Sweet Potato Storage.

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INTRODUCTION.

The sweet potato Impomoea batatas *is one of the basic food crops in the subsistence economy of the people of Papua and New Guinea, and is of predominant importance in the agriculture and diet of the Highlanders. The crop is readily propagated from cuttings or slips and under conditions of reasonable distribution of rainfall it has a growing season extending throughout most of the year. Thus, under the tropical conditions of the Territory of Papua and New Guinea the question of storage of tubers has not arisen as, with a regular planting programme, the supply of fresh tubers can be maintained. The sweet potato is essentially a plant of the tropics and sub-tropics and is very sensitive to low temperatures. Its growth is restricted by cool weather, the plant being damaged by temperatures below 50 degrees F. It will not withstand frosts for even short periods. It is a crop originating in the American tropics and its culture has spread into the southern and mid-western portions of the United States where it is being grown on a commercial scale. In the United States the sweet potato crop has to be harvested before it is damaged by frosts and consequently methods were developed for storing the tubers in order to extend their marketable life, to prevent gluts and to preserve planting material for the ensuing year.*

In Papua and New Guinea storage methods have not been used in the past, and there is very little knowledge of the storage requirements for tubers. It is considered, however, that sweet potato storage could be practised with benefit in those portions of the Highlands where food shortages occur when the crop is damaged by periodic frosts. These shortages are thought to have gained prominence in recent years mainly because, owing to population pressure, the area under cultivation was extended into frost affected regions, and secondly because the people are relying to a greater extent than before on the produce of the higher, frost-susceptible gardens. The sweet potato is also an important item of commerce as relatively large quantities are sold for consumption in towns and on plantations. The tubers are highly perishable, and some knowledge of the appropriate storage methods might help to reduce wastage and make possible the more economical utilization of supplies.

DIGGING THE CROP.

SWEET potato should be dug when it is fully grown. A slight yellowing of the foliage will indicate the right stage. Care must be taken when digging not to injure the tubers, which are easily cut and bruised. The tubers should never be thrown from one row to another, or into heaps or into bags. The best practice is to place them straight into baskets or boxes in which they will be stored, so that handling is reduced as much as possible. If much soil adheres to the tubers, they may be left exposed for an hour or two to allow them to dry before being placed in the containers, but in hot weather exposure might result in sunscald. Naturally, no damaged, diseased or rotting tubers should be placed in the containers intended for storage.

In California, in the San Joaquin Valley (Minges and Morris, 1953) field piles are sometimes used for temporary storage. The crop is

carefully stacked in piles about 2 ft. to 3 ft. wide, 4 ft. to 6 ft. long and 2½ ft. to 3½ ft. high, containing 250 to 500 lb. of tubers. The piles are covered with wrapping paper and then a 5 in. to 6 in. thick layer of sweet potato vines or straw is placed over the paper. But these field piles are only useful for protecting the tubers from sun and rain and must not be used for curing or storage.

CURING.

Before the sweet potato can be stored successfully, it must be cured. The tuber is covered by a periderm that is effective in retarding water loss and acts as a barrier against infection. At harvest this skin is unavoidably broken. Curing hastens the healing of wounds (cuts, breaks, bruises) made during digging and handling.

If a sweet potato is cut or bruised, a heavy, sticky, milky juice exudes from the injured cells. This juice dries in a few hours and may appear to have closed the wound, but in fact several days are required for the growth of new cells that would protect the interior from infection. The wounds will heal by suberization and the development of wound periderm. These new cells are similar to periderm in their ability to prevent infection. Because of its corky nature this layer is commonly called wound cork. The layer of cork is generally five to six cells thick, covered by a layer of four to five dead parenchyma cells. The mere presence of a dried and hardened surface over a wound is no indication that it has been healed by a layer of wound cork. The dry, hardened surface offers too little protection to prevent infection. Curing is not a drying process ; in fact drying should be kept to a minimum by maintaining the humidity as high as possible.

The object of the curing process is to encourage the rapid development of the wound cork and curing involves placing the tubers in a room having the appropriate temperature and humidity for this purpose. Therefore, sweet potato should be cured as soon as possible after being dug. It is sometimes recommended that, on harvesting, the tubers should be exposed to the sun and wind in order to dry them, but no healing occurs when cuts or bruises are exposed to drying winds. If healing is to take place, the tubers must be placed in storage at the right temperature and relative humidity within a few hours of digging.

When surface cuts have healed several layers of parenchyma always remain. Under conditions unfavourable to rapid periderm development the outer cells of the wound may dry to a considerable depth so that a thick layer of dead or partly dead parenchyma is formed. The thickness of this parenchyma is indicative of wound healing conditions. In general, under conditions favourable to wound healing, a cork layer five to six cells thick forms at a depth of some four to five cells beneath the wound surface. The new cork forms a continuous uniform layer. After satisfactory healing there is no change in thickness of dead surface parenchyma and usually little change in total periderm thickness. The wound surface is smooth and nearly white in colour. Wounds that heal poorly tend to be sunken and grey in colour. Broken ends are present on all tubers. These wounds differ from bruises because the wounded surface is relatively more exposed and severs vascular tissue and laticifers. In healing, both the sieve tubes and laticifers collapse or are pinched off and the periderm layer becomes continuous across the end surface.

The optimum conditions for wound healing and hence for curing are a temperature of 85 degrees to 89 degrees F. and a relative humidity of 92 per cent. Under these conditions the growth of wound cork begins in two days and is well developed in five to six days. At lower or higher temperatures or at a lower humidity it develops less rapidly. Even if the temperature is high enough, healing will not take place promptly if the air immediately surrounding the tubers is dry, e.g., of 66 per cent. relative humidity or less. The value of curing can be illustrated by data from Hawaii (Poole, 1955), where six weeks after harvesting the percentage of sound tubers from cured and uncured samples was 99.0 and 53.9 respectively (average results from tests of four different varieties).

The length of time required for proper curing cannot be stated as definitely as can the temperature and humidity requirements. The condition of the crop at harvest, the season of the year, the weather during the curing period, the temperature of curing, the efficiency of the operation, all determine how rapidly the curing process will proceed. In practice the curing period generally ranges from five to 20 days.

In general the following curing periods are suggested :—

Curing temperature degrees F.	No. of days.
85	4 to 7
80	8 to 10
75	15 to 20
70	25 to 30

Curing for too long results in excessive sprouting. Curing temperatures below 85 degrees F. are not recommended. Practical signs that the tubers are cured are :

1. Non-slipping of the skin ;
2. The appearance of purplish buds ; and
3. The dry, spongy appearance of the skin.

It is necessary to emphasize that the object of curing is not to remove moisture, as is commonly believed. Very little ventilation is necessary or even desirable in most sweet potato storage houses. Ventilation is only necessary to prevent the condensation of moisture and for temperature control. Maintaining a relative humidity of over 90 per cent. not only promotes healing, but greatly reduces shrinkage. The healing of wounds is but one of several important changes that take place in the sweet potato tuber during curing. The main loss in weight is due to evaporation of moisture, which may cause shrinkage, although tubers that have lost five to ten per cent. of their original weight during curing do not appear shrunken or shrivelled and will remain sound and firm.

The sweet potatoes must be left undisturbed after they are placed in the curing shed until they are removed for marketing or consumption. Handling will cause new wounds or breaks in the skin through which organisms can enter and thereby destroy the effect of curing. If the original cuts and bruises have been well healed during the curing period it is inadvisable to make new bruises by sorting or by shifting the tubers from one container to another. It is even inadvisable to take out rotten potatoes during storage, if this necessitates handling the whole lot.

In a warm climate, such as California, desirable curing temperatures can often be obtained without, or with only a little, artificial heat. The generation of heat by the tubers helps to raise the temperature and to maintain it during the curing period.

All sweet potato contains an enzyme, beta amylase, which when heated converts starch into the sugars maltose and dextrin. The temperatures of curing, 80 to 85 degrees F., are sufficient to convert much of the starch, but cooking is even more effective in converting the remaining starch.

Thus the main factors in curing are :—

1. Control of moisture (humidity) ;
2. Control of temperature ; and
3. Control of ventilation.

The main effects of curing are :

1. Extension of storage period of the tubers ;
2. Even firming of flesh and toughening of skin to prevent development of storage diseases ; and
3. Increase of the sugar content and improvement in the flavour.

STORAGE CONDITIONS FOR THE TUBERS.

After the sweet potato is cured, the temperature of the storage chamber should be reduced to 60 degrees F., but not lower than 50 degrees to 55 degrees F., as rapidly as possible, preferably in one week. Continued high temperature, after curing is completed, results in excessive sprouting. If exposed to temperatures below 50 degrees F., chilling could cause injury. Similarly, keeping and eating qualities are adversely affected by temperatures below 50 degrees F., following curing. For best results during the storage period the relative humidity of the air should be maintained at about 85 to 90 per cent. If it gets too damp, i.e., there is condensation of moisture, the ventilators or doors should be opened for a brief period. If the storage temperature is above 60 degrees F. it may lead to shortened storage life, sprouting and decay. The most important requirement of sweet potato storage is the ability to maintain the desirable conditions of temperature and relative humidity.

METHODS OF STORAGE.

In the United States special curing and storage houses are recommended and are necessary for the preservation of sweet potato. Such storage houses should be well insulated to conserve heat. The wall and ceiling materials should be of a type which is not damaged by moisture. They have no windows, only top and bottom ventilators. It is usual for the storage house to have an earthen floor which helps to maintain high humidity. A slatted floor is usually 1 ft. above ground level to permit free circulation of air. The source of artificial heat is also placed below the slats. Intake ventilators at floor level and exhaust fans in the ceiling are essential for temperature and humidity control. The size of the storage house will depend on the quantity handled—a 14 ft. x 12 ft. building has a 500-bushel capacity (55 lb./bush.). One cubic foot of storage space will hold about 25 lb. of tubers in containers.

A simple storage house with adobe walls has been described for use in Arizona (Crider and Albert, 1925). It has walls 10 inches thick and a gabled roof. There are ventilation holes at the top and bottom of the walls. The adobe construction is cheap, simple to build and has high insulating properties. Heat is provided by an oil stove. The sweet potato is stored on racks.

For the storage of small quantities of tubers the Tennessee Valley Authority has obtained good results by curing and storing in insulated cabinets, installed in unheated buildings. These cabinets have floor and roof ventilators, a raised slat floor, with a thermostatically controlled 220 watt electric heater under the slat floor.

In the extreme south of the United States, e.g., in southern Louisiana, natural heat only is used. The usual practice is to store the sweet potato in a warehouse-type building. Heat is only supplied if there is danger of the temperature in it dropping below 50 degrees F. If no artificial heat is employed it is desirable for the tubers to be warm when placed in the building, which should be of such size that it could be filled rapidly, as the sweet potato itself generates heat and the temperature of a full storage house will be higher than one which is half full.

As the average temperature inside these storage houses is generally less than 85 degrees F., the curing period will be longer, perhaps one month. The practice of curing with natural heat is practicable only where and when the average temperature at harvest time and for three to four weeks thereafter does not fall below 70 degrees F.

The recommendations of Poole (1955) for storage under conditions in Hawaii are :

1. The roots must be cured with as little handling as possible between the field and the curing shed. Shallow trays are best ;
2. A Quonset hut proved effective for curing the tubers, but was less suitable for storage ; and
3. Storage at natural room temperatures can only be done well between December and April (cool months) ; at other times artificially cooled rooms are necessary.

The above recommendations appear particularly applicable to conditions in Papua and New Guinea if large-scale storage is contemplated, e.g., at Port Moresby, where there is a large potential market for sweet potato requiring regular supplies throughout the year.

Whatever the size of the storage house an important requirement is cleanliness. All crop residues, soil, etc., must be removed. Before putting in the fresh crop of tubers the walls, partitions, ceiling, floors, racks, etc., should be thoroughly sprayed with a solution of 2 lb. of copper sulphate in 50 gallons of water, or with a solution of borax, 15 lb. in 50 gallons of water.

HOME STORAGE.

Good results have been obtained by merely wrapping sweet potato in newspaper and storing them in a cabinet in a building where the temperature is above 55 degrees F. Another storage method is in sawdust. The tubers should be held at a temperature of 75 degrees to 85 degrees F. for approximately two weeks, then stored in a cool place where the temperature does not drop below 55 degrees F. If sawdust is used, care must be taken to ensure that it is very dry ; otherwise root growth or rots might develop.

In a closed room or small shed with sunshine entering each day, the temperature may reach 80 degrees F. without extra heat. Conditions similar to commercial curing can be created by

covering the boxes or baskets of tubers (preferably on an earthen floor) with sacks or a tarpaulin to keep the air moist around them. But it may be necessary at times to remove the covering if there is condensation of moisture.

PIT STORAGE.

Pit storage is only recommended when there is no opportunity for a better method. Storage pits should be located where the drainage is good. They may have board sides lined with straw, a tight fitting wooden cover, and a roof to keep off rain. Such a pit has the same temperature as the soil. Perhaps more suitable is a pile or hill. In this, the level of the bed should be several inches above ground level. Two small trenches should be dug across the bed at right angles to each other to provide for ventilation at the base—perforated boards are placed over the trenches. At the point where the trenches cross, a small box, made of boards eight inches wide and with open ends, should be placed to form a flue upwards through the pile of sweet potato. Holes should be bored in the boards forming the flue to increase ventilation. The earthen floor should be covered with four to five inches of straw, hay or leaves. The sweet potato tubers are then placed in a conical pile around the flue. An eight-inch layer of straw or hay or similar material is placed over the tubers and then a layer of soil about six inches in depth. A wooden frame 12 in. x 18 in. containing a trap door can be placed on the straw. This will make it easier to examine the tubers and to remove them from the pile. The end of the trenches and of the flue should be screened to prevent entry by rats and mice. It is also advisable to protect the pile from the weather, particularly from rain, by erecting a roof over it. It is better to make several small pits, or piles rather than a single large one, because the entire contents should be removed when the pit is opened.

The New Zealand Maoris are known to have used storage of sweet potato. Two types were described by Best (1925).

1. *Semi-Subterranean* : Rectangular excavations, often in sloping ground or on the brinks of terraces, with a timber roof. The roof was covered with earth. Tubers were placed on dunnage of dried manukau (*Leptospermum* spp.) or fern brush. The whole structure could be sealed.

2. *Subterranean* : Well-like pits dug into the ground (*Figure* 1) which, after filling were sealed. There seems to have been considerable variation of storage technique from district to district, and this is generally ascribed to variances in soil and rainfall conditions.

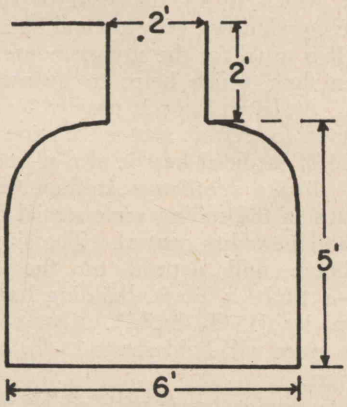

Figure 1.

The disadvantages of pit storage are :

1. Heavy loss due to decay ;
2. Inferior quality due to lack of proper curing ;
3. Limited keeping quality once removed from the pit ; and
4. Danger of rat damage in the pits.

In experiments in Barbados in 1937 (McIntosh, 1942) it was found that after a $3\frac{1}{2}$ months' storage period a total of 30 per cent. loss in weight occurred. This consisted of 18 per cent. due chiefly to loss of moisture and 12 per cent. due to actual rot. American data (Miller, 1922) give losses in pits or banks as high as 40 per cent.

It is considered that under Highland conditions, the usual kunai houses would be suitable for the storage of sweet potato to overcome shortages expected as a result of frosts. The tubers would have to be placed on racks or boxes to ensure aeration while smoke fires would ensure adequate temperature during the curing period.

CHILLING INJURY IN STORAGE.

The symptoms produced by chilling are surface pitting, increased susceptibility to decay, loss of table quality and loss of sprouting ability.

The damage to sweet potato tubers by frost or chilling has been summarized by Lutz (1945) :

Injury to freshly harvested non-cured Porto Rico sweet potato was evident after they had been held two days at 32 degrees F., four days at 40 degrees F. or 10 to 21 days at 50 degrees F. Slightly longer exposures at 32 degrees F. and 40 degrees F. were necessary to produce injury in cured sweet potato—the latter was not impaired in quality by exposure at 50 degrees F. for up to 30 days.

Decay during storage was increased in non-cured sweet potato by holding them for four to ten days at 32 degrees F. to 50 degrees F. Somewhat longer exposures were necessary to increase the decay of cured sweet potato held at 32 degrees F. and 40 degrees F. Holding cured sweet potato at 50 degrees F. did not effect decay.

A delay of 30 days or longer between harvesting the tubers and subjecting them to low temperatures prevented much of the loss from decay and injury which otherwise occurred in non-cured sweet potato.

Non-cured sweet potato stored for four to four-and-a-half months at a constant temperature of 50 degrees F. suffered practically 100 per cent. loss from decay. The loss was less in storage at 55 degrees F. and still less at 60 degrees F. Although cured sweet potato held at constant temperatures of 50 degrees F. and higher did not develop significantly more decay than comparable ones held in the storage house, culinary quality was adversely affected when held at 50 degrees F.

SUMMARY OF THE ESSENTIAL FEATURES OF GOOD STORAGE.

Sweet potato must be :

1. Well matured before digging.

2. Carefully handled to prevent bruising.

3. Well cured immediately after being put in storage—

   (i) at a constant temperature of 80 degrees F. to 89 degrees F. ; and

   (ii) at a relative humidity of 85 to 92 per cent. to promote healing and reduce shrinkage.

4. Following curing stored at a controlled temperature and humidity around 55 degrees F.—

   (i) if the temperature drops below 50 degrees F, artificial heat must be employed ; if it reaches 60 degrees F., the store must be cooled ; and

   (ii) the relative humidity in the store must be maintained at 85 per cent. to 90 per cent. If the walls, ceiling or sweet potato become wet, it may be necessary to open the ventilators to remove the excessively moist air. If the relative humidity falls below 85 per cent., water should be sprinkled on the floors.

(Received January, 1965.)

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