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POSTHARVEST PHYSIOLOGY AND STORAGE OF ROOT AND TUBER CROPS IN SUB SAHARAN AFRICA

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Abstract: *The review explored the significance of postharvest handling practices in improving the quality and shelf life of root and tuber crops in Africa, where these crops are essential sources of food, employment, and income, with Africa contributing 23% to global production, and Nigeria, Ghana, Cote d'Ivoire, and other sub-Saharan countries being among the top producers. Cassava, sweet potato, and yam are the most widely produced and consumed root and tuber crops in Africa, efficiently converting natural resources into caloric energy, making them a vital component of food security in the region. However, postharvest deterioration resulted in significant losses, emphasizing the need for adequate storage facilities and preservation technologies, while physiological factors and indicators, such as respiration and transpiration, played an essential role in determining quality and behavior during postharvest. Studies had shown that advances in modifying post-harvest technologies, such as cold storage and modified atmosphere packaging, had improved quality, but adoption was limited by cost, infrastructure, and awareness. The review had concluded that improving postharvest handling practices is critical to reducing losses, improving availability, and contributing to food security, reduce malnutrition, and enhance livelihoods for millions in the region, where growth in total food and feed use had been strongest for roots and tubers, and utilization had continued to expand and diversify, with roots and tubers remaining major contributors to food consumption, particularly in sub-Saharan Africa, where per capita consumption had totaled 181kg/capita, with cassava and yam being the most important.*

Keywords: *Sub Saharan Africa, Roots and Tubers, Postharvest technologies, Physiology, losses, Storage, Deterioration, Losses.*

INTRODUCTION

The global population is projected to be about 9.7 billion people by 2050 (FAO, 2000). This will require a 60% increase in global food production compared with 2005-2007 levels, with more available access (Coursey, 2000). Chronically under malnourished people are about 815 million people especially in sub Saharan Africa (Dipeolu, *et al*. 2002). In Africa, roots and tubers are generally grown in countries located in the sub Saharan zones, notably Nigeria, Ghana, Cote d'Ivoire, Benin, Cameroon, Mozambique, Angola, Uganda, Malawi, Madagascar, and Rwanda. In Africa, roughly 40% of roots and tubers crops are produced by Nigeria followed by Democratic republic of Congo (10%), Ghana (8%), Tanzaniz (4%), Mozanbique (3%), Uganda (5%) and Cote d'Ivoire. (FAO, 1995). The contribution of roots and tubers crops to the world supply of calories is only 5% compared to 48% for cereals and 46% to other foods. In sub-Saharan Africa, the roots and tubers crops contribute 14% to the calorie supply as compared to 51% for cereals and 37% for other foods (Scott, 1992).

The tropical roots and tuber crops are a group of plants which includes cassava (Manihot esculenta), sweetpotato (Ipomoea batatas), yam (Diascorea spp). They provide stable carbohydrate source and calorie for an estimated population of over 500 million people (O'Hair, 1990). Roots and tubers together constitute a significant share of the total volume and value of horticultural crops worldwide. These commodities are particularly important as a source of food, employment, and income in developing countries where the bulk of the world's producer, processor, and consumer reside (Adebayo et al, 2003).

Root and tuber crops are second only in importance to cereals as a global source of carbohydrates. They also provide some minerals and essential vitamins, although a proportion of the minerals and vitamins may be lost during processing as, for example, in the case of cassava. The quantity and quality of the protein in starchy staples are variable and relatively low on a fresh weight basis but compare favorably with some cereals on a dry weight basis. In most traditional diets vegetable soups, meat, groundnuts, grain legumes and fish are good sources of protein and are frequently used to supplement root crops and compensate for their protein deficiencies. In some parts of Africa the diet is supplemented with the tender leaves of sweet potato, cassava and cocoyam which are rich sources of protein, minerals and vitamins (Hahn, 1984).

Status of Roots and Tubers in Food Production

Roots and tubers together constitute a significant share of the total volume and value of horticultural crops worldwide. These commodities are practically important as a source of food, employment, and income in developing countries where the bulk of the world producers, processors and consumers reside (Sanni et al, 2003). In this new millennium, roots and tubers will play an important role in meeting the food requirement, feed uses, and income needs of the world's food system (Sanni et al 2003). Utilization of roots and tubers in sub Saharan Africa is continuing to expand and diversify during the last three decades. But both the growth in use and increase in the number band relative importance of particular end use categories (food, feed, processed food products, industrial input) evolved in a highly uneven fashion across crops and geographical regions (Gregory et al, 2000). Growth in total food and feed use was strongest for roots and tubers. Uses of roots and tuber continue to diversify into industrial products and raw materials in Nigeria and Ghana (Nweke, 1992). The region has experience low or negative economic growth and booming population, and has continue to rely on roots and tuber as major contributors to food consumption. Cassava (62%) and yam (33%) accounted for nearly all of the total increase in human consumption of roots and tubers in sub Saharan Africa, the increase for potato was negligible and that for sweet potato modest in absolute terms (Sanni *et al* 2003)

Roots and Tubers Production Statistics

The most important roots and tubers in terms of production are Cassava (48.8%), and sweet potato (39.8%), while yams (9.4%) and taro (2.0%) are less important. Most of the cassava produced in Sub Sahara Africa. Africa dominates the production of roots and tubers (Sanni, 2003). In sub Saharan Africa the per capita consumption of root crops totals to about 181kg/capita with cassava (115kg/capita and yam (39kg/capita) being the most important. African countries contribute roughly 23% to the world production of roots and tubers (Sanni, 2003). The main roots and tubers crops produced in Africa are

i. Cassava (53% of the world population)

ii. Yam (96% of the world production)

iii. Sweet potato (7% of the world production)

iv. Potato (4% of the world production)

v. Other roots (70% of the world production)

(FAO, 1995)

Processing, Utilization and Consumption of Roots and Tubers

Like many other foods roots and tubers are usually eaten raw. They undergo some form of processing and cooking before they are consumption. The processing methods are boiling, fermentation, drying and grinding to make flours, depending on the varieties of roots and tubers. The purpose of these methods is to make roots and tubers and their more palatable and digestible and to make them safe for consumption. Processing also provides a variety of products, which are convenient to cook, prepare and consume than the original raw material. Traditionally, women play a vital role in all stages involve in the processing of root and tuber crops (Adebayo et al, 2003). The post-harvest activities of processing, storage and marketing are undertaking mainly by women, though, recent shows that men are beginning to take the aspect of processing of root and tubers crops through the purchasing and management of electrically operated grinding machine and dryers (Adebayo et al,2003, Sanni, 2006).

Storage of Roots and Tuber Crops

Storage refers essentially to the post-harvest gathering or collection of food crops at some safe prescribed conditions into appropriate/designated structure where it can be protected from weather pest, rodents and spillage organism. Production of root and tuber crops could be increased to meet future needs, although consumption has been tending to decline. The decline has been associated with increased urbanization, which does not favor highly perishable and labour intensive product. Further research should be geared towards converting starchy roots into less perishable and more convenient food product for the urban population of perishable products such as roots and tubers to minimize post-harvest risk (IFPRI, 2000). Fresh cassava roots, once harvested, deteriorates rapidly and therefore are best left un harvested until needed. Sweet potato and yams, however exhibit a period of dormancy, and curing can thus extend their storage life, alternatively, yams, cocoyam and cassava may be stored in undergoing pits harvesting. During storage, roots and tubers undergo significant alterations in carbohydrates chemistry depending upon the intending use (Schorr-Galindo and Guiraud, 1997). Losses during storage are known to be high and depending on the type, species and the storage environment, may be of the order of 30-60% during the course of few days to six months. Once harvested, roots and tubers are more perishable than grains. This is related to their higher moisture content, greater susceptibility to physical damage and higher metabolic activity. While losses of grains are due primarily to external factors such as insects, rodents and mould damage, roots and tubers are primarily affected by two types of postharvest deterioration: primary physiological deterioration that is the initial cause of loss of market acceptability and secondary deterioration due to microbial spoilage (Booth and Coursey, 1974). Even among roots and tubers there is a wide range in perish ability: while some varieties of yam and sweet potato can be stored for several months, cassava has a particularly short shelf-life (1-3 days). Where cassava is harvested and processed or consumed locally this is not a great problem, but it is a serious constraint for the development of marketing, where the distance between production and consumption/process increases (Westby et al., 2004). As well as direct physical loss of the crop, postharvest deterioration causes a reduction in quality that results in price discounts and so contributes to economic losses (Naziri et al., 2014; Wenham, 1995; Westby et al., 2004). Furthermore, there can be additional losses due to change in use. For example, if harvested cassava roots cannot be marketed within two or three days of harvest then they may be processed into dried products of low quality, which have lower value (Westby et al., 2004). The principal causes of loss include

i. Mechanical damage
ii. Physiological changes within the plant
iii. Infection by decay organism and pest infestation
iv. Weight loss due to dessication
v. Loss of carbohydrate and water due to respiration
vi. Sprouting
vii. Microbial damage, especially as a result of wounds
viii. Losses due to rodents and insects

Physiological Changes during Post-Harvest Storage of Tuber Crops

Roots and tuber crops, including yam cassava, potatoes, sweet potatoes, taro, elephant foot yam, are globally recognized for their significant contribution to food security and nutrition (Afek, 2004). However, once harvested, the tubers and rhizomes undergo various physiological and biochemical changes that can impact their quality, nutritional composition, and shelf life. A comprehensive understanding of the metabolic and biochemical transformations occurring during post-harvest storage is essential for implementing adequate storage and preservation strategies. These transformations involve intricate interactions between enzymes, substrates, and environmental factors, resulting in alterations in carbohydrate, lipid, and protein metabolism, as well as the presence of phytochemicals.

Mechanical Damage

The skin of a mature root or tuber is normally an effective barrier against most potentially invading bacteria and fungi causing rotting of the tissues. Any rupture of this barrier caused by damage or injury to the skin will provide an entry point for infection and will also stimulate physiological deterioration and dehydration. There are different degrees of mechanical damage, from small bruises to deep cuts and they may be sustained at any stage, from pre-harvest operations, through harvesting and subsequent handling operations when the product is graded, packed and transported for market or, simply, even carried to the farmer's house. Serious mechanical injury, which may result in the product being rejected during grading, is a direct loss. Damage to the tuber skin that is not immediately obvious can lead to physiological deterioration and allow the entry of pathogens (Sudheer and Indira, 2007).

Respiration

Roots and tubers are living organisms and as such, they respire. The respiration process results in the oxidation of the starch (a polymer of glucose) contained in the cells of the tuber, which converts it into water, carbon dioxide and heat energy. During this transformation of the starch the dry matter of the tuber is reduced (Mishra and Gamage, 2007). For respiration to occur freely a supply of oxygen is needed and the resulting carbon dioxide and heat have to be removed from the products' environment. A limited supply of oxygen and inadequate removal of carbon dioxide may lead to effective asphyxiation and the death of product tissue. The rate of respiration is assessed either by measuring the uptake of oxygen or the quantity of carbon dioxide released and is expressed in milligrams of CO_2 per kilogram of tuber per hour (Bergman, 1999).

Generally, the rate of respiration is relatively high at harvest, followed shortly by a decrease, especially during storage, then followed by an increase once sprouting begins. For example, the dry matter losses for potatoes stored at 10°C are approximately 1% to 2% during the first month after harvest, 0.8% per month during storage but rising to 1% to 5% per month when sprouting is well advanced (Burton, 1966; Rastovski *et al.,* 1981).

Respiration rate of tubers is at its minimum and the dry matter losses are correspondingly reduced. For example, it has been shown that immediately after harvest yam tubers (D. rotundata) respire at a rate of 15mL CO_2/kg fresh weight/hour at 25°C. The respiration rate will later drop as low as 3 ml CO_2/kg/hr and remain at that level until sprouting starts. During sprouting the respiration rate increases dramatically to over 30mL CO_2/kg/hr (Cooke *et al*., 1988).

Damage and wound healing greatly influence respiration. It has been found that simply cutting through a potato will double its respiration rate and dropping the potato from a height of about 1 meter will so damage a potato skin as to increase respiration by 30% to 50%. For sweet potatoes the rate of respiration of a damaged tuber doubles in response to a wound after a delay of about 20 hours. This effect is known as wound respiration response (Pringle et al 2009).

Curing

This is a method used to extend the shelf life of roots and tuber crops. Root and tuber crops undergo injury during harvesting and handling. The method involves the application of high temperature and relative humidity for a specific period of time in other to heal the wounded skin that was bruised during harvesting. A protected layer is being formed with the process. Curing can be accomplished either in the field immediately after harvesting or in the curing structures conditioned for the process specifically (Akanbi, 1996). Yam are cured in the field by piling them in a partially shaded area with cut grass or straw spread on to serve as an insulating materials and covering it with canvas of woven grass. The purpose is to provide sufficient temperature and relative humidity, and it takes up to four days. A modern curing method involves implementing a house with air conditioning with fans and heaters to produce the required temperature. The fans are used to distribute the heat evenly towards the lower part of the room where the crops are kept. Bulk bins can be used where they will be stack together with a gap of about 10cm-15cm between rows and to allow adequate air flow (Walter 1982).

Dormancy and Sprouting

Definition and types of dormancy

Dormancy is a critical physiological process in tubers that enables them to endure unfavourable conditions and maintain long-term viability. It involves suspended growth and metabolic activity until suitable conditions for sprouting and growth are present. Two primary types of dormancies are observed in tubers: Endodormancy: Endodormancy is an internal form of dormancy regulated by physiological factors within the tuber itself. During this period, tuber growth and metabolic processes are inhibited, and the tuber becomes unresponsive to external triggers for sprouting. Hormones such as abscisic acid (ABA) and ethylene suppress tuber sprouting and maintain dormancy (Gong *et al.,* 2021; Mani *et al.,* 2014). Eco-dormancy: Eco-dormancy, also known as exodormancy, is influenced by external environmental factors. It occurs when external conditions, such as temperature, moisture, or photoperiod, are unfavorable for tuber growth and sprouting. Eco-dormancy prevents tubers from sprouting under unfavorable conditions, allowing them to conserve resources until more favorable conditions arise (Suttle, 2007). Yam, cocoyam, potato and sweet potato tubers propagate vegetative. To counter what is often an unfavorable climate at the end of their growth period, they go into a dormant phase. The beginning of this period is considered to be the point of the physiological maturity of the tubers, also called "wilting point". The dormancy period can be defined as the period of reduced endogenous metabolic activity during which the tuber shows no intrinsic or bud growth, although it retains the potential for future growth. Dormancy is both a species and a varietal characteristic. It is also affected by other factors, temperature is the most important but others, including moisture, oxygen and CO2 content of the storage atmosphere, the extent of wounding and any disease of the tuber, real or putative, although norm ally of lesser importance may, occasionally, have an over-riding effect. The cassava root, as opposed to other roots and tubers, is a plant of presentation and not propagation. It has no dormancy and it senesces soon after harvesting (Wills and Golding, 2016). Passam (1982) suggested that differences in the dormancy of yam species are the result of the ecological environments in which the different species have evolved. For example, varieties of yam native to regions with marked arid seasons have a longer period of dormancy than those that are native to regions with shorter dry seasons. D. cayenensis, which originates from the West African forest zone where the dry season is very short, shows almost continuous vegetative growth. In contrast, D. alata and D. rotundata, originating respectively in Asia and Africa, appear to be adapted to climates where there is a longer dry season during which the plant survives as a resting tuber. These inherent differences in dormancy are responsible to a large extent for variations in the ability of different species to store well.

Lower storage temperatures are widely practiced as a technique for reducing the metabolic activity of roots and tubers and prolonging their dormancy. Temperatures of 16° to 17°C have been used to prolong the storage period for D. alata tubers for up to four months, provided the tubers were properly cured prior to storage in order to control infection by wound pathogens. For potatoes, sprout growth is practically negligible at 4°C and below and increases with increasing temperature. However, avoidance of sprouting by low temperatures leads to sweetening of the tuber, which is considered to lower the value of the stored crop (Rav *et al.,* 1996). While roots and tubers remain dormant they can be stored satisfactorily, (provided they are undamaged and free from disease). As soon as dormancy is broken and sprouting begins, the rate of dry matter loss increases dramatically since the formation of sprouts requires energy, which is drawn from the tubers' carbohydrate reserves. The rate of water loss also increases and if this becomes excessive the tubers dry out allowing pathogens to penetrate the tuber, potentially causing severe damage if not total loss, making continued storage quite impracticable (Ravi *et al.,* 1996).

Pathological factors

All living organisms are subject to invasion by microorganisms, fungi, bacteria and viruses, which constitute the most serious cause of direct post-harvest loss in tropical root crops. These disease organisms are widely distributed in the air and soil and on dead and decaying plant material. The extent of the occurrence and the magnitude of losses due to pathogenic microorganisms are very variable. The time of infection varies with the crop and with different diseases, it can occur in the field before harvest or at any time afterwards. Since many post-harvest pathogens are introduced through wounds, one of the major factors governing the incidence and magnitude of such losses is the physical condition of the produce. The cork layer surrounding the roots and tubers is intended to serve as a barrier against bacterial and fungal attack. When this protective barrier is damaged the plant is predisposed to pathogenic infection (Brackett, 1994).

Losses reducing the quantity of sound produce are, generally, the more serious losses but are often underestimated because they are not easily recognized or evaluated. They are often caused by infection of the produce in the field before harvest either by a primary infection or a secondary infection following an initial infection by one of a few specific pathogens, normally through a wound. The initial infections cause a breakdown of the host tissues and once these primary pathogens are established, they are followed by an invasion by a broad spectrum of secondary pathogens.

Losses affecting the quality of the produce and which occur when the disease affects only the surface of the produce do not necessarily affect the intrinsic quality or quantity of the commodity but makes the crop less attractive to the consumer or buyer in the market. In crops grown for domestic consumption, the result is not necessarily serious since the affected skin can often be removed and the undamaged interior can be used. For crops intended for a commercial market, qualitative losses usually result in financial loss. In yams, sweet potatoes and potatoes, diseases causing internal blemishes also reduce the final quality of the crop (Antunes and Cavaco, 2010).

Damage by Extremes of Temperatures

Roots and tubers are susceptible to extremely low or high storage temperatures. Yams, cassava and sweet potatoes are known to suffer from chilling damage at 12°C or below, while for potatoes, cocoyams and sweet potatoes this type of damage occurs at 2°C or below. The extent of chilling damage usually depends on a time/temperature interaction. The most common symptoms are internal tissue breakdown, increased water loss, susceptibility to decay, failure to sprout and changes in culinary qualities, cooking and taste. Potatoes respire strongly at temperatures of 30°C and above. At these high temperature levels, the tubers require a great deal of oxygen and respire a considerable volume of carbon dioxide. At a certain point, the rate of respiration is so great that the cells can no longer obtain sufficient oxygen to sustain the rate induced by the temperature and the carbon dioxide formed cannot be disseminated. This ultimately leads to the death of the cells, giving rise to what is commonly known as "black heart" (Rastovski *et al,* 1981).

Table 1.1: Causes of loss in roots and tubers and their effect

Factor	Mechanism	Stage Affected	Results
Mechanical	Rupture	Harvest	Moisture loss
	Bruising	Harvest, Transport	Access to pest
	Crushing	Transport, Storage	Total loss
Physiological	Transpiration	All stages before processing	Water loss
	Respiration		Dry matter loss
	Chilling	Cold storage	Loss of palatability
	Sprouting	Storage	
Pathogenic bacteria	Necrosis and tissue damage	Preharvest	Partial loss

Principles of Storage for Roots and Tubers

Root and tuber crops are still living organisms after they have been harvested and losses that occur during storage arise mainly from their physical and physiological condition. To ensure effective storage of root and tuber crops, these major causative factors need to be properly understood and, where appropriate, be properly controlled, taking into account the socio-economic factors which prevail in the areas of production and marketing (Kiaya, 2014). It has been stated that the key to reducing losses is in 'soft' infrastructure investments, improved market integration, and in value addition through processing. This is particularly pertinent to cassava where although in the export markets refrigeration or coating the root with paraffin wax are used to extend shelf-life to over a month, such procedures are too expensive to be adopted by local markets in developing countries. Sweet potato and yam are different as they have relatively long shelf-lives under ambient conditions. But there is scope for improving shelf-life by a process of curing. If immediately after harvest the product is stored for a few days in a warm, high humidity environment then the healing of harvest damage is promoted which reduces water loss so that quality is retained. Sweet potato is particularly prone to preharvest infestation of the sweet potato weevil (Cylas spp.), which leads to postharvest deterioration. Considerable effort is being expended to overcome this problem both through production of bt-sweetpotato and natural resistance. In the case of yams there would be benefits if cultivars could be developed with tubers that have extended periods of dormancy (Verma and Joshi, 2000). For most root and tuber crops a significant proportion of the crop is processed. Transformation of the crop into a more storable form reduces physical losses as well as providing income and employment. Where processing leads to increased value of the product it can effectively change a situation of postharvest loss to one of net economic gain. Both dried and fermented products are common but here are still subject to physical losses, albeit at a lower rate than the fresh product. Significant volumes of by-products, such as peel, siftings and cassava pulp, are produced during processing (Wenham, 1995).

Control of Mechanical Damage

Root and tuber crops need to be handled gently to minimize bruising and breaking of the skin because of its relatively soft texture compared, for example, to cereal grains. The effect of mechanical injury resulting in external and/or internal bruising and tissue discoloration is often underestimated. Severely damaged tubers should not be stored for three reasons; because of lower quality, because of the increased risk of subsequent pathogenic losses and because of the risk of introducing disease organisms into sound produce. Most mechanical damage occurs as a result of careless handling at harvest and during transport to and within a store since, generally in the tropics, food handling procedures are poorly developed and fresh produce is all too frequently treated as an inert object. Careful harvesting and proper handling of roots and tubers is, therefore, an important step towards successful storage. Crops are most likely to be injured at harvest by the digging tools, which may be wooden sticks, machetes, hoes or forks. Therefore, immediately after harvest, the crop must undergo the operation of curing. The need for curing as a method of reducing the onset of disease is well recognized and the technique is becoming more widely understood and practiced (Sudheer and Indira, 2007).

Proper packaging and handling

The ideal in packaging is to protect the produce from damage during handling, transport and storage and to provide containers of uniform size that are conveniently stacked and handled, easily accounted for in quantity and, where appropriate, in weight. In many developing countries traditional baskets and various types of trays or buckets are used for transporting produce to the house or to village markets. These are usually of low cost, made from readily available material and serve the purpose for transport over short distances. But, they have many disadvantages in large loads carried over long distances: they are difficult to clean when contaminated with decay organisms; they often lack rigidity and distort when stacked thus applying severe local pressure to their contents they are frequently very variable in shape and therefore are difficult to load, especially for long journeys. Being of local manufacture they are often rather crude and may have sharp edges or splinters causing cuts and punctures to the commodity (Paine and Paine, 2012).

Many authorities have observed that produce being transported and marketed in commercial quantities needs better packaging in appropriately sized units if losses are to be minimized and to achieve economical use of transport. The shape of packages is significant because of need to load for maximum capacity and stability. Round baskets, whether cylindrical or tapered, hold considerably less produce than boxes occupying the same cubic space; a cylindrical basket contains only 78.5% by volume compared with a rectangular box occupying the same space on a vehicle (Wills and Napier-Munn, 2015).

Control of Temperature

Temperature has a great influence on many factors that cause loss during storage. It is the single most important factor affecting the rate of respiration; it also influences the rate of sprout growth, the development of rotting micro-organisms and insect infestation. At 10°C, the rates of sprout development, rotting and respiration are shown to be moderate but at 4°C, sprouting is stopped, while rotting and respiration continue but at very low levels (Ragaert et al., 2007)

With the exception of highland areas, low temperature storage in the tropics within the range 10° to 15°C can only be envisaged by using a refrigeration process of some kind. At subsistence or small farmer level this is generally not practical because of cost implications and the technical support needed to sustain conventional refrigeration technology. Only in very dry areas is simple evaporative cooling at all successful but even this simple technology needs a prime mover to be operating almost continuously. Therefore, successful storage of roots and tubers in any sort of structure depends very much on natural ventilation to remove respiration heat, to remove carbon dioxide, which in concentration can lead to the breakdown of dormancy, and to keep the temperature of the crop as low as possible. Ventilation should be with the coolest possible air; night time ventilation is not only the coolest but has the highest relative humidity, so that water loss through transpiration is also held to a minimum (Onwueme and Charles, 1994).

Control of Sprouting

How long roots and tubers, with the exception of cassava, can be made to remain dormant with limited endogenous metabolic activity is, generally, the determining factor in how long the commodity can be stored. The end of dormancy leads to the initiation of sprouting which, in turn, means increased respiration and dry matter loss. Therefore, if the duration of storage is to be longer than the natural dormancy period an alternative method to prevent or delay sprouting is needed. One or more of three methods can be used: (Coursey, 1983)

Storage at low temperatures

Cold storage and refrigeration are essential for preserving the quality and prolonging the shelf life of tubers. Lower temperatures, such as 4°C, have decreased polyphenol oxidase (PPO) activity in potatoes and sweet potatoes, reducing browning and maintaining overall quality during storage (Sun et al., 2011). Ultrasound treatment has been shown to inhibit browning and improve the antioxidant capacity of fresh-cut sweet potatoes throughout the refrigeration period (Pan et al., 2020). In the case of sweet potato tuberous roots, a combination of low temperature conditioning and cold storage promotes rapid sweetening while preserving quality (Li et al., 2018). Jerusalem artichoke tubers can benefit from refrigerated storage at zero degrees Celsius with a relative humidity of 90% (El-Awady and Ghoneem, 2011). These studies collectively emphasize the importance of cold storage and refrigeration techniques in preserving the quality and extending the storage life of tubers. For potatoes stored at 4°C sprout growth is negligible; for yams storage at 15° to 16°C prolonged the dormancy period for six months. But, socio-economic constraints in most developing countries will limit the use of refrigeration in the storage of roots and tubers at farmer level.

Chemical sprout inhibitors

In stores using natural air ventilation, with relatively high ambient temperatures (20°C to 30°C such as are normally experienced in tropical and subtropical lowlands) and for any period of storage beyond the normal or natural end of the dormancy period, the use of sprout inhibiting chemicals is the only practical means of controlling sprouting. This treatment has proved effective on potatoes and sweet potatoes (Onwueme and Charles, 1994). CIPC (isopropyl-N-chlorophenylcarbamate) is the chemical most commonly used as a sprout suppressant. It is mixed with an inert filler to give a concentration of about 2%, and applied as a dust on potatoes at a rate of 1.0-1.5kg per ton of produce and it has been very effective in delaying and reducing sprout growth. As sprout suppressants also inhibit the development of wound cork, they must be applied only after the curing operation has been completed or a few weeks after harvest when wounds have healed and any lesions would have naturally sealed off.

Control of Damage Caused by Insects

Insect pests can be the cause of serious losses in stored roots and tubers, yams and sweet potatoes in particular. Surveys carried out in 1981, 1983 and 1984 in Côte d'Ivoire showed increasing levels of infestation of stored yams over a period of four months' storage, with 63% of stored tubers being infested by moths and weight losses of 25% attributed to insects. (Sauphanor and Ratnadass, 1985).

Good hygiene is of paramount importance in insect control including, particularly, the destruction by burning of infested tubers and rubbish that can act as host to a variety of insect pests and cleaning and disinfection of the store structure. In many areas it may still be necessary to use some form of chemical control especially if storage is extended over several months. Various methods of control of the potato tuber moth in potato stores have been tested in many countries. In stores in Bangladesh dried and crushed Lantana camara, as well as the insecticide Decamethrin (Decis), has been reported to be effective. Deltamethrin used as a spray of 2.5g active ingredient per 100 liter of water, has been reported to be effective in controlling moths (Tineidae sp) on stored yams (Sauphanor and Ratnadass 1985).

Insecticides may be applied as dusts on the planting material, on the soil during the tuber-forming period, or as sprays applied to the growing crop. The same observations on the misuse and application of unsuitable chemicals apply equally to use insecticides as to fungicides. Allegedly safer and more practical alternative control methods are continually being developed which are particularly suitable for subsistence agriculture. Some level of control can be achieved through the use of established insect repellents, such as "lantana" and through crop rotation and forms of shifting cultivation which reduce the likelihood of a serious build-up of soilborne pests. Another promising control is the use of cultivars that have a marked genetic resistance to insects and new cultivars are being bred with resistance characteristics (Morse *et al.,* 2000).

Conclusion

The perishability and postharvest losses of root and tuber crops are the major constraints in the utilization of these crops. Root and tuber crops are still living organisms after they have been harvested and losses that occur during storage arise mainly from their physical and physiological condition. Several simple, low-cost traditional methods are being followed by fanners in different parts of the world to store different root and tuber crops in the fresh state. To ensure effective storage of root and tuber crops, these major causative factors need to be properly understood and, where appropriate, be properly controlled, taking into account the socio-economic factors which prevail in the areas of production and marketing. For our finding to be relevant roots and tubers should be developed in line with processing and product innovations, substitution level, root storage stability pre and post processing, novelty product i.e modified product bioavailability of staples and new product.

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