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TROPICAL SWEET POTATO STORAGE: A LITERATURE REVIEW

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SUMMARY

1. Sweet potato is grown in many countries and is a staple crop in some. The roots are highly perishable and storage is avoided in the tropics if possible. Storage methods for temperate countries have been developed but storage under tropical conditions has received less attention.

2. Losses during storage may be physical, physiological or pathological, or may be caused by pests. For optimum storage the roots should be cured at 27 - 33°C and 85 - 95% relative humidity for 4 - 10 days then stored at 12 - 16°C and 85 - 90% relative humidity. Ventilation is needed during curing and storage. Maximum storage periods of five months to one year are reported under optimum conditions, depending on the cultivar.

3. Tropical storage methods reviewed include pit storage, clamp or mound storage and huts and buildings (indoor) storage. In all cases losses were usually high during storage and are reported as mainly physiological, resulting from high temperatures and low relative humidity, though pathological losses, i.e. rotting, were also significant in some cases. There are a number of examples of each method however which hold potential for further development into appropriate storage methods for tropical countries. Experimentation with all three methods is recommended for a given location as the effects of climate and sweet potato variety, and lack of information on the conditions during storage by the three methods, make choice of a single best method difficult.

INTRODUCTION

4. Sweet potato (*Ipomoea batatas* (L.) Lam.) is grown practically throughout the tropical world and in many temperate zones. Its starchy roots serve as a staple crop in a number of countries. The major producing areas are South-East Asia, Brazil, Central and East Africa and China (Proctor *et al.*, 1981).

5. Sweet potato roots are harvested three to eight months after sowing. Storage of the roots is avoided in the tropics if possible because of their high perishability; this is a major barrier to the wider utilisation of the crop in the tropics (Kay, 1987). One way of avoiding storage is to grow and harvest sweet potatoes all year round. This is possible in some tropical climates (Booth, 1974). Such continuous harvesting is not always possible however, and even in regions where it is, it becomes less attractive economically as cash cropping replaces subsistence farming (Booth, 1974). Allied to year-round production is in-ground storage, in which the roots are left in the ground for up to four months after maturity and removed as necessary. This method is limited by the risk of losses caused by pests, diseases, germination and cracking of the roots. It also incurs what may be significant opportunity costs by using fields for storage rather than for growing a new crop (Tardif-Douglin, 1991).

6. In temperate, developed regions, continuous harvesting is not possible and sweet potatoes have to be stored if they are required outside the growing season (Proctor *et al.*, 1981). The storage behaviour of sweet potatoes under temperate conditions has been studied extensively. Sophisticated storage methods have been developed which rely on the control of temperature and relative humidity (r.h.) to achieve the optimum conditions for storage. Much less work has been done on the behaviour of sweet potatoes under tropical conditions however. This paper is a review of tropical storage methods that have been described in the literature, preceded by a description of the optimum conditions for storage and of the types of losses and changes that occur during storage.

POST-HARVEST LOSSES AND CHANGES, AND PHYSICAL PARAMETERS

7. Sweet potatoes have a high moisture content and a relatively thin and delicate skin. They remain metabolically active after harvest, are highly perishable and easily damaged. As a fresh commodity they are therefore difficult to store. Overall losses from farmer to consumer even using controlled storage conditions can be as high as 35%, comprising storage and wholesale (19%), retailing (4%) and household (12%) (Woolfe, 1992). In developing countries losses are certain to be higher as ambient conditions are more extreme and handling less developed.

Losses

8. These may be **physical**, **physiological** or **pathological** (Woolfe, 1992, Booth, 1974).

9. **Physical losses** result from mechanical damage, i.e. cuts, grazes and skinning injuries, which usually occur during harvest but also during subsequent handling

operations. Their importance is frequently overlooked, as the extent of physiological and pathological losses (see below), to which damaged roots are pre-disposed, is hard to quantify (Booth, 1974). Wounds resulting from physical damage may be healed by curing (see below) to prevent excessive moisture losses and entry of micro-organisms, and handling may be improved, e.g. by using cartons or boxes for transport rather than sacks (Booth, 1974).

10. **Physiological losses** include transpiratory (wilting or evaporatory) loss of water, and respiratory loss of dry matter, both of which increase with increasing temperatures. Pithiness, due to an increase in intercellular spaces, may result. High temperatures also encourage sprouting, which increases moisture and respiratory losses.

11. Sprouting has been controlled using chemical sprout suppressants, e.g. maleic hydrazide applied before harvest, or methyl ester of naphthalene acetic acid (MENA) applied in acetone on paper interleaved during storage (Bouwkamp, 1985). Booth (1974) lists managerial and economic factors and lack of suitable storage facilities as limiting the attractiveness of chemical sprout suppressants in the tropics.

12. Temperatures below 10°C may cause chilling injury. Symptoms are internal breakdown, off flavours and greatly increased rotting, caused by the reduced rate of periderm formation (see Curing below) allowing fungal infection into the unprotected flesh (Morris, 1981). Chilling can also resulting in hard-core, a disorder which causes areas of the root to remain hard after cooking.

13. **Pathological losses** caused by fungi, bacteria and viruses are a major cause of losses. These are both quantitative, e.g. tissue breakdown, and qualitative, e.g. surface blemishes. Toxins or bitter flavours may also be produced in roots infected by certain fungi, and viruses may cause internal blemishes. Jenkins (1982) lists *Rhizopus oryzae* (soft rot) and *Botryodiplodia theobromae* (Java black rot) as responsible for 78% of infections in Bangladesh, though species vary with regions. Control should be through prevention (Kay, 1987), as chemical control methods are expensive, not readily available and often incompatible with normal handling operations in the tropics (Booth, 1974). Physiological changes and physical damage can lead to higher susceptibility to pathogenic attack.

14. Pests losses also occur. Sweet potato weevils, *Cylas* spp., are the most important insect pests in this respect. Infestation may begin in the field and continue in storage. Both quantitative and qualitative losses are caused, e.g. weight loss, discolouration and bitter tastes. Weevil mortality may be high (89.5%) if storage temperatures can be reduced to 20°C, and hot water dips before storage may also control infestations (Bouwkamp, 1985). Rodents may also cause significant losses during storage: control must be by exclusion.

Biochemical changes

15. During storage starch is lost through metabolism while levels of sugars (e.g. sucrose, fructose and glucose) increase. The relative concentration of protein

increases during storage, as does carotene. Dry matter, pectins and vitamin C decrease during storage (Bouwkamp, 1985).

Physical parameters

16. Roots vary greatly in size, shape and characteristics. They range from a few centimetres to 0.3m in length and may weigh from 100g to 1 kg, with some of 5 kg being reported (Kay, 1987). The bulk density of roots is around 500 kg/m^3.

OPTIMUM STORAGE CONDITIONS

Curing

17. Sweet potatoes are highly susceptible to physical damage when harvested. Curing the roots before storage helps to prevent the entry of pathogens into wounds and reduces moisture loss during storage. It is achieved by exposing the roots to a high temperature and relative humidity for a period immediately after harvest. These conditions encourage the formation of wound periderm at the site of the damage which forms a barrier to pathogen entry and moisture loss.

18. The optimum conditions for curing are widely published (e.g. Kay, 1985, Iconwueme, 1978, Morris, 1981, Kushman, 1975, Picha, 1987). The temperature should be in the range 27 - 33°C and the relative humidity (r.h.) in the range 85 - 95%. These conditions should be held for 4-10 days. It is important to ventilate during curing to prevent the build-up of carbon dioxide and reduction of oxygen around the respiring roots. Sound roots convert 57 dm^3 of oxygen/ton/day to carbon dioxide and require ventilation at 4-5 times this rate (Wagner *et. al.*, 1983). After curing, the temperature must be reduced rapidly to avoid sprouting, and handling must be avoided to prevent further damage. In tropical areas conditions close to the optimum for curing, particularly temperatures, may exist naturally or be easily achievable, e.g. by covering roots to raise the r.h.

Storage

19. The optimum conditions for storage are again widely published (e.g. COPR, 1978; Hardenburg *et al.* 1986; Jenkins, 1982; Wagner *et al.*, 1983; Picha, 1986; Kay, 1987). Temperature should be in the range 12-16°C, r.h. in the range 85-90%. Ventilation should be provided at a rate of 0.5 air changes per hour (Silva, 1990, Wagner *et. al.*, 1983) to avoid oxygen concentration falling below 7% or carbon dioxide concentration rising above 10%, which can cause loss of flavour (Iconwueme, 1978). Maximum storage periods of five months (Hardenburg *et al.*,1986) to one year (Picha, 1986, Bouwkamp, 1985) are claimed under ideal conditions, depending on the sweet potato cultivar. It is not clear to what extent the conditions required for curing and storage are dependent on the cultivar being stored: the conditions quoted above are likely to have been determined for US cultivars grown under US conditions, not for tropical cultivars.

20. Between 0 and 10°C chilling injury occurs, resulting in off flavours, tissue breakdown and increased rotting. Above 16°C respiration increases, and dehydration,

sprouting, pithiness and cavities can occur. At relative humidities above 90% condensation can form on or near the roots which may lead to rotting. Weight losses of approximately 2% per month may be expected during storage (Hardenburg *et al.*, 1986) under ideal conditions. Unlike curing, the relatively low temperatures necessary for optimum storage are not common in the tropics; this is the main barrier to successful storage in such regions.

TROPICAL STORAGE METHODS

21. In-ground storage was mentioned in the introduction as a tropical storage method. There are a number of other traditional and experimental storage methods described in the literature. Table 1, adapted from Proctor *et al.* (1981) summarises these methods on a country-by-country basis. There are three main methods described: pit, clamp (or mound) and indoor storage (e.g. huts, buildings or other stores.) These three methods are described in detail below.

Pits storage

22. Storage underground has been practised in many countries, with varying success.

23. Bouwkamp (1985), Keleny (1965) and Cooley (1951) all describe traditional pit storage by Maoris in New Zealand. Pits are of two sorts:

a. dug into sloping ground or on the brinks of terraces, lined with plant material (or gravel then rotten wood) and roofed with timber and earth. Seed potatoes are put at the rear, followed by the best eating potatoes then the poorest eating potatoes at the front. The structure is tightly sealed.

b. well like, dug into the ground and sealed.

24. Ventilation is limited and losses are reported to be high, with causes described as decay, "inferior quality" due to lack of curing, limited keeping quality once removed from the pit and possible rodent damage.

25. In Barbados, sweet potatoes have been stored for up to four months in pits though one to two months is more usual because of spoilage, presumably rotting, and sprouting (Bouwkamp, 1985).

26. Gooding and Campbell (1964) compared various storage methods in Trinidad. They used a bamboo lined pit holding 20 lbs (9.1 kg) of local smallholders' roots, dimensions 2 x 2 x 2 feet, shaded by a thatched roof. The pit was opened for ventilation for 1 hour each week. In comparison to the other methods tested (see below), the pit incurring the least weight losses, 22.1% after 8 weeks, and the highest sprouting, 81.2% of roots. In a separate trial weight losses and sprouting were slightly reduced when the pit was permanently closed, i.e. it was not opened for ventilation.

27. Keleny (1965) suggests various methods for storage in Papua New Guinea, including pit storage, though this is recommended only where there is no opportunity for a better method. The pits may be lined with boards and straw and have a tight fitting cover and roof. The pit will have the same temperature as the soil. Woolfe (1992) mentions grass-lined pits with roots alternated with grass layers in Papua New Guinea, and leaf lined holes with roots sprinkled with wood ash and covered with dried leaves or grass in Cameroon.

28. Pit storage is described in Nyasaland (Malawi), where pits were dusted with lime and roots layered between wood ash (Anon. 1949). Woolfe (1992) also reports pit storage in Malawi and Zimbabwe by this method. The pits in Malawi are dug underneath maize or groundnut silos and storage lasts for 3-4 months, beyond which losses are heavy. Experimental work on pits containing 5 kg of roots showed that sun curing before storage in the pits was detrimental to storability, and ash application had no significant effect. The closing of the pit with grass and soil had the effect of raising the r.h., and the protection provided by silos or thatched roofs modified external high temperatures as well as preventing contact with rain.

29. In Nigeria, pit storage is one method recommended for sweet potato storage (Chinaka, 1983). The pit should be 0.5 x 0.5 x 0.5 m and lined with dry grass, coconut shell or sticks. The roots are cured, treated with ash and piled to within 0.15m of the top of the pit which is then covered lightly with dry grass and soil and finally with a mat or zinc sheet to keep rain off.

30. Mukhopadhyay *et al.* (1991) report pit storage in India, where the roots are placed between layers of wood ash, earth and straw. Experiments comparing different storage media showed local earth to be the most practical material, giving nearly 50% losses after 30 days and 58% losses after 90 days, though the exact nature of the storage method was not clear.

31. In the Philippines, Bouwkamp (1985) reports storage in a trench 0.5 m deep covered in sand and sheltered by a roof. 30% of roots decayed and 45% sprouted after an unspecified period.

32. Woolfe (1992) describes Chinese pit store at some length. In this case, and in the regions covered, ambient temperatures during some periods of the year are likely to be low, as they are in Korea (Hong, 1982), so the function of the store would be to keep the roots warm rather than cool. The principles outlined however are worth noting.

33. The site for a pit should be free from wind and on high terrain with compact soil and good drainage. The water table should be at least 0.35 m below the pit bottom during the storage season and should never rise to the pit bottom during the rest of the year to avoid damage. Old pits should be cleaned to expose new soil and disinfected with burning wood, straw or sulphur. The pit should contain $1 m^3$ of space for every 500-600 kg of roots, allowing 30-50% space to maintain aerobic conditions. There are four types of pit: well, cave, canopy and ditch. Wells may be very deep, 5-6.6 metres, with several rooms leading off the main well tube. The well mouth should be 0.3m above the ground to exclude rain. Losses are claimed to be 2-3% in some

cases (though the period of storage is not specified), with conditions held at 15°C and 80% r.h. Caves are dug into hill slopes and again can be large. The ground and walls are lined with straw and roots are piled up inside then covered with more straw, leaving a 0.33m space at the top. The door is sealed and a bamboo tube inserted through the door and into the pile of roots for ventilation. Canopy pits are more simple, being a rectangular or cylindrical pit of approximately 2m depth lined with soft grass for insulation. Roots are piled inside and covered with more grass and possibly bran and bean leaves if temperatures are low. The entrance is covered with sticks and straw to 0.3 m followed by earth to 0.5-0.7m. A small entrance is left at the south-east corner which is stopped with straw. Criss-cross channels may be cut into the floor and covered by sticks then connected to the surface by wells for ventilation. A ditch cellar is again simple, being a ditch approximately 1.3m deep and as long as necessary, lined with straw, filled with roots and topped with straw. 0.17 m thick layers of earth and straw are placed over the entrance for thermal insulation and criss-cross channels and wells are used as before for ventilation. Access for inspection is not possible.

Summary of pit storage

34. In many countries losses during pit storage have been found to be high and the method has little to recommend it. However, there are a number of cases reported where storage has been possible for two to four months before losses become excessive, these being in Trinidad (Gooding and Campbell, 1964), Barbados (Bouwkamp, 1985) and Malawi (Woolfe, 1992), the latter providing most details. These examples suggest that the method has potential for development as a storage technique employing technology of an appropriate level.

35. Features that most pits have in common are a lining of dry plant material such as straw, leaves or grass and a covering for the stored roots of the same material. The roots are also often layered with wood ash or dry plant material. The function of these materials is not clear: plant material may act as dunnage, i.e. to hold the roots away from the earth walls and floor, as insulation to reduce temperature changes, or may modify the storage atmosphere by allowing the plant material to decay. Ash may have some effect on insect pests, moulds or the storage atmosphere, or may function only as a packing material, though the work reported by Woolfe (1992) in Malawi suggests that ash has no significant effect during storage. Lime added to the pit may have the effect of absorbing carbon dioxide, though whether to a significant extent is questionable.

36. In some cases pits are tightly sealed. In view of the necessary storage conditions, ventilation, such as that used in China, would appear to be more beneficial, allowing hot air and carbon dioxide to escape and oxygen to enter. However, in the work reported by Woolfe (1992) in Malawi it was found that closing pits with grass and soil raised the r.h., which is beneficial to storage. Careful design of ventilation therefore seems necessary.

37. Many structures are provided with a cover and/or a roof. This stops rain from entering the pit (and causing decay) and may also provide shade to keep the pit cool. Both these points were considered important in Malawi (Woolfe, 1992). It is

obviously important to site the pit where the water table will not rise above the pit bottom. Prevention of rodent damage must be considered in pit design.

Clamps

38. Clamps are simple, low cost structures, used for storage in the field or elsewhere outdoors. Before describing the use of clamps for sweet potato storage, reference may be made to clamps used for Irish potatoes, for which more detailed information is available.

Potato clamps

39. Booth and Shaw (1981) describe clamps used in the storage of Irish potatoes. The potatoes are piled into heaps and covered with alternate layers of straw and soil. Clamp sizes and shapes are adapted to local conditions. The pile is 1-3 m wide, as high as the angle of repose will allow (1/3 to 1/2 of the base width) and as long as necessary. It is built on a bed of straw and covered with a 0.15 - 0.20 m thick thatch-like layer of straw when built. A 0.15-0.3 m thick layer of soil can then be added, not heavily compacted. A second layer of straw then soil may be used.

40. In hotter areas a potato clamp should be less than 1.5 m wide and may have a base ventilation duct under the pile and chimney type ventilators along the length. No soil may be used to cover the clamp, just extra straw and/or corn stalks used for shade (the purpose of the soil covering being to insulate against low temperatures.) Rain penetration has to be avoided. A drainage ditch should be dug around the clamp to remove water.

Tropical sweet potato clamps

41. In Trinidad (Kennard, 1944), clamps were made by digging a trench 6 inches deep and 4 feet wide and covered it with cane 'trash'. Roots were piled to 2.5 feet high then covered in more trash and soil to 3 inches. Storage was for 1-3 months and the loss in weight of marketable roots estimated. Losses were 30% during one year (18% decay, 12% shrinkage) and 24.2% during the next (11.2% decay, 12.4% shrinkage, 0.625% sprouting). Gooding and Campbell (1964) used a clamp in their experiments in Trinidad, shaded by a thatched roof, lined with dry grass and covered in grass and soil. Mean weight loss was 26.4% after 8 weeks, with 77.06% sprouting. Opening the clamps for one hour per week for ventilation increased weight loss and sprouting.

42. In Barbados (Anon, 1960, Bouwkamp, 1985) clamps were made by digging a 3 ft deep trench, width 3 ft, in well drained soil and lining with dried grass or other vegetation. Insect and disease free roots were piled to 3 ft deep, then covered in dried vegetation, followed by soil to at least 1 foot and then more vegetation. Storage up to 4 months, losing 20% weight but retaining palatability, was possible.

43. Aldous (1976) conducted trials for various types of mould or clamp in Papua New Guinea. These were made by placing alternating layers of sticks on the ground then covering with semi-dry grass. A cone approximately 1.3 m in diameter and 1.6 m

high was formed over the base using sticks. The structure was filled with sweet potatoes then the sticks were covered in 0.1 m of grass. In some cases a trench was dug under the mound and a hurricane lantern placed in it to provide curing heat for 10 to 20 days. Some mounds were shaded by a thatched roof. 40 - 50 days was the limit of successful storage (weight loss 25.3% after 42 days, 15.2% after 49 days at different sites). The benefit or otherwise of a roof and curing with the lantern was not obvious. Larger roots (0.5-1 kg) stored more successfully. It is recommended that the grass cover should be thicker, the apex be open to allow ventilation and the mould be built in shade.

44. Keleny (1965) also describes mounds used in Papua New Guinea. A bed is made several inches higher than ground level and two trenches dug across it at right angles for ventilation. These are covered with perforated boards. A flue made of eight inch wide perforated boards formed into an open ended box is placed upright where the trenches cross. Plant material four-five inches deep is placed on the soil base then the roots placed in a pile around the flue. This is covered in eight inches of plant material and six inches of soil. Ventilation ducts are screened from rodents and a roof is erected over the mound. No assessment is given of the performance of the system. Several small pits are recommended rather than one large one, so that each could be completely emptied when needed.

45. Woolfe (1992) reports clamp storage in India in which the roots are heaped up, covered by a thin layer rice straw and plastered with soil/cow dung mixture which is pierced with ventilation holes. Farmers claim a storage life of 6 months, though simulated storage conditions gave 70% and 50% losses after 2 months.

Summary of clamp storage

46. As with pits, there are many examples of clamps incurring high losses but also promising instances where storage was possible for two to three months or more. The methods reported from Trinidad (Gooding and Campbell, 1964 and Kennard, 1944) and Barbados (Anon., 1960 and Bouwkamp, 1985) are the most successful methods described, and suggest that the method has potential for development. The important point is made by Bouwkamp (1985) that insect and disease free roots only should be put into store. The technology is again of an appropriate level.

47. Common to all clamps is the lining of the ground and covering of the root heap with dry vegetation. The clamp can either be built in a deep trench, approaching a pit store, as in Barbados (Anon., 1960 and Bouwkamp, 1985), in a shallow trench or at ground level. In many cases the heap of roots, covered in vegetation, is also covered in a layer of soil but this is not necessarily the case and is not recommended by Booth and Shaw (1981) for Irish potato clamps. Shading the clamp with a roof (or by building under shade) did not give a demonstrable benefit in Aldous's (1976) experiments but would seem to make sense.

48. Ventilation is suggested for Irish potato clamps but is not mentioned in most of the sweet potato work, other than by Keleny (1965) who describes an elaborate ventilation system, and Gooding and Campbell (1964) who opened clamps for one hour per week for ventilation but incurred greater weight losses and sprouting. Curing

would appear to be impossible as a separate operation in clamp storage as the roots have to be subsequently piled into the clamp, thus causing more wounds. It may also be unnecessary as the conditions in tropical clamps may be close to those needed for curing.

Huts, buildings and other structures (Indoor storage)

49. A variety of different structures are used for sweet potato storage, most often huts or buildings primarily used for living or storing other commodities, but including drums, baskets etc. used only for sweet potatoes.

50. Kennard's (1944) storage trials in Trinidad included storage in bags and in uncovered heaps in an undescribed store room. The sacks were found to be best, with losses of 16.7 - 19%, mostly physiological. Comparison of storage losses of different varieties of sweet potato in sacks showed some varieties to be outstanding, others completely unsuitable for storage. This latter fact demonstrates the profound effect of sweet potato variety on storage performance.

51. Gooding and Campbell (1964) included storage in cardboard cartons on the soil surface and 1 ft high racks covered with grass, both shaded by thatched roofs, in their experiments in Trinidad. Both treatments used 20 lb of local smallholders' roots and lasted 8 weeks. The carton gave weight losses of 29.24%, the rack 34.9%, with sprouting 55.29% and 49.4% respectively. The losses were worse than the pit and clamp tested in the trials (see above), though sprouting was less.

52. Blyth (1943) and Anon.(1949) report storage methods in Rhodesia (Zimbabwe) and Nyasaland (Malawi). In Rhodesia, 50lb of roots were placed in a drum with alternate layers of fresh wood ash and stored for 4 months. After this period only two or three roots were claimed to have decomposed. Whether the drum was in or out of doors was not mentioned. In Nyasaland roots were mixed with fresh wood ash and stored in drums or wicker structures (nkhokwes) indoors, reportedly for over 5 months without deterioration. No attempt appears to have been made in either case to measure weight loss.

53. Tidbury (1945) tried the drum and ash method of Blyth (1943) in Zanzibar. Freshly dug roots were placed in large wooden boxes between layers of coconut husk ash. After one month all the roots were reported to be rotten and mouldy. The humid climate of Zanzibar was blamed for the failure of the trials.

54. George and Kamara (1988) tested seven sweet potato clones in Sierra Leone under traditional storage conditions, these being storage in baskets or on earth floors in well ventilated buildings. Roots were cured for 4 days then stored in 4 kg lots. Weight loss was measured and inspections made periodically. Mean weight losses were 12.5-15.4% in baskets, 13.6-28.4% on the floor after an unspecified period. Graphical results show the mean weight losses to be approximately 33% and 28% on the floor and in baskets respectively after 20 days. Each clone showed different patterns of loss. Rotting varied dramatically between clones (3.7-50.1%) but was similar between floor and basket. It was concluded that traditional storage results in high losses, mainly due to physiological losses and microbial rots.

55. Jenkins (1982) describes trials undertaken to investigate traditional storage methods in Bangladesh. In the traditional method roots are placed in shallow piles on earthen floors of farmers' houses, which are made of split bamboo with bamboo or thatched roofs. Roots may also be piled uncovered on a bamboo bench or individual roots may be suspended from the roof. Temperatures in the huts are 24-35°C, 70-90% r.h. or higher, storage is for 2-4 months. Losses, 20-25%, are blamed on high respiration causing physiological loss. The following trials were conducted to compare possible improvements to traditional stores:

a. storage in bamboo baskets, half of which were wrapped in plastic sheet for 7 days to promote high r.h. for curing;

b. treatment with and without a fungicide (thiabendazole);

c. combinations of high r.h. storage (90-95% r.h. using plastic bags) and a sprout suppressant (1% solution of maleic hydrazide applied as a dip.)

56. In all cases the baskets were stored off the ground in a bamboo hut, with temperatures ranging from 20-35°C, though mostly in the range 24-35°C, and 70-95% r.h. In trial a. no significant differences between cured and un-cured roots emerged after 5 weeks. Mean weight loss was 19.3%, while 75.7% and 78.1% of roots had sprouted in the covered and uncovered baskets respectively, but 90% of roots were basically sound. Physiological losses were blamed for the loss in weight. In trial b. there were again no significant differences between treatments after 5 weeks. Mean weight loss was 22.1%, with 14.8% and 10.1% of roots affected by fungal rots and 50% and 59.1% of roots sprouting in the treated and untreated lots respectively. The fungicide used was not effective against *Rhizopus oryzae*, the species involved in the decay. In trial c. weight loss was reduced from approximately 21% to 11% over 8 weeks by the application of constantly high r.h. using plastic bags. The sprout suppressant reduced sprouting significantly but had no effect on weight loss.

57. Jenkins (1982) concluded that losses were mainly physiological, the temperatures during storage inducing near maximum rates of respiration, and the r.h. being low sufficiently often to allow rapid evaporation. Losses of 30-35% over 3-4 months are predicted for ambient storage in Bangladesh. Maintaining high r.h. was shown to be very effective in reducing losses. A number of simple measures are recommended for improving quality:

a. Careful handling at all times;

b. removal of soil from roots prior to storage;

c. quality control followed by separate storage of damaged roots and their rapid utilisation;

d. utilisation of small roots first;

e. covering storage layers or piles of roots with suitable materials to build up and maintain high humidity.

58. Keleny (1965) describes methods of home storage in Papua New Guinea. In one method the roots are wrapped in newspaper and put in a cabinet in a building above 13°C. Another method uses dry sawdust in a cool place, again above 13°C, after curing for two weeks at 24-29.5°C. Curing conditions can be achieved in a closed room or shed simply by covering boxes or baskets of roots with sacks or tarpaulins to keep the air moist. Aldous (1976) also looked at storage in Papua New Guinea. A small bush house was fitted with shelves inside and a fire was kept burning inside. Wet copra bags were hung from the rafters to raise the r.h. The method was found to be poor, allowing storage for 2-3 weeks only. Chinaka (1983) in Nigeria suggests storage in the house either in a sawdust heap in a corner, placing cured and ash treated roots on 0.1m of sawdust and covering with another 0.05m, or on racks for a short time.

59. Woolfe (1992) mentions indoor storage in a number of countries, including Vietnam (floor or hung from the ceiling for 1-3 months), Papua New Guinea (shelves in dark well ventilated area over fire smoke) and Cameroon (sun curing then storage in baskets covered with banana leaves or grass or in a dry place.) In the Philippines rice stores are often adapted for sweet potato storage after the rice has been almost used up, and slatted bamboo huts giving diffused light reduced sprouting by 99%. Store houses are used in China and in Korea (Hong, 1982) but these are in cool areas where heating is necessary. In Indonesia roots were stored in sand, soil, ash, rice husks and gunny bags but no advantage was found over open baskets: weight loss was in general more than 25%.

Summary of indoor storage methods

60. There is conflicting advice in the literature regarding the success of storage in structures of various kinds, which may be partly due to the tendency to describe the basket or drum etc. used to hold the roots but not the environment in which they are stored. An example of this is the drum/basket and ash storage method reported from Malawi, Rhodesia and Zanzibar (Anon., 1949, Blyth, 1943, Tidbury, 1945 respectively), cited as successful in the first two cases and a complete failure in the latter. Whether the roots were indoors or not is not clear in all the cases, and the function of the ash is not described or investigated. Kennard's (1944) tests in Trinidad demonstrated the effect of sweet potato variety on storage performance. This latter fact must be borne in mind when comparing different storage methods.

61. The simplest storage methods are storage on the floor of a hut or house in a pile or in a sack or basket. In several experiments these were found to be the best storage methods, despite high losses. There is a general consensus that losses are mainly physiological, i.e. evaporation and respiration but also pathological, i.e. rotting. Where conditions have been measured, temperatures were generally far higher than the 13-16°C optimum storage range, and the r.h. varied between 70-95%. Jenkins (1982) showed that even under these conditions losses could be substantially reduced by raising the r.h. around the roots using a cover or bag, and also that curing was not justified under such conditions. The methods developed by Jenkins (1982) appear not only to show the best performance, 11% losses after 8 weeks, but are also simple and offer the most scope for continued development. The plasic bags used may not

however be regarded as appropriate to some tropical situations, so an investigation of alternative materials would be necessary before the method was recommended.

62. A few instances of adapting existing stores for sweet potato storage are mentioned though without any real indication of performance. The requirement, as for all structures, is to keep the roots as cool and humid as possible.

63. In conclusion, is appears that simple is best, i.e. putting roots into bags, baskets or heaps (though the avoidance of further damage afforded by bags or especially baskets may be preferred) inside a hut or house. Attention should be focused on keeping the atmosphere cool and humid, the latter by using a cover as suggested by Jenkins (1982).

CONCLUSIONS

64. Sweet potatoes are highly perishable and are difficult to store in tropical conditions. Storage is avoided if possible by continuous and piecemeal harvesting. This risks losses during storage and becomes increasingly less economically viable as production changes from subsistence to market orientation.

65. The optimum conditions for sweet potato storage are a period of curing for 4-10 days at 27-33°C and 85-95% relative humidity followed by storage at 12-16°C and 85-90% relative humidity. Under these conditions storage for five months to one year may be possible, depending on the variety. Ventilation is needed during both curing and storage.

66. The behaviour of sweet potatoes under temperate storage conditions has been studied extensively, but there is relatively little information available on storage under tropical conditions.

67. Pit, storage, clamp or mound storage and storage in huts or buildings are all methods which have been described in the literature for tropical regions. In many cases weight losses are high and are blamed mainly on physiological losses caused by high ambient temperatures and relatively low relative humidities though also on rotting. Despite this, there are a number of examples of each storage method which have potential for further development. They may be summarised as follows:

> a. Pit storage reported by Gooding and Campbell (1964) in Trinidad, Bouwkamp (1985) in Barbados and Woolfe (1992) in Malawi, the latter giving the most detail. The pits and roots are sprinkled with ash, though this was found to be unnecessary in an experiment, covered by straw and soil and protected from rain and sun by a thatched roof or by siting under a silo.
>
> b. Clamp storage reported by Gooding and Campbell (1964) and Kennard (1944) in Trinidad and Anon. (1960) and Bouwkamp (1985) in Barbados. Dry vegetation is used to cover the ground a heap of roots is built then covered by more vegetation then soil. The clamp may be built in a trench, as in Barbados, though this was so deep that it may be considered to be a pit. Insect and disease free roots only are selected for storage.

c. Storage reported by Jenkins (1982) in bamboo huts in Bangladesh using baskets loosely covered by plastic bags and held off the floor. Curing was found to have no effect under the ambient conditions.

68. Each of these methods employs appropriate levels of technology with the possible exception of iii., though alternative materials may be found to fulfil the function of the plastic bags.

69. Kennard (1944) showed that sweet potato variety has a profound effect on storage performance. It is therefore difficult to reach any conclusions on the best method of storage from the literature. In any location the local sweet potato varieties and the climate will play a large part in the success of a storage method, so experimentation with all three of the methods suggested above would seem justified. In addition, there is little information on the conditions during storage so, again, it is difficult to draw any conclusions on which storage method is theoretically the best.

70. There is little mention of the relative importance of insect losses in the literature reviewed, other than the recommendation to avoid insect (and disease) affected roots when selecting for storage (Bouwkamp, 1985).

71. Some weight loss seems bound to occur during storage. Under optimum storage conditions a loss of 2% per month may be expected (Hardenburg *et al.*, 1986).

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Table 1. Tropical methods of sweet potato storage. After Proctor *et al.* (1981).

Country	Method	Temp. and r.h.	Loss/ %	Storage period/ months	Major cause of loss or comments	Source
USA	Pits, banks, cellars	-	40	-	Decay	Miller (1922)
Barbados	Clamp	-	30	3.5	12% rot 18% evaporation	Keleny (1965)
	Pit	-	20	4	Evaporation	Anon. (1960), Bouwkamp (1985)
Trinidad	Clamp	-	15	2	Loss dependent on variety	Anon. (1940)
	Sacks	-	17-47	1-3	do.	Kennard (1944)
	Clamp	-	24.2-30	-		do.
	Heap indoors	-	24.5	-		do.
	Sacks indoors	-	16.7-19	-		do.
	Pit	-	22.1	2	Better when not ventilated	Gooding and Campbell (1964)
	Clamp	-	26.4	2		do.
	Cardboard carton on soil	-	29.2	2		do.
	Rack covered in grass	-	34.9	2		do.
Rhodesia	Drum/wood ash	-	c.0	4	1 or 2 in 50 lbs	Blyth(1943)
Zanzibar	Box/coconut husk ash	-	100	1	Rot	Tidbury (1945)
British Solomon Islands	Unstated	-	31	1.5	Weight loss	Hall (1970)
			35	1	Root rot	
			65	2	Root rot	

Table 1 (cont.)

Country	Method	Temp. and r.h.	Loss/ %	Storage period/ months	Major cause of loss or comments	Source
Papua NG	Paper/sawdust	>13°C	-	-	-	Keleny (1965)
	Clamp/mound	-	-	-	-	do.
	Clamp	14.2 - 28.6°C	15.2- 25.3%	40-50 days	Physiological	Aldous (1976)
	House/racks	-	-	2-3 weeks	Hard to maintain r.h.	do.
	Pits	-	-	1	Not successful	
N. Zealand	Pit/ semi-underground	-	Heavy	-	Decay, rats	Keleny (1965)
Bangladesh	House floor, bench, roof hung	24-35°C, 70-90%	20-25	2-4	Physiological, sprouting	Jenkins (1982)
	In-house basket/ cured	27-34°C, 75-85%	19.3	1	Physiological, sprouting	do.
	Basket, fungicide dip		22.1	1	Water loss, sprouting, rot	do.
	Basket in plastic bag, sprout suppressants.	20-35°C, 70-95%	11	2	Some rotting, low loss in plastic bag (high r.h.)	do.
Sierra Leone	Basket in-house	23-29°C, 70-86%	28	20 days	Physiological, rot	George and Kamara (1988)
	Floor		33	20 days	do.	
Nigeria	Pit, in house sawdust heap	-	-	-	-	Chinaka (1983)

Table 1 (cont.)

Country	Method	Temp. and r.h.	Loss/ %	Storage period/ months	Major cause of loss or comments	Source
Malawi (Nyasaland)	Wood ash/lime in pit	-	Usually high	2	Rot	Anon. (1949)
	Wood ash in drum/ basket in-house	-	-	5	"without loss"	do.
	Pit	-	-	3-4		Woolfe(1992)
	Pit	-	16.8%	6½	Rotting. 5 kg per pit.	Woolfe (1992)
India	Pits, layered with ash, soil or straw	-	50	30 days	Best method was using soil	Mukhopadhyay (1991)
	Clamp	-	50-70%	2		Woolfe (1992)
Philippines	Pit	-	30%	-	Decay	Bouwkamp (1985)
Caribbean	Bag on a concrete floor in a shed	-	-	6-8 weeks	Best methods tested	Gooding and Campbell (1964)
	Clamp/pit	-	-	do.	do.	do.