTH CAROLINA
SWEET POTATO
U.S. No. 1
50 lbs. net
PRODUCE OF U.S.A.
PACKED AND SHIPPED BY
HAROLD OUEBEDEAUX PRODUCE
Sweetpotatoes/Yam
PACKERS
Selected
LOUISIANA YAMS
M. RICHARD & SON
Classic
North Carolina
SWEET POTATOE
POINTER BRAND
A Pointer on Quality
YAMS / SWEET POTATOES
Quality and Service since 1942
Distributed By SOUTHERN PRODUCE DISTRIBUTORS, INC.
GODWIN PRODUCE CO.
OUR SPECIALTY IS HOUSE CURED YAMS
The Pride of North Carolina
WASHED AND WAXED
40 LBS. NET
PUERTO RICAN TYPE
DUNN, NORTH CAROLINA PHONE
CINNAMON & SUGAR
Sweet Potatoes
YAMS
HEART
OTATOES
& Nutritious
WASHED
WAXED
CAJAN QUEEN
SWEET POTATOES
YAMS
40 LBS. NET WT.
TEXAS
ROADHOUSE
Sweet Potatoes
SWEET MAGNOLIA
U.S. No. 1
Louisiana
SWEET POTATOES
SAMPSON KING
NUTRITIONALLY FRESH®
SWEET POTATOES/YAMS
Distributed by Wayne E. Bailey Produce Co.
Chadbourn, North Carolina 28431
PIERRE'S PRIDE
YAMS
PURE WINNER
U.S. No 1
SWEET POTATOES
Louisiana Porto Rican
Dri-Pak
BRAND
Old-Fashioned — Hand-Packed
NORTH CAROLINA
SWEET POTATOES
We Be Yammin'
cajun style
SWEET PO
LIZZY'S DELIGHTS
Thornhill Farms
SWEET POTATOES
They're just plain good for you!
40 LBS. NET WT.
SHARKEY'S FINEST
sweet potatoes
Cajan
GOLD
Yams
Go for the GOLD
NORTH CAROLINA
Queen Ann
BRAND
WASHED AND WAXED
YAMS
SWEET POTATOES
SWEET POTATO
Bursting with Beta-Carotene
s Pride
40 LBS. NET
NORTH CAROLINA
YAMS
SWEET POTATOE
MORNING GLORY
LOUISIANA
PORTO RICAN
SWEET POTATOES
PRODUCE OF U.S.A.
U.S. No. 1
PELICAN PACKING CO.
CHURCH POINT, LOUISIANA
WAYNE E. BAILEY
NUTRITIONAL ALL STARS
SWEET POTATOES
Cajun Sw
Yam
LOUISIANA
NUGGETS
KILN DRIED
PORTO RICAN
SWEET POTATOES
Sun Beauty
YAMS
BAKER'S CHOICE
Sweet Potatoes
Old Timers
Louisiana Porto Rican Yams
KILN DRIED
CAJUN GOLD
"It's Raining on Dez"
LOUISIANA BEAUREGARD YAMS
HIGH IN BETA-CAROTENE • RICH IN VITAMIN A
NORTH
CAROLINA
SWEET POTATOES
NATURALLY
HEALTHY
BAYOU MAID
LOUISIANA
PORTO RICAN
SWEET POTATOES
U.S. No. 1
CARENCRO SWEET POTATO COOPERATIVE, INC.
TATER GATOR
BEAUREGARD
YAMS
40 LBS.
NET WT.
18.1 KG.
NASH'S PR
NORTH CAROLINA
YAMS
SWEET POTATOES
NASH PRODUCE C
NASHVILLE, NC
ny's Pride
potatoes/Yams
NUTRITIONALLY F
Play Boy
Brand
SWEET POTATOES/YAMS
Distributed by Wayne E. Bailey Produce Co.
Chadbourn, North Carolina 28431 910-654-5163
NET WT.
40 LBS. NET
JUMBO
SWEET POTATOES
DEER MARK
LOUISIANA
PORTO RICAN
SWEET POTATOES
U.S. No. 1
OPELOUSAS
SWEET POTATO CO.
General
LOUISIA
VICTO
NOYELLES
50 LBS. NET
BRAND
U.S. No. 1
DOVE
Louisiana
YAMS
Sweet Potatoes
SWEET POTATOES

5,000 copies of this public document were printed at a cost of $7,916.00 or $1.58 per copy.

PUBLISHED BY NORTH CAROLINA COOPERATIVE EXTENSION SERVICE.

Design by Marie Reese
Printed by Theo Davis Printing of Zebulon, N.C.

Research support provided by USDA CSREES Risk Avoidance and Mitigation Program under grant number 2003-51101-02106.

8/08—5M—VB

AG-413-10-B
E08-50291