OBJECTIVE EVALUATION OF QUALITY CHANGES

IN STORED SWEET POTATOES

BY

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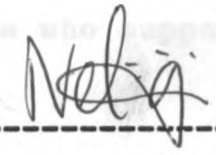
DECLARATION

This is my original work and has not been presented for a degree in any other University.



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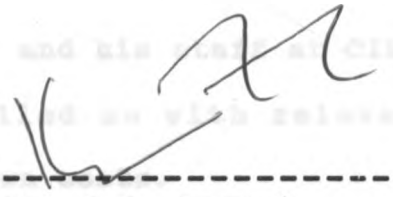

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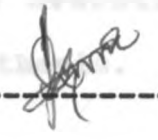

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ABSTRACT

Physical and chemical changes in sweet potato roots were studied with regard to sequential harvesting time and various traditional and conventional storage conditions. Nutritional constitution and cooking characteristics were also considered in three selected cultivars. In addition, objective evaluation of changes in textural properties of stored roots and the degradation kinetics of vitamin constituents were investigated.

Increases in weight, specific gravity and dry matter content of the Cv. KSP 20 roots with chronological age could be described by definite mathematical relationships using a computer program. Maximum dry matter accumulation in Cv. KSP 20 occurred in 160 days after planting and corresponded to the onset of foliage senescence.

Roots of various weights were found to be significantly different in physical and chemical composition. Total solids, specific gravity, vitamin C and reducing sugar content all depended on the root weight. Total solids and root weight were found to be logarithmically related while specific gravity varied with root weight in an exponential fashion. Specific

gravity was also exponentially related to total solids. All these relationships were described by suitable equations.

The cultivar Nyeri had maximum total solids and specific gravity followed by Nyakura and lastly KSP 20. Nyeri also had twice as much crude protein as Cvs. Nyakura and KSP 20. All varieties were found to be good sources of Na, K and Mg. Vitamin C occurs in good quantities in all the three cultivars sufficient for all dietary groups except for children. These cultivars were however not good sources of provitamin A carotenoids.

Optimal cooking time depended on dry matter content of the roots. Hence, Cv. KSP 20 had least cooking time followed by Cv. Nyakura and lastly Nyeri. Cooking time could also be explained in terms of certain derived thermal properties of the roots. Optimal cooking times as gauged by sensory evaluation were also the times when there were no further decrease in back-extrusion force. Back-extrusion was therefore a better method of objective measurement of textural properties of cooked potatoes than puncture test technique.

Roots buried in soil or saw-dust could be stored for 12 weeks, just as long as those stored at the

conventional temperature of 15°C, save for sprouting. Alterations in textural properties of Cv. KSP 20 roots under various storage conditions were objectively quantifiable by back-extrusion technique after 12 weeks storage duration. Least changes occurred in roots stored at ambient, in soil and in saw-dust and these changes could be explained in terms of corresponding enzymatic modifications of root carbohydrate constituents especially starch. Development of physiological disorders was responsible for the anomalous increases in textural indices for roots stored at 15°C and 20°C.

Degradation of vitamin C and β-carotene in roots stored at various temperatures were found to obey first order reaction kinetics. In addition, it was deduced that the critical temperature of storage for Cv. KSP 20 lies in the neighbourhood of 15°C.

1. INTRODUCTION

Sweet potato, Ipomoea batatas L. Lam is a member of the family Convolvulaceae, genus Ipomoea, section batatas, and species Ipomoea batatas (Huaman and De la Puente, 1988). It is the only member of the Convolvulaceae family of nutritional and commercial significance (Onwueme, 1982).

Among the root and tuber crops, its production is only superseded by the white potato Solanum tuberosum in the whole world (FAO, 1987). In Kenya, the cultivation of sweet potato transcends all the agro-ecological zones from the marginal areas where few other crops would thrive to the rich high potential areas of the highlands. Several varieties of this crop are grown in various parts of the country albeit mostly on subsistence scale. The immensity of this varietal diversity is a favourable potential for selection and improvement of those with desirable qualities. Gor (1989) has compiled the germplasm of sweet potato accessories maintained at various Kenya Agricultural Research Institute (KARI) regional centres and research stations. Over 500 lines are being maintained, most of which are national landraces (Ewell, 1989). Screening with the aid of appropriate descriptors is already underway to exclude duplicity of accessories (Huaman, 1987).

However, despite its genetic diversity, climatic

adaptability and versatility towards seasonal variations, sweet potato remains merely a surviving crop with an under-exploited potential. FAO (1987) and Ministry of Agriculture, Kenya (1984 - 1987), show a general trend of decline in annual production of sweet potato, with occasional production overshots especially in years with unfavourable climatic conditions. This indicates that sweet potato has been used as a seasonal fall-back or 'cheat hunger' food resorted to during times of scarcity and promptly abandoned to inferior status during times of plenty. Several factors may be contributory towards the seeming unpopularity of sweet potato as food for humans. These include negative psychological associations, ignorance of the nutritive potential of the crop, high sugar content, fluctuation of supplies and flatulence. In addition, sweet potato is a perishable crop with limited ways of post-harvest handling and utilization (Tsou and Villareal, 1982; Horton, 1989). The recent turn of events has signified increasing interest towards concerted research efforts on sweet potato, elicited by the ever worsening global food crisis situation. In fact, the International Potato Centre (CIP) in Peru has now expanded its mandate to include sweet potato in recognition of its unique potential as a hardy crop which can thrive in a broad range of growing conditions including semi-arid

areas, its low costs and low risks of production, and its duality as food for humans as well as feed for livestock (Ewell, 1988). The Government of Kenya has also embarked on a rehabilitation plan for arid and semi-arid areas by creating a ministry to undertake this venture and sweet potato could be one of the crops destined for these areas. A report by the Ministry of Agriculture and Livestock Development (1986), also places sweet potato and cassava in the highest of three priority groups due to their potential contribution to national food security, equity, nutrition and economic growth. Pioneering activities have been instigated at the various research institutions, notably KARI, with the support of the government and other collaborative organisations aimed at improvement and increased utilization of sweet potato.

At a workshop jointly convened by International Centre of Tropical Agriculture (CIAT), International Potato Centre (CIP) and International Institute of Tropical Agriculture (IITA) (1987) on improvement of Sweet Potato in Africa held at Nairobi - Kenya, several recommendations emerged which set forth the future research activities to be undertaken in close cooperation with other international research organizations and participating national programs. The working group on post-harvest technology and socio-economics

enumerated priority areas to which the present study is expected to render part service especially with regard to post-harvest storage.

It should be increasingly appreciated that the prevalent sequential or piece-meal harvesting of mature sweet potato roots in which the garden is in effect a means of storage cannot continue for long. This is due to pressures on land, risks associated with this type of harvesting including diseases and pests which cause extensive quantitative and qualitative losses, and also due to the possibility of using sweet potato as a cash earner by storing bulk harvested roots so that they can be sold during periods of sweet potato shortage to achieve better prices.

The above observations call for evaluation of available sweet potato cultivars for nutritional and processing potential as well as development and evaluation of suitable storage facilities that would help in ensuring continuous supply of sweet potatoes throughout the year, while maintaining the nutritional and other quality aspects of the roots. In developing such adequate storage facilities, it is expedient to evaluate existing rudimentary ones so that on the basis of that knowledge, their suitability or unsuitability for more rigorous development can be judged.

This project was therefore intended to meet the

following objectives:

1. To determine the nutritional and physical characteristics of selected sweet potato cultivars.

2. To evaluate the cooking characteristics of selected sweet potato cultivars.

3. To evaluate the effect of storage conditions on the nutritional and textural qualities of a selected sweet potato cultivar.

2. LITERATURE REVIEW

2.1 ORIGIN, PRODUCTION AND UTILIZATION OF SWEET POTATOES

2.1.1 ORIGIN

Sweet potato *Ipomoea batatas* originated from the American continent particularly in the northwest region of South America (Yen, 1982). It was later dispatched to the rest of the American tropics by the Spanish, Portuguese and Iberian explorers before 1492. Columbus introduced the *batatas* line to Europe and the Portuguese explorers further transferred the West Indian clones of this line grown in Mediterranean Europe to India, East Indies and Africa (Yen, 1982). Today, sweet potato is grown in most parts of the tropical and sub-tropical world, and in the warmer areas of the temperate regions (Onwueme, 1982).

2.1.2 PRODUCTION

Sweet potato has played an indispensable role as a source of food in the Asian continent (Steve *et al.*, 1985). Asia alone accounts for over 90% of the world's total production followed by Africa which accounts for a mere 5% (Ewell and Mutuura, 1990). Table 2.1 gives a continental comparison of sweet potato production (FAO, 1989b). In Eastern and Southern Africa, Uganda has the highest output

Table 2.1: Continental Comparison of Sweet Potato Production

Content	Area Under Sweet Potato (1000 ha)	Production (1000 mt)
Asia	7593	120,927
Africa	1184	5,949
North and Central America	202	1,350
Europe	5	86
Oceania	118	567
South America	155	1,476
World	9258	130,355

Source: FAO (1989b)

followed by Rwanda, Burundi and Madagascar. Kenya, where grains are the major staples, has a mean per capita annual production of 14.5 kg (Ewell and Mutuura, 1990). The total annual production of sweet potatoes in Kenya has been estimated at 380 metric tonnes (FAO, 1989b). The annual production reports of the Ministry of Agriculture (1987) estimate the total production at about 200 metric tonnes (Table 2.2). Of this, Nyanza Province accounts for over one third followed by Western, Central, Eastern, Coast and Rift Valley. According to Ewell and Mutuura (1990) the most common varieties of sweet potatoes grown in Kenya are the red skin and white fleshed followed by white skin and white fleshed. In Nyanza province, a cultivar known as Lodha in the local dialect which is yellow fleshed and white skinned is very popular (Ojijo, 1990). Sweet potato production in this area is mainly from May to February with March and April having least production. An early maturing variety, known as mwezi tatu, which matures in three months is very popular in Western parts of the country. It is yellow fleshed and gives very high yields. An imported cultivar designated KSP 20 developed at IITA in Nigeria (also designated TIS 2534) has been widely distributed in Machakos, Embu and other parts of Central Province. It matures within about 5 months (Ojijo,1990).

Table 2.2: Sweet Potato Production by Provinces in Kenya

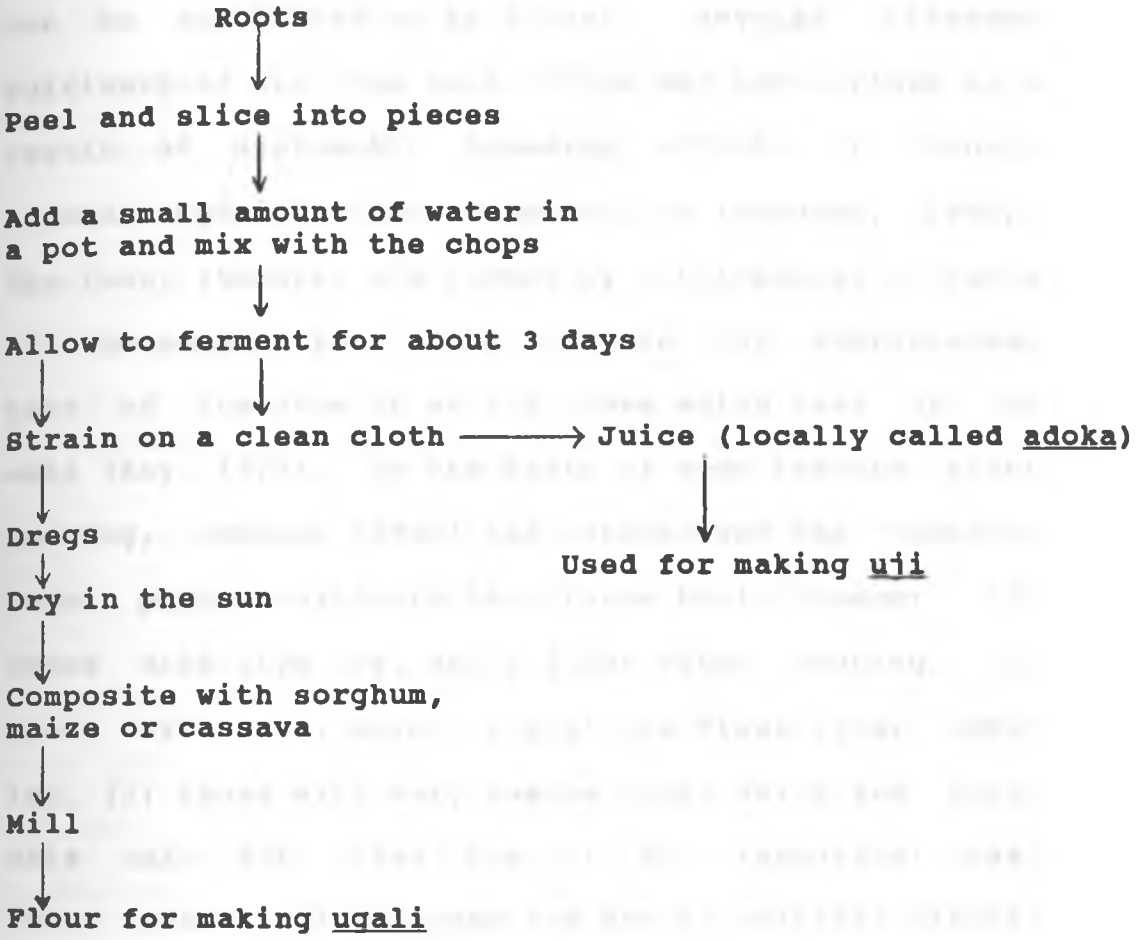
Province	Hectarage (ha)	Production (tons)
Nyanza	16,567	108,747
Western	7,465	67,980
Eastern	3,370	17,443
Central	3,428	30,364
Coast	628	7,384
Rift Valley	311	4,464
Total	31,769	236,382

Source: Ministry of Agriculture, Provincial Annual Reports (1987), Kenya

2.1.3 SWEET POTATO UTILIZATION

Sweet potato has been cultivated by most traditional communities in Kenya as a security crop mostly during times of unfavourable weather conditions. It cannot be regarded as a staple food and in most cases there are limited means of utilizing it as human food. In a preliminary survey carried out by the author, several communities boil the roots, peeled or unpeeled, and take it along with tea, fermented uji or fermented milk for breakfast, lunch or supper. The vines may also be used as a vegetable cooked with other local vegetables and eaten along with ugali. The use of sweet potato as a staple has been hampered by its sweetness. However, some communities have practiced a desweetening process which involves fermentation by the natural microbial flora (Figure 1). Fresh sweet potato tubers are peeled, comminuted and the spontaneously fermented in traditional pots. The juice is strained out and the remaining dregs are dried and mixed with sorghum, maize or cassava and milled into flour for making ugali or uji (Ojijo, 1990). Sweet potato roots are boiled and eaten with coconut juice among the communities in the coastal regions of Kenya mostly during Ramadhan, a Muslim fasting season. Flatulence is frequently cited as a major problem after eating boiled sweet potato roots.

Figure 2.1: Traditional Desweetening of Sweet Potato Roots



2.2 SWEET POTATO PLANT

Sweet potato is a herbaceous perennial plant but can be cultivated as an annual. Several different cultivars of the crop exist which may have arisen as a result of systematic breeding efforts or through natural hybridization and mutations (Onwueme, 1982). The root, (tubers) are formed by a thickening of parts of the adventitious roots close to the subterranean part of the stem or at the nodes which rest on the soil (Kay, 1973). On the basis of root texture after cooking, Onwueme (1982) has categorised the numerous sweet potato cultivars into three basic groups: (1) those with firm dry, mealy flesh after cooking, (2) those with soft, moist, gelatinous flesh after cooking, (3) those with very coarse roots which are suitable only for animal feed or for industrial use. These textural differences are due to cultivar differences in content of amylolytic enzymes, notably β-amylase (Sistrunk et. al., 1954; Walter et. al. 1975). Other varietal differences also exist with regard to the colour of the root skin; colour of the root flesh; shape of the root; shape, vennation and pigmentation of leaves; stem structure and pigmentation; mode of growth; depth of rooting; time of maturity; resistance to disease and other vegetative characteristics (Kay, 1973; Onwueme, 1982).

The mature sweet potato root may exhibit various shapes from spherical to nearly cylindrical or spindle shaped, weighing from 0.1 kg to over 1 kg and in length from a few centimeters to over 30 centimeters (Onwueme, 1982). The colour of the skin and the root flesh is determined by the relative intensities of carotenoids and anthocyanin pigments present (Onwueme, 1982; Kay, 1973).

2.3 SWEET POTATO PRODUCTION REQUIREMENTS

2.3.1 EDAPHIC AND ENVIRONMENTAL REQUIREMENTS

The soil conditions under which sweet potatoes are grown should promote maximum root yield and pose minimal risk of root infection by disease causing organisms. Light textured soils of sandy loam type with sub-soil of sufficient porosity for adequate aeration to growing roots are ideal (Kay, 1973; Bauwkamp, 1985). Root yield is reduced when the crop is grown in poorly drained hydromorphic soils (Alvarez, 1987). Good roots result when sweet potatoes are grown in soils with a water table at or below 50 cm while waterlogged soils result in retarded root development and root rot in the soil or during subsequent storage (Onwueme, 1982; Bouwkamp, 1985). Retardation of root growth in waterlogged soils is mainly due to

inadequate supply of oxygen (Watanabe et al., 1986).

Although sweet potatoes are not exacting as to pH requirements, extremely acidic soils can reduce yields by up to 60% (Alvarez, 1987). A pH range of 5.6 - 6.6 is usually recommended (Kay, 1973; Onwueme, 1982). However, it has also been reported that lower pH ranges (pH 5.2 - 5.4) may be necessary for minimal incidence of soil rot caused by Steptomyces ipomoea (Bouwkamp, 1985).

Optimum growth temperatures range between 24 - 35°C, while at temperatures lower than 10°C, growth ceases altogether (Kay, 1973; Bouwkamp, 1985). At higher altitude areas where temperatures are cooler, growth cycles are increased and yields considerably reduced (Alvarez, 1987).

As sweet potato roots are capable of permeating to deep layers in the soil, the crop is hardy and exhibits considerable drought tolerance. However, for optimal growth, sweet potatoes require at least 50cm of rain during their growing season and an annual rainfall of 75 - 100cm (Kay, 1973). Despite their drought tolerance, yields can be very much reduced if a water shortage occurs 50 - 60 days after planting when storage root initiation has begun (Kay, 1973).

Light intensity and day length are other factors

which determine the performance of sweet potato. Sweet potato is a sun loving crop and does best where the light intensity is relatively high (Onwueme, 1982). Short days with low light intensity promote root formation, while long days tend to favour vine development at the expense of the storage roots (Onwueme, 1982; Kay 1973). Exposure of the root system to light prevents formation of storage root (Onwueme, 1982). When roots have been formed and are growing, exposure to light results in a cessation of root enlargement, a decrease in starch content, and an increase in the fiber content of the root (Hozyo and Kato, 1976). Roots whose growth have been curtailed or retarded can be reversed by restoration to darkness (Onwueme, 1982).

The amount and nature of fertilizer in the soil also affects root development. Thus, excessive nitrogen fertilizer in the soil has been reported to delay root formation (Onwueme, 1982).

2.3.2. LAND PREPARATION, PLANTING AND WEEDING

Sweet potatoes can be planted on flat land, mounds or ridges. The growing of sweet potatoes on flat land is practiced to a limited extent as it results in low tuber yield (Kay, 1973). However, others contend that sweet potatoes planted on flat

land can be harvested over a long period (Ndolo, 1989). Planting on manually prepared mounds is widely practised in tropical areas. In the Western parts of Kenya, it is almost universally practiced. Sweet potato planted on mounds give good yields and bigger tubers (Kay, 1973; Onwueme, 1982; Ndolo, 1989). In soils with high water table, this practice might appear mandatory as the mounds raise the growing tubers sufficiently high to avoid waterlogging (Kay, 1973). However, mound preparation is a labour intensive field operation and where cheap labour is unavailable, it might be dispensed with altogether (Onwueme, 1982). Planting on ridges seems to be the most widely accepted practice. It is not as labour intensive as with mounds and gives equally good or even better yields (Ndolo, 1989; Onwueme, 1982 and Kay, 1973).

Vine cuttings are usually the recommended planting materials (Onwueme, 1982). Generally, vine cutting is a good means of propagation as: (1) plants derived from vine cuttings are free from soil borne diseases, (2) by propagating with the vines, the entire tuber harvest can be saved for consumption or utilization instead of reserving some of it for planting purposes, (3) vine cuttings yield more heavily than setts (sprouted tubers), and produce tubers of

more uniform size and shape (Onwueme, 1982). Vine top cuttings are generally preferred, although mid-vine cuttings may be used (Shanmugavelu et al., 1972). The yield of storage roots tend to increase with increase in the length of the vine cutting used, but a length of 30 cm is generally recommended (Onwueme, 1982).

The vine cuttings are inserted into the soil at an angle so that one half to two-thirds of its length is beneath the soil (Onwueme, 1982). Field spacing on mounds or ridges is determined by (1) the growth habit and root setting characteristics of the cultivar, (2) type and fertility level of the soil, (3) length of the growing season. (Kay, 1973). Generally, the vines are normally planted 25 - 30 cm apart on ridges set 60 - 75 cm apart. Where the plants are grown on mounds, two or three vine cuttings may be planted on each mound placed 0.7 - 1 m apart (Onwueme, 1982).

Weeding is not very critical in sweet potatoes as the plant rapidly develops a canopy which suppresses the weeds underneath. However, it may be necessary to do a hoe weeding about four weeks after planting (Onwueme, 1982). Weeding can be advantageous especially when carried out at the onset of storage root development. During weeding, the soil is bulked and heaped around the stems and vines to encourage devel-

opment of more storage roots. This leads to increase in yields (Ojijo,1990).

2.3.3 HARVESTING SWEET POTATOES

2.3.3.1. TIME OF HARVEST

Criteria such as mean yield, grade or amount of nutritional components of roots may be used to determine time of harvest. Edmond and Ammerman (1971) have reported that the yield per acre of tubers of three varieties of sweet potato tested in various locations in the U.S.A increased with the time of harvest. The colour and carotene contents were also shown to increase with time of harvest. As there is no time after planting for which the tuber yield or carotene content is maximum, these indices do not assign a definite harvest date and this would be a decision undertaken arbitrarily by the person concerned.

However, where sweet potato is grown as an annual crop, a growing period of 3 - 8 months depending on the cultivar and the prevailing environmental situation has been recommended (Kay, 1973; Onwueme, 1982).

The time of harvest can also be ascertained by foliage senescence manifested by a yellowing and falling of leaves, and when the sap exuded from severed roots does not readily darken (Onwueme, 1982;

Kay, 1973). Where sweet potato is planted on mounds, it is a common practice by traditional small scale farmers to start harvesting when lines of cracks develop on the mounds. According to CIP, sweet potatoes are mature when weight of roots reach 100g (Ojijo, 1990). When to start harvesting can therefore be ascertained by sampling of representative roots and weighing them at periodic intervals after onset of tuberization.

2.3.3.2 MODE OF HARVESTING

Sweet potato is generally harvested as needed (also referred to as sequential or piece-meal harvesting) when the roots have matured (Onwueme, 1982). In Kenya, this mode of harvesting is the most prevalent, although some farmers have practised bulk harvesting (Ojijo, 1990) occasionally. As the roots are left out in the field and harvested only when required, piece-meal harvesting can be seen as a form of storage method. Despite its popularity, this method of harvesting sweet potatoes has many attendant disadvantages. Many of the roots are past their prime at the time when they are harvested and the damage resulting from the sweet potato weevil is enhanced when harvesting is delayed (Onwueme, 1982). Furthermore, when the roots are left out for a long time in the field, massive losses from marauding rodents and burrowing

animals as well as from nocturnal animals like porcupines can be incurred. Also, as population density increases and land gets more scarce, especially in high population density areas, retaining the sweet potato crop in the field for a long time may be undesirable as the same field would be required for cultivation of other crops. Needless to say, when the roots are left out in the field for a prolonged time, there is bound to be appreciable loss of nutritional and culinary qualities. Sequential harvesting therefore seems a besieged practice and a great need exists for developing adequate storage facilities so that sweet potatoes can be harvested once in bulk and stored.

In a preliminary survey carried out by this author among some sweet potato growing communities in Kenya, sporadic cases exist where some farmers have practiced bulk harvesting and stored the harvested roots in the soil or in saw-dust. Despite the fact that sweet potato is highly perishable, such farmers could manage to store the roots for a good length of time (one month). Where bulk storage of sweet potatoes has been widely practiced like in U.S.A (Edmond and Ammerman, 1971), special sophisticated storage structures with temperature, relative humidity, light and ventilation control devices have been

employed. This is an expensive method in a third world situation like Kenya. The method becomes even more unpopular as the economic returns from growing sweet potatoes is not very impressive to warrant such massive capital investment (Gor, 1989). The traditional storage techniques pointed above therefore present us with practical simplistic approach towards development of more viable storage systems in our own situation.

As sweet potato is almost wholly grown on a small scale basis in Kenya, harvesting is done manually usually by women (Ndolo, 1989). Mechanization may be applied where large scale production is involved and a good account of mechanical harvesters developed in the U.S.A has been given by Edmond and Ammerman (1971). Whichever method of harvesting is employed, minimal damage to roots should be ensured to prevent impairment of storage life (Onwueme, 1982).

2.4 CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF SWEET POTATO ROOT

2.4.1 SWEET POTATO ROOT

The storage roots of sweet potato develop as a result of the secondary growth of a few specialised roots within 20 - 25 cm of the soil. Such roots destined to become tuberous or storage roots are

structurally different from the ordinary fibrous roots in that they have a different number of xylem points, they possess a small pith at the center, and the root primordia which give rise to them are slightly larger than those of ordinary roots (Onwueme, 1982).

Basically, the sweet potato roots are similar to the white potato tubers although differences exist with regard to size and the nature of secondary differentiation of tissues. As in the white potato, the sweet potato root is bounded by an outer periderm which consists of dead cells several layers thick and pierced by lenticels (Burton, 1982). Beneath the periderm is the parenchymatous cortex which forms the major part of the root and is the seat of storage parenchyma (Burton, 1982). Starch deposition in the cells of the cortex contribute to the bulk of the root (Onwueme, 1982). Further development of the tuberous roots depend on an increase in both the number and size of cells in the stele (vascular bundles) and on the development of starch granules in the cells (Hahn and Hozyo, 1984). Most of the storage tissues of sweet potato arise through the meristematic activity of the vascular cambium and the anomalous cambium formed from individual vessels within the primary xylem (Onwueme, 1982). Due to deposition of starch in the storage parenchyma, the tissues appear white

(Burton, 1982), but depending on the relative proportions of carotenoids and anthocyanin pigments present, the storage tissue may vary in colour from white, cream, orange, yellow or pink.

2.4.2 DRY MATTER OF ROOTS

The nutritionally important components of the tuberous roots reside in the dry matter portion. The dry matter content is therefore an indication of the quantity of nutritional components of the roots. Several factors, however, affect the extent of dry matter yield in sweet potatoes. The rate of dry matter accumulation in the root tuber depends on the cultivar (Austin and Aung, 1973). Cultivars with high sink demands encourage increased production of photosynthate by the source (leaves) with consequent increase in dry matter accumulation in the sink or tuberous roots (Wilson, 1982). Increased moisture content of the soil especially under supplemental irrigation has been reported to decrease the dry matter content of roots (Constantine *et al.*, 1974; Ton, 1978). Soil temperature also affects storage root growth and hence dry matter productivity. Spence and Humphries (1972) have reported a 81% increase in dry matter productivity at 25°C root temperature compared with 15°C. Basing their findings on two

cultivars grown under different soil pH conditions, Constantin et al. (1975) reported that the cultivars grown in soil pH 4.4 to 5.1 had a higher dry matter content than those grown in pH 5.3 to 6.3 or pH 6.4 to 7.2. Seemingly, higher pH or less acidic soils lower the dry matter yield. Nitrogen fertilizer application reportedly does not affect dry matter accumulation (Constantin et al., 1974) although it affects the development of storage roots (Wilson, 1967). High levels of soil nitrogen stimulate vine growth at the expense of the storage roots (Stino and Lashin, 1953) resulting in reduced dry matter yield. High potassium levels in the soil has been reported to reduce dry matter content of roots (Constantin et al., 1977). However, other beneficial effects of potassium in influencing storage root enlargement, increasing the photosynthetic rate (Tsuno and Fujise, 1965) and in increasing the concentration gradient between source and sink (Murata and Akazawa, 1968) are compensatory resulting in substantially higher yields in the plants with the net effect of more dry matter per hectare (Constantin et al., 1977).

According to Purcell et al., (1976), the dry matter content of sixteen sweet potato cultivars harvested on four different dates decreased at a linear rate. On the contrary, Scott and Bouwkamp

(1975) have reported a slight increase in dry matter content with chronological age of roots for four cultivars tested. Agata (1982) has reported a linear increase in dry matter over the growing period till harvest. Harvesting was done after about five months. Bourke (1985) reported that the dry matter yield of sweet potatoes increased with the growing period upto a maximum at about peak flowering period and thereafter declines. The effect of growing period on dry matter content of storage roots may be important in determining the harvest date at maximum dry matter yield. Other climatic and agronomic factors may still affect the dry matter content of tuberous roots as well as the dry matter yield in general adding more to the variability in reported literature values. Table 2.3 gives the dry matter content of some sweet potato cultivars reported by three different sources.

2.4.2.1 CARBOHYDRATES

The major part of sweet potato roots is made up of carbohydrates. According to Palmer (1982), upto 90% of the dry weight of sweet potato roots is made up of carbohydrates. The major carbohydrate components are starch, sugars and fibre (cellulose, hemicelluloses and traces of lignin) (Collins, 1987). Of these, starch is the predominant making up to 29% of the fresh tuber weight (Onwueme, 1982). Starch exists

Table 2.3: Proximate Composition of Sweet Potato Roots

Dry Matter %	13[a] - 32	19[b] - 50	20[c] - 37
Protein, % (N x 6.25	1.0 - 4.0	0.95 - 2.4	1 - 3
CHO, %	6.6 - 2.7	10.3 - 37.9	18 - 33
Crude Fibre, %	0.8 - 1.9	0.5 - 7.5	1 - 2
Fat, %	0.17 - 1.0	Trace	Trace
Ash, %	0.74 - 1.70	0.88 - 1.38	Not Indicated by autho

Sources:

[a] Bradbury and Holloway (1988)

[b] Onwueme, (1982)

[c] Burton (1982)

as granules containing two polymers of glucose, amylose and amylopectin, which are evenly distributed throughout the granules and are associated with each other by hydrogen bonds (Karel, 1975) and probably physical tangling and knotting of the molecular chains (Ojijo, 1990). In sweet potato, the starch is composed of 70% amylopectin and 30% amylose (Collins, 1987 and Onwueme, 1982). They did not specify the varieties used. During the initial stages of sweet potato tuber development, the amylose content of starch granules are reportedly high and decreases progressively with development (Fujimoto et al., 1972). The average chain length of amylose molecules also seems to be much longer at early stages of development (Fujimoto, et al., 1972). In addition, varietal variation in amylose content has also been reported (Tsou and Hong, 1989). Varietal differences also exist with regard to physico-chemical properties such as gelatinization temperatures, retrogradation properties, enthalpy needed for gelatinization and susceptibility to pancreatic digestion (Tsou and Hong, 1989). The phosphorous content of sweep potato starches susceptible to pancreatic digestion have also been found to be slightly lower than that of resistance lines (Tsou and Hong, 1989). The characteristics of lower phosphorous and high amylose contents may then be associated with the susceptibility to digestive

enzymes although seasonal effects also have a bearing on sweet potato starch digestibility (Tsou and Hong, 1989). According to a review by Gracza (1965), phosphate groups in starch are attached to C-6 carbon of D-glucose in close proximity to the branch points. This means that the phosphorous in starch are associated with α -1,6- glycosidic linkages. In white potato, the amylopectin contains more esterified phosphate than the amylose while phospholipids are primarily associated with the amylose (Gracza, 1965). The small amount of phosphorous found in amylose is suggestive of a few α-1,6- linkages to phosphate which imparts α-amylase resistance to the neighbouring glycosidic linkages. In addition, during gelatinization, the swelling behaviour of starch is controlled by the strength and character of the miscellar network within the granule, which in turn depend on the degree and kind of association (Leach, 1965). The degree of association is affected by, among other factors, the ratio of amylose to amylopectin. Starches with high amylose are very highly associated and have limited swelling and solubilization (Leach, 1965). Presence of ionizable esterified phosphate groups assist swelling due to mutual electrical repulsion (Leach, 1965). Starch granules with high amylose content and low amounts of phosphate groups will

therefore have limited swelling ability during gelatinization and consequently low digestibility.

As a nutritional constituent, starch is the principal energy source of sweet potatoes (Tsou and Yang, 1984). However, the poor digestibility of sweet potato starch (Tsou and Hong, 1989) has been implicated as a flatulence inducing factor (Tsou and Yang, 1984; Palmer, 1982). Flatulence is a major cause of resistance to eating sweet potatoes (Tsou and Villareal, 1982; Palmer, 1982). It is reportedly caused by starch and indigestible fibre residues in sweet potato (Tsou and Yang, 1984). Induction of flatulence by sweet potato in experimental rats is reportedly variety specific among sweet potato cultivars (Tsou and Yang, 1984). However, effect of gas formation can be reduced through cooking. Once starch is properly gelatinized, flatulence induced by sweet potato starch is very low (Tsou and Yang, 1984). Palmer (1982), reported that certain key textural attributes contributory to sweet potato acceptability are affected by the starch content. These include firmness of canned sweet potatoes, mouthfeel characteristics of baked potatoes and moistness of baked potatoes. In addition, starch is also contributory to the development of culinary qualities of cured and processed sweet potato roots by the action of amylolytic enzymes

(Hamann et al., 1980).

Tsou and Yang (1984) working on four cultivars found that sucrose was the main free sugar in raw sweet potatoes. The total sugar content varied from 13.8 to 28.1% dry basis, while no fructose was detected in all the lines tested. In cooked roots, maltose is the major free sugar (Collins, 1987). Sucrose may be thermally degraded into invert sugars on cooking. Generally, there are two amylolytic systems in sweet potatoes, one responsible for maltose formation during heat processing and the other responsible for formation of monosaccharides and sucrose during raw roots storage (Deobald et al., 1969). The development of flavour during cooking of sweet potato is due to β-amylase activity which converts short chain dextrins into maltose. During storage, α-amylase activity predominates. This enzyme splits the bonds in the interior of the starch substrate forming dextrins and reducing sugars (Karel, 1975). The polymeric structure of starch is greatly degraded by the action of this enzyme causing important textural changes. In baked sweet potatoes, mouth-feel characteristics are due to β-amylase activity (Collins, 1987; Walter et al., 1975).

As with other carbohydrates, the level of sugars in sweet potato roots is affected by cultivar, culti-

vation practice, cooking, storage, curing, processing and the method of analysis (Palmer, 1982). Scott and Bouwkamp (1975) working with four cultivars failed to show a trend in total and reducing sugars with regard to chronological age of sweet potato roots.

Fiber consists of cellulose, hemicellulose and some materials that encrust the cell walls such as lignins and pectic substances (Meyer, 1960; Hodge and Osman, 1976). Only 20 - 50% of total dietary fiber is represented by the residual crude fibre determined by proximate analysis (Hodge and Osman, 1976). The crude fibre may vary with climatic, soil conditions and degree of maturity (Meyer, 1960). In sweet potatoes, the fiber may form upto 2% of fresh weight (Burton, 1982). It is reportedly increased by increased application of K-fertilizer to growing roots (Constantin et al., 1977). The pectic constituents of sweet potato fibre are important in the rheological properties of cooked tubers (Wanda and Walter, 1985). Also as reviewed by Palmer (1982), they are responsible among other constituents for texture and viscosity of canned sweet potatoes, hard core formation in chilled roots, and moistness of baked roots. The likely health benefits of sweet potato dietary fibre have been reported (Palmer, 1982). In fact, Huang (1982) demonstrated a hypocholesterolemic effect (reduction of

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serum cholesterol and total lipids) in rats fed dietary fibre isolated from a sweet potato cultivar. Cholesterol is synthesized in many organs of the body as well as being absorbed from the diet. It can be eliminated from the blood stream into the small intestine via the bile either in its original form or after conversion into conjugated bile acids in the liver (Coates, 1983). As they pass along the intestine the bile acids and cholesterol are largely reabsorbed in the enterohepatic cycle. Those that escape absorption undergo microbial modification into different end products which appear in the feaces (Coates, 1983). Certain components of dietary fibre are able to bind bile acids thereby preventing their reabsorption from the intestines and increasing their excretion (Leveille, 1977). Cholesterol synthesis and the degradation of cholesterol into bile acids are under feedback control (Leveille, 1977). Removal and subsequent excretion of bile acids after binding with dietary fibre ensures conversion of cholesterol into bile acids hence reducing the level of serum cholesterol. Only certain food fibres are capable of this hypocholesterolemic effect and sweet potato fibre seems to be one of them. Other sweet potato cell wall polysaccharides consisting mainly of cellulose and hemi-cellulose have been shown to suppress digestibility of gelatinized starches by porcine pancreatic α-amylase

(Ontani and Mizaki, 1985). The non-digestible fiber fractions may also be a flatulence inducing factors in sweet potatoes (Tsou and Yang, 1984).

2.4.2.2 PROTEIN

The variability in protein content of sweet potato roots is evident from Table 2.3. According to Yang (1982), the protein content of sweet potato tubers depends on the cultivar, season and location of cultivation, growing period, and the nature and level of application of fertilizers. Increased application of K and P to the soil results in reduced protein content of roots (Constantin et al., 1977), while increased application of N results in increased protein content (Constantin et al., 1974). Protein content of roots is also reduced by high soil moisture levels especially under supplemental irrigation (Constantin et al., 1974). As the growing period progresses, the protein content of sweet potato roots decrease (Yang, 1982). Infact, a rate of decrease of 0.0067% per day has been reported by Purcell et al. (1976) for 16 cultivars investigated.

According to Walter and Purcell (1986), 60 - 80% of nitrogenous material of sweet potato roots is protein and the remainder is mostly amino and amide nitrogen. About two-thirds of the protein is globulin in nature (Onwueme, 1982; Huang, 1982). The protein

has been separated into white and chromoplast fractions having varying mineral and amino acid profiles (Walter and Catignani, 1981). The chromoplast fraction had a higher iron and some essential amino-acid content than the white fraction. Sulphur containing amino acid profile was lower in casein than in the chromoplast fraction while the white fraction was deficient in lysine compared to FAO standard (Walter and Catignani, 1981).

Generally, sweet potato protein is of good nutritional value with reasonable amounts of essential amino-acids although limiting in sulphur containing amino-acids (Onwueme, 1982). Table 2.4 gives the amino-acid profile of sweet potato protein. There is however, an excess of lysine suggesting its potential usefulness as a suplement to grain products (Purcell, et al., 1978). According to Yang (1982), when 30% of wheat flour was replaced by sweet potatoes, the biological value (BV) increased from 72 to 80 for male rats and from 65 to 71 for female rats. When part of a rice diet was replaced by sweet potato, the BV increased from 87 to 89 for male rats and from 80 to 83 for female rats. The protein does not occur in sufficient amounts to provide adequate protein-calorie ratio (Purcell et al., 1987), but a 13% equicalorie sweet potato substitution in place of rice has been

Table 2.4: Essential Amino-acid Composition of Sweet Potato Root Protein (mg per 100g edible portion)

	N(g)	Total	Cys	Ile	Leu	Lys	Met	Phe	Thr	Tyr	Trp	Val
Yellow, raw	0.19	376	13	44	65	40	46	46	29	21	57	59
Pale, raw	0.19	376	13	44	65	40	46	46	29	21	57	59

Source: West et al. (1988)

shown to enhance human nutrition (Yang, 1982). If sweet potatoes contribute over 90% of total calories in a diet, protein deficiency is likely to occur and therefore supplementation with protein rich foods like fish is necessary (Huang, 1982).

According to Walter and Catignani (1981), the protein efficiency ration (PER) values of two cultivars of sweet potato tested were equal to the ANRC reference casein value. These authors also reported that the Net Protein Ration (NPR) estimate for sweet potato protein was equal to that of casein. However, protein true digestibility of precooked high rice and precooked wheat flour were found to decrease when substituted with 30% precooked sweet potato (Yang, 1982). This was attributed to presence of trypsin inhibitor in sweet potato.

Three different trypsin inhibitors have been isolated in sweet potato (Suguira et al., 1973). These were found to exhibit three characteristics namely: they were strong inhibitors of trypsin, weak inhibitors of plasmin and kallikrein and did not inhibit pepsin or chymotrypsin. Dickey and Collins (1984), reported a significant gradient of trypsin inhibitor activity dependent on the cultivar. The highest levels of activity were found at the proximal or stem end of roots which is also the point of pro-

tein concentration. Also, in all the cultivars investigated, a high level of trypsin inhibitor activity occurred in the cortical region. Fortunately, sweet potato trypsin inhibitors are not heat stable and ordinary baking or boiling is enough to reduce the activity to insignificant levels (Dickey and Collins, 1984). Heat processing, however, has been reported to lower bioavailability of lysine depending on its severity and the amounts of reducing sugars present during heating (Walter and Purcell, 1986).

2.4.2.3 FAT

Sweet potatoes generally contain little or trace amounts of fat in the tuberous roots (Bradbury and Holloway, 1988; Onwueme, 1982; Burton, 1982; Lee and Lee, 1972). Of the little that is present, Lee and Lee (1972) have reported the important lipid constituents fractionated by thin layer chromatography (TLC). The sweet potato cultivar tested contained 1.75% total lipids on dry basis. Of this, free lipid accounted for 0.95% and the rest of 0.85% were bound lipid. The free lipid fraction had 13 components while the bound lipid fraction had 9 components of which 34.5% were phospholipids and 17.2% free fatty acids. The free fatty acids consisted mainly of 30.1% palmitic acid, 16.7% linoleic acid, 15.8% oleic acid and 9.8% linolenic acid.

2.4.2.4 VITAMINS

Freshly harvested sweet potato roots can contain considerable amounts of vitamin C and the deep yellow varieties can provide sufficient quantities of pro-vitamin A carotenoids (Huang, 1982; Woolfe, 1989; Kay, 1973). Vitamin B_1 or thiamine also occurs in large quantities from 0.8 to 1.0 mg/1000 kCal, about twice the level required by humans (Huang, 1982). Other vitamins of importance and their respective composition in the sweet potato roots are given in Table 2.5 (Burton, 1982; Bradbury and Holloway, 1988). However, the amounts of these vitamins available for nutrition will depend on a number of factors such as post-harvest handling methods, processing prior to utilization and duration and conditions of storage. Vitamin C is especially labile and deteriorates rapidly post-harvest. Ascorbic acid is readily oxidized into dehydro-ascrobic acid in the presence of ascorbic acid oxidase, high pH conditions and catalytic metals such as copper. Dehydro-ascorbic acid has 80 - 100% of the activity of ascorbic acid (Cooke, 1974) and when oxidation of ascorbic acid proceeds only to this extent, loss of antiscorbutic potency of sweet potato roots can be considered minimal. In fresh foodstuffs, the level of dehydroascorbic acid is relatively small and for practical purposes can be ignored in the

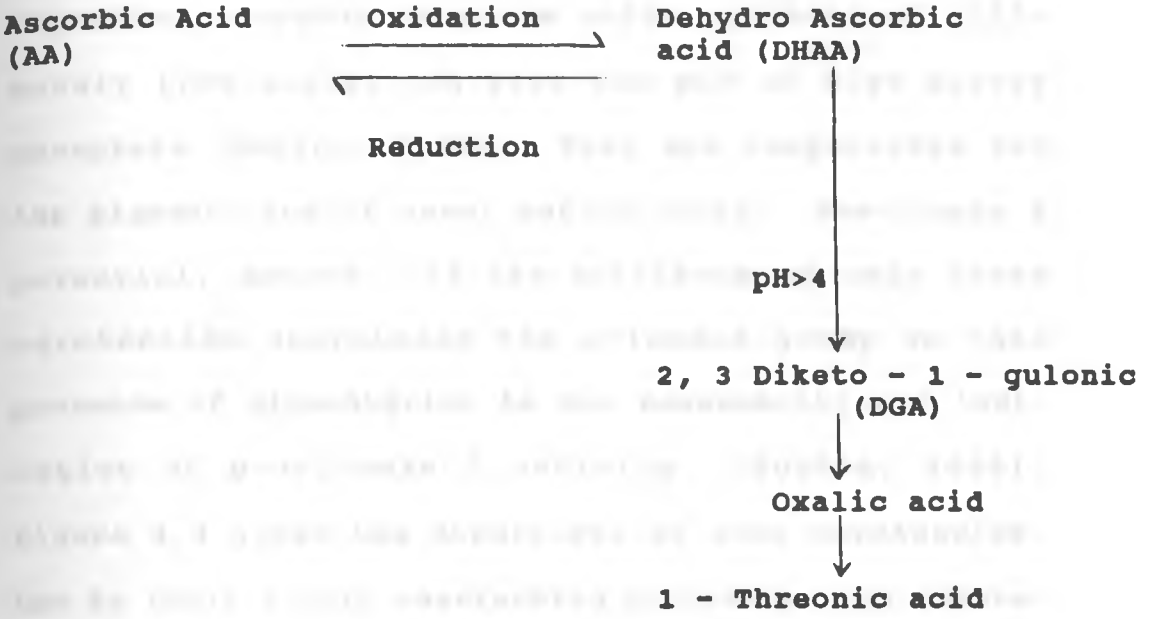
Table 2.5: Vitamin Composition of Sweet Potato Roots (mg/100g)

Provitamin A	4[a]	0.11 - 2.7[b]	Vit. B_6	0.22[a]	-[b]
Thiamine	0.10	0.086 - 0.16	Folic Acid	0.05	-
Riboflavin	0.06	0.028 - 0.7	Pantothenic Acid	0.9	-
Nicotinic acid	0.8	0.45 - 1.14	Vit. D	0	0
Vitamin C	25	11 - 58			
Vitamin E	4	-			

[a] Burton (1982); [b] - Bradbury and Holloway (1988)

chemical estimation of vitamin C content using oxidizing dyes like bromosucciinimide (Cooke, 1974). Dehydro-ascorbic acid can, however, be irreversibly oxidized further to form diketogulonic acid which is biologically inactive and does not posses antiscorbutic activity. The oxidative degradation of ascorbic acid is represented in Figure 2.2 (Cooke, 1974). Anaerobic vitamin C degradation is much lower than catalyzed vitamin C degradation and is maximum at pH 4 and minimum at pH 2 (Ojijo, 1990). The extent of loss of vitamin C can be indicative of the degree of sweet potato deterioration in storage. Post-harvest storage will affect the anti-ascorbutic value of sweet potato roots to an extent commensurate with the time and temperature of storage, extent to which cellular tissue may be damaged and extent of ascorbic acid oxidase activity (Oliver, 1967). Boiling sweet potato roots can also result in extensive loss of vitamin C mainly through leaching and high temperature enhanced oxidation. According to Bradbury and Sing (1986), the loss of total vitamin C - ascorbic acid and dehydroascrobic acid - can be upto 65% on boiling if water is discarded, 20% if water is retained and 50% on baking. Woolfe (1989) has reported that the percent daily requirement of an adult person's vitamin needs suppled by 100g of boiled sweet potato roots are: vitamin A - 100%, thiamine - 5%, riboflavin -

Figure 2.2: Degradation of Ascorbic Acid

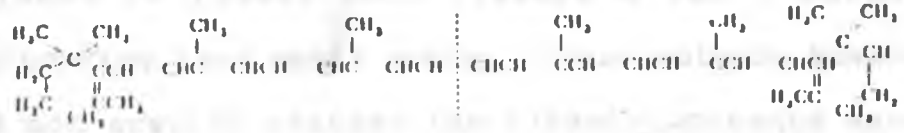


Source: Cooke (1974)

upto 8%, niacin - 3%, folic acid - 6%, vitamin B_6 - upto 11% and ascorbic acid - 57%.

The carotenoids are tetraterpenes made up of 8 repeating 5-carbon isoprene units synthesized ultimately from acetyl coA with the aid of high energy phosphate (Burton, 1982). They are responsible for the pigmentation of sweet potato roots. Provitamin A potential, however, is the attribute of only those carotenoids containing the β-ionone group so that presence of pigmentation is not necessarily and indication of provitamin A activity (Burton, 1982). Figure 2.3 gives the structures of some carotenoids. Due to their highly unsaturated structure, the carotenoids are potentially very reactive although they are very stable in the intact living plant tissues (Burton, 1982). β-carotene is the most important and predominant provitamin A carotenoid. The native all-trans stereo-isomeric form of it is very stable but photodegradation can lead to formation of its cis-isomer which has a lesser pro-vitamin A potential (Pesek and Warthesen, 1988). Losses in β-carotene or pro-vitamin A potential in sweet potato roots can also result during storage and processing although to a lesser extent than vitamin C (Woolfe, 1989). Increase in carotene content during storage of sweet potato roots has also been reported (Burton, 1982). According to Lanier and Sistrunk (1979) large roots have

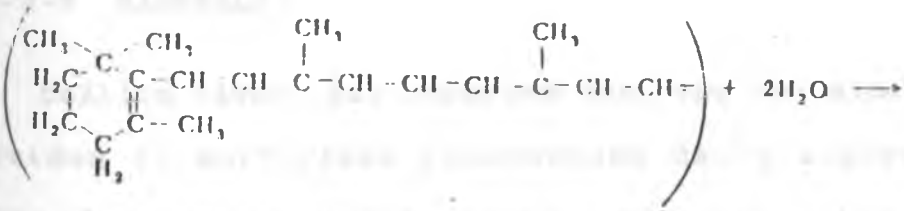
ig. 2.3: Structures of some Carotenoids and Vitamin A



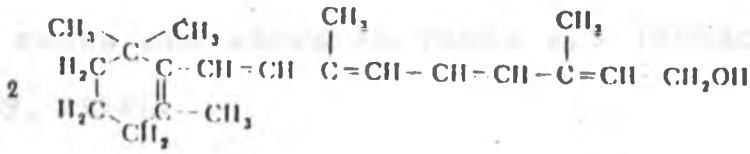
γ Carotene

α-Carotene

β-carotene



β Carotene



Vitamin A

Source: Meyer (1960)

been found to retain both vitamin A and C better during cooking than small roots. These authors however did not specify whether the vitamin contents were higher in large raw roots than in small ones. The better retention of vitamins in large roots could also be due to overcooking of the small roots if both categories of roots were given same cooking times. According to Pol et al. (1988), the vitamin A potency of β-carotene was reduced by 2 - 12% by the presence of cis-isomers in raw vegetables. Isomerization on cooking enhanced this loss upto 9%. These losses were however based on leafy vegetables, probably similar modes of losses occur in cooked tuberous roots. Bouwkamp and Kantzes (1977) have reported that carotene contents of sweet potato roots were not increased by the application of nematicides 1 - 2 weeks before transplanting.

2.4.2.5 MINERALS

Collins (1987) has reported that the two minerals provided in sufficient recommended daily allowance (RDA) from sweet potato roots are iron - 10% and potassium - 15% . The mineral composition of sweet potato roots are shown in Table 2.6 (Bradbury and Holloway, 1988).

Table 2.6: Mineral Composition of Sweet Potato Roots (mg/100g)[a]

Ca	21 - 110	Cu	0.15 - 0.17
P	30 - 94	Zn	0.21 - 0.59
Mg	12 - 62	Mn	0.11 - 0.25
Na	1 - 52	Al	0.82
K	260 - 530	B	0.10
S	13 - 16		
Fe	0.4 - 4.5		

[a] Bradbury and Holloway (1988)

2.5 SWEET POTATO STORAGE

2.5.1 THE NEED FOR SWEET POTATO STORAGE

Detachments of sweet potato roots from the parent plant heralds several deteriorative processes including water loss, depletion of metabolic substrates and accumulation of harmful products of metabolism. The root tissues become susceptible to invasion by parasitic micro-organisms whose attack is accentuated by mechanical damage afflicted during handling of the roots. This underlines the perishability of sweet potato roots. However, as with other root crops, sweet potatoes exhibit a period of dormancy thus enabling them to be stored for short periods (FAO, 1989a). It can thus be said that the extent of sweet potato root storage life depends partly on the successful manipulation and prolongation of this dormancy period.

The perishability and hence the problem of sweet potato storage has been circumvented by widespread practice of piece-meal harvesting. However, the limitations of this system of harvesting have been outlined in a preceding section of this study (see 2.3.2) where it was argued that a need exists for the development of adequate storage facilities to enable bulk harvesting and storage of sweet potato roots. The storage of sweet potato roots can also be looked

at in terms of its economic implications. The principal economic features in any storage system include investment in the storage plant and the return on the investment due to sales of stored produce (Hinton, 1973). Among other factors, the return on investment is affected by the price received for the stored produce. This price would be regulated *inter alia* by advantageous selling in the open market at times of relative shortage (Hinton, 1973). The pricing of sweet potato roots at wholesale markets in Kenya is characterized by a fluctuating regime, with lowest prices occurring at harvest seasons and peak prices at times of the year with relative shortage (Gor, 1989). Suitable storage facilities can be built to extend the marketable life of produce and hence the marketing season (Hinton, 1973). With storage, sweet potatoes can be bought by consumers out of season with the resultant economic merit of raising the price of the whole crop. Storage and pre-storage practices like curing also have important organoleptic consequences. Due to carbohydrate changes that take place during curing and storage of sweet potatoes (Picha, 1987) enhancement of culinary quality and sensory properties result (Walter, 1987). Curing has been found to attenuate the flavour and texture of baked sweet potatoes (Hamann, *et al.*, 1980).

2.5.2 SWEET POTATO STORAGE STRUCTURES

In most tropical countries, sweet potato roots may be stored in underground pits covered with grass or the tubers may be kept on platforms or in baskets (Onwueme, 1982). In Kenya, storage of sweet potato roots is virtually non-existent save for certain sporadic cases of rudimentary underground pits covered with grass or soil (Ojijo, 1990). As already alluded to in Section 2.5.1, piece-meal harvesting has been widely undertaken to obviate storage.

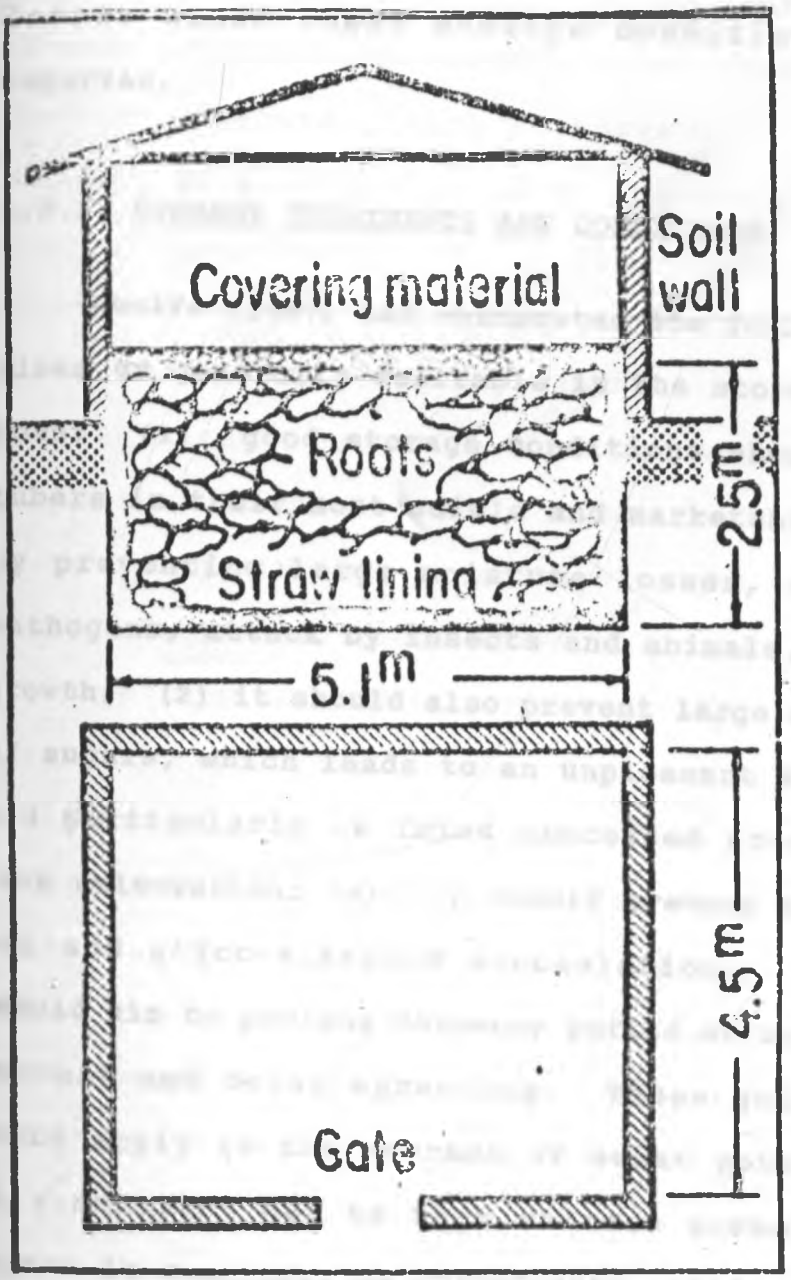
That sweet potatoes have been stored under these seemingly primitive structures points to the fact that there were benefits derived from the practice. An elucidation of the nature and extent of losses pertaining to sweet potato roots stored under these conditions, which is partial concern of this study, would be a major step towards their improvement. The potential advantages of such structures are their simplicity and low costs of construction rendering them suitable to a third world situation pertaining in Kenya.

However, due to considerable global disparities in economic and technological development and even in annual weather regimes, other countries have developed

sweet potato storage structures of varying sophistication. For example, in the U.S.A, developments in sweet potato storage have been with regard to structures with provisions for temperature and relative humidity controls (Edmond and Ammerman, 1971). It is an established fact that sweet potatoes exhibit a critical temperature range of 12 - 15°C within which storage can be optimal (Uritani et al., 1984). Reduction in excessive moisture loss is also achieved by maintaining sufficiently high relative humidities of the range 85 - 90% (Hamann et al., 1980; Uritani et al., 1984). Developed countries have therefore invested in huge storage houses which are air conditioned with insulation, lighting, humidification and heating devices (Edmond and Ammerman, 1971). Such store houses can handle huge bulks of sweet potato roots and in most cases the operations are mechanized. In other parts of the world, sweet potato storage is undertaken advantageously at certain times of favourable weather conditions. According to Hong (1982), sweet potatoes can be stored for upto seven months in Korea, mostly during winter in specially designed underground storehouses. The temperatures in these storehouses are controlled not by artificial heating systems but by natural ambient temperatures. This is an advantage unimaginable in tropical countries like Kenya where ambient temperatures for most periods of

the year are above optimal storage temperatures for sweet potato and encourage extensive loss notably through sprouting and microbial proliferation. The Korean storage structures are designed such that the temperatures inside are below the optimum range for sweet potato (12 - 15°C), but is brought to near optimality when the roots are introduced. An example of an indoor semi-underground storage structure which reportedly achieves 100% storability with minimal sprouting of roots is reproduced in Figure 2.4 (Hong, 1982). Elsewhere in Bangladesh, Jenkins (1982) has reported losses of 20 - 25% when tubers are stored for 2 - 4 months in shallow piles on the earthen floors of farm houses at 24 - 35°C and 70 - 90% RH. Large variations in temperature and relative humidity were definitely responsible for the loss. In the Phillipines, sweet potato tubers have been stored for upto 3 months in ventilated village storage structures in which the relative humidity may be controlled at ambient temperatures (Data et al., 1987). It seems that application of ash on sweet potato roots destined for storage is a village practice in Malawi. However, Kwapata (1984) has reported that this practice does not necessarily increase the storageability of sweet potato roots. Winarmo (1982) has also reported earlier accounts of sweet potato storage in pits between

Fig. 2.4: Indoor Semi-underground Storage of Sweet Potatoes in Korea



Source: Hong (1982)

layers of wood ash, earth (soil) and straw. In India, the roots are spread in the sun for a week and then stored in a well ventilated room with frequent inspections to eliminate any unhealthy roots. Extent of losses under these storage conditions were not reported.

2.5.3 STORAGE TREATMENTS AND CONDITIONS

Woolfe (1987) has enumerated the following conditions as generally desirable in the storage of potatoes: (1) good storage conditions should maintain tubers in their most edible and marketable condition by preventing large moisture losses, spoilage by pathogens, attack by insects and animals, and sprout growth; (2) it should also prevent large accumulation of sugars, which leads to an unpleasant sweet taste, and particularly in fried processed products, to a dark colouration; (3) it should prevent tuber greening and glyco-alkaloid accumulation; (4) and it should aim to prolong dormancy period of roots from harvest and delay sprouting. These guidelines no doubt apply to the storage of sweet potatoes. The only contrast may be that whereas accumulation of sugars is seemingly an unfortunate artefact in potato storage, it is actually desirable to some extent in the enhancement of culinary qualities especially with

regard to flavour of baked sweet potatoes (Hamann et al., 1980). As a general principle, only roots free from disease and carefully harvested and handled should be considered for storage (Booth, 1974). Storage of bruised roots can be enhanced by exposing them to moderately high temperatures and relative humidity to facilitate healing of wounds and development of periderm (Booth, 1974). Harvested tubers meant for storage should be cured promptly so that infection by facultatively parasitic micro-organisms and undesirable moisture loss can be minimised. A comparison between cured and uncured sweet potato roots showed that the percentage weight loss in cured roots and uncured roots after a storage duration of 113 days were 17% and 42%, respectively (Booth, 1974). Generally, artificial curing of harvested sweet potato roots is achieved at 30 - 32°C and 80 - 90% relative humidity for 4 - 7 days (Booth, 1974; Edmond and Ammerman, 1971; Bradbury and Holloway, 1988; FAO, 1989). Curing has also reportedly been achieved at higher conditions such as at 30 - 32° and 90 - 95% RH for 7 to 10 days (Picha, 1986a). The length of curing period seems to depend on the harvest temperature with tubers harvested at lower temperatures requiring higher temperatures and longer time of curing (Edmond and Ammerman, 1971). A natural curing

procedure which involves exposing roots wrapped in black PVC sheets to the sun for 3 - 5 days has been tried at the Coast Agricultural Research Station in Mtwapa (Ojijo, 1990). This curing procedure is simple and cheap as it does not involve expensive equipments with temperature and relative humidity control devices. However, when sun curing time is unnecessarily prolonged, significant reduction in storage aptitude of roots might result with an increase in the percentage of decayed roots (Kwapata, 1984). It has also been contended that curing can be dispensed with altogether in tropical countries especially during sunny weather when prevailing conditions at harvest can promote authentic curing (Onwueme, 1982). Harvesting regimes in such climates can be synchronised with warm weather to obviate curing. Artificial curing seems to be more critical in temperate countries where ambient conditions are not conducive to suberization and wound periderm formation for a good part of the year. The sun curing procedure was adopted in this study.

During suberization of wounded surfaces', the cells and intercellular spaces just underneath the wound become filled with sap, and there is formation of unsaturated fatty-acids which combine with oxygen of the air in the formation of suberin, a protective compound against water loss and microbial attack

(Edmond and Ammerman, 1971). According to Kollatukudy and Dean (1974), respiration of tissues increases rapidly immediately after wounding, preceding the formation of aliphatic and phenolic suberin components. The phenolic constituents are responsible for prevention of pathogen entry while the aliphatic constituents prevents water loss. It has been found that Γ-Hydroxyacids and dicarboxylic acids constitute two of the major aliphatic components of suberin (Aggrawal and Kolattukudy, 1977). In potato tubers, dicarboxylic acids constitute a major component of the aliphatic monomers of the suberin deposited in the wound periderm. Experiments with potato discs has also revealed that a wound induced Γ-hydroxyacid dehydrogenase is involved in suberin biosynthesis (Agrawal and Kolattukudy, 1977).

The protective function of the suberized layer is only temporarily effective and a more permanent periderm layer soon develops when certain cells just at the back of the suberized layer loose their large vacuoles and assume the function of meristematic cells which are collectively called wound cambium or wound phellogen (Edmond and Ammerman, 1971). These cells divide tangentially and the walls of the daughter cells finally become impregnated with suberin, tannin, and other water and fungus resistant materials called

wound cork or wound phellem (Edmond and Ammerman, 1971). Absicic acid (ABA) has been reported to induce elaboration of key enzymes responsible for suberization and wound phellem formation (Cottle and Kolattukudy, 1982). ABA can therefore be used to advantage during artificial curing. Broadly, curing promotes healing of wounds which reduces the onset of diseases which are a major source of post-harvest losses, and reduces weight loss of stored tubers due to biological processes such as respiration, transpiration and sprouting (Bradbury and Holloway, 1988). As physical or mechanical injury during growth, harvesting or post-harvest handling is almost inevitable, curing is a mandatory operation prior to storage. Successful storage of sweet potato roots therefore depends on rapid formation of wound periderm during curing and maintenance of the wound and intact periderm in healthy condition during subsequent storage to reduce shrinkage and rotting (Edmond and Ammerman, 1971).

After curing, storage is facilitated by temperatures of 10 - 15°C and 85 - 90% RH (Bradbury and Holloway, 1988). Temperatures below 8°C may cause chilling injury while higher temperatures beyond 15°C promote sprouting and hasten damage from fungal infection and insect infestation during subsequent storage (Bradbury and Holloway, 1988). Storage at chilling

roots. Quantitatively, Bradbury and Holloway (1988) have reported a 12% increase in sugars when sweet potatoes are stored at 8 - 10°C and 80 - 85% RH for 4 months. Baba et al., (1987) have reported an increase from 1.5% to 6.9%, dry weight basis, in reducing sugars during the first month of storage eventually stabilizing at 5% for the remainder of the duration; a linear increase in non-reducing sugar content from 4.4 to 14.2%; and a decrease in starch content from 76.8% to 66.7% over a storage duration of 6 months at 13°C. Levels of reducing sugars which accumulated in roots stored for a long period were not reduced by reconditioning at 20 - 30°C for 14 days.

According to Chang and Kays (1981), extremes in oxygen concentration (0 and 100%) increases sucrose and total sugar but decreased reducing sugars. Roots stored at low oxygen concentrations (<5%) accumulated more total sugar than roots stored in higher oxygen concentrations. It was apparent that reducing sugars were utilized via the respiratory pathway more rapidly than at higher oxygen concentrations. Production of sugars at low oxygen concentrations was seemingly greater than utilization and consequently total sugars increased at 2.5% and 5.0% oxygen. However, no significant differences in root starch content were detected between the various storage oxygen concentra-

tions during the test period (Chang and Kays, 1981), indicating that there was starch resynthesis from the sugars.

2.5.6.1.1 CARBOHYDRATE CHANGES AND CULINARY QUALITIES OF PROCESSED ROOTS

Hydrolytic degradation of carbohydrates results in accumulation of sugars responsible for enhanced flavour notes and mouthfeel characteristics in baked and cooked sweet potato roots (Walter, 1987; Bradbury and Holloway, 1988). However, prolonged storage may result in undesirable senescence sweetening (Burton, 1982).

2.5.6.1.2 CARBOHYDRATE CHANGES AND TEXTURAL PROPERTIES OF STORED ROOTS

2.5.6.1.2.1 DEFINATION OF TEXTURAL PROPERTIES

With the ever growing awareness among Food Technologists of the importance of texture as a key quality attribute in foods, several attempts have been made to enact a universal definition of the term as it applies to foods. For the present purpose, however, it will suffice to adapt the remarks due to Bourne (1982) after a review of such attempts. Firstly, it would be more appropriate to define textural properties and not just texture. This is due to the fact

that texture is composed of many different physical sensations and so it is more convenient to define textural properties, which refers to a group of related properties, rather than just texture, which infers a single parameter. Accordingly, the textural properties of a food are that group of physical characteristics that arise from the structural elements of the food, are sensed by feeling of touch, are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time and distance.

2.5.6.1.2.2 MESUREMENT OF TEXTURAL PROPERTIES

According to the above definition, textural properties can be perceived subjectively by the sense of touch. Sensory textural evaluation may involve finger feel or tasting. When judging foods by tasting, properties such as softness in biting, ease of disintegration into fragments, connection of the fibers, and other pressure and softness sensations on the tongue, hard palate and cheeks are considered (Jellinek, 1979). Textural properties of a food can also be evaluated by physical rheological and objective methods. According to Kramer (1973), objective techniques for measuring sensory properties have the basic disadvantage of measuring sensory properties

only indirectly and are, therefore, accurate only to the extent that they are analogous to the human sensory response. Despite this limitation, objective textural evaluations are not subject to drift, fatigue and are more precisely calibratable than human sensors (Kramer, 1973). There is no universal methodology for instrumental textural evaluation and especially where natural solid and semi-solid foods are concerned, the proposed technique should be thoroughly examined and validated to ensure its accuracy and precision before being applied. The procedure to accomplish this is described by Kramer (1973). In the instrumental evaluation of textural properties of potatoes, Adam et al., (1980) considered the pulp of raw potatoes as a tough elastic material in which the smaller viscous component of the rheological behaviour could be neglected with respect to the required accuracy of results. They used axial compression and puncture techniques in the quantification of textural properties. In the latter procedure, a cylindrical loading indenter was penetrated, at constant speed, into the sample, cut out in the form of a plate from the raw potato pulp. The strength or force at the point of rupture or bio-yield point was measured. Wright et al. (1968) also used the puncture technique as an objective measurement of structural changes in stored sweet potato cultivars. Bourne (1979) has also

reviewed the application of the puncture test in the measurement of firmness of cooked vegetables. Puncture tests are usually carried out with instruments that automatically draw out force-distance or force-time curves. Usually the cross-head speed and the chart speed are synchronized so that the force-time curves can be analysed as force-deformation curve (Wright et al., 1968). Of equal importance in the measurement of firmness of cooked potatoes is the compression - extrusion testing (Bourne, 1979). The principle of extrusion testing involves applying force to a sample of food until it flows through an outlet that may be in the form of one or more slots or holes that are in the test cell (Bourne, 1982). The food is compressed until the structure is disrupted and the food extrudes through these outlets. Usually the maximum force required to accomplish extrusion is taken as an index of textural quality (Bourne, 1982). Kozempel (1988) has used a back-extrusion technique to measure texture of cooked potatoes. This technique was adapted in measuring the changes in textural properties of stored sweet potatoes as reported in this study. It should be realized that in objective analysis of textural properties of foods, the choice of cross-head speed and compression percentage should be such that the results obtained will correlate with

subjective sensory measurements (McKenna, 1980). In applying these techniques, use has been made of recommended test conditions as detailed elsewhere in this study.

2.5.6.2. STRUCTURAL CHANGES AND TEXTURAL PROPERTIES IN STORED SWEET POTATOES

According to Picha (1986a), freshly harvested sweet potato roots have less desirable textural characteristics than cured and stored roots. This implies a change in the structural constituents responsible for the change in textural quality of roots. Carbohydrates affect firmness, dryness and mouthfeel in cooked sweet potatoes (Picha, 1987). Firmness has been correlated with starch and alcohol insoluble solids (AIS), texture and viscosity have been correlated with pectic substances, mouthfeel with starch and dextrin content, softness after cooking with polysaccharide content, and moistness with starch and protopectin (Palmer, 1982). Hydrolytic degradation of carbohydrates in sweet potatoes would, therefore, be expected to alter textural properties. Starch degradation in stored roots has been reviewed above. Sistrunk (1977) has reported decrease in hemicellulose, a polysaccharide, in sweet potato roots stored at 15°C. Controlled atmosphere storage under increased oxygen concentration has also resulted in an

increase in protopectin content (Chang and Kays, 1981). In an apparent reference to textural change, Chang and Kays (1981) have also reported that it was difficult to rupture the macro-structure of roots stored at low oxygen concentration. Other changes that may be responsible for changes in textural properties include water loss and dry matter (Booth, 1984; Picha, 1986b; Edmond and Ammerman, 1971), development of pithiness and hardcore (Ryall and Lipton, 1979) and other alterations in root constituents.

2.5.6.3. VITAMIN CHANGES IN STORED SWEET POTATO ROOTS

When sweet potato roots are subjected to storage, changes in vitamin content inevitably occur and the extent is dependent on the storage conditions and duration. β-carotene content in sweet potato roots have been reported to increase in the early part of storage followed by eventual loss after about 4 months (Burton, 1982). This indicates that synthesis of β-carotene does not cease at harvest but continues in storage upto some time. Ryall and Lipton (1979) reported that inability to synthesize carotene in harvested roots can be induced by chilling temperatures (below 10°C). When sweet potato roots were stored at temperatures above 10°C for 3 months, there was complete retention of β-carotene (Woolfe, 1989).

As the storage temperature increases, however, losses in β-carotene become evident. Bradbury and Holloway (1989) reported 18% loss in β-carotene when roots were stored at 24°C for 4 months. A similar amount of loss, 15%, has also been reported for roots canned and stored for 18 months (Elkins, 1979). The storage conditions were not indicated.

Vitamin C losses in stored sweet potatoes are comparatively considerable. Woolfe (1989) reported 75% retention of vitamin C when roots were stored above 10°C for 3 months. Losses in total vitamin C for roots stored at 0, 15 and 25°C were 3, 16 and 17%, respectively, after a storage duration of 28 days (Bradbury and Holloway, 1988). As expected, the higher the storage temperature the higher the loss. Reviewing earlier work, Bradbury and Holloway (1988) have also presented comparative vitamin C losses of 49% after 4 months storage at 24°C and 41% after storage of 4 months at 8 - 10°C and 80 - 85% RH. Synthesis as well as loss in vitamin C can occur in storage (Burton, 1982). Losses in other vitamins for roots stored at temperatures above 10°C for 3 months have also been compiled by Woolfe (1989) as thiamine - 20%, and riboflavin - 35%. Elkins (1979) reported complete retention of niacin and riboflavin in roots canned and stored for 18 months under unspec-

ified conditions.

Of interest to the Food Technologist is the knowledge of the kinetic parameters such as order of the reaction, the reaction rate and the dependence of this rate on temperature. These enable one to predict the extent of vitamin degradation in storage for a given storage duration and conditions. For a 1st order reaction, the rate is proportional to the concentration of the reacting substance (Lund, 1975). Thus, for a particular temperature,

$$-dC/dt = kC \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1,$$

where C is the concentration of the reacting substance, -dC/dt is the rate of decrease in the concentration and k is the rate constant (Lund, 1975). The above equation shows that the rate is proportional to the first power of concentration, thus first order reaction. Rearranging and integrating the above equation, the following is obtained:

$$-\int_{C_1}^{C} dC/C = k\int_{t_1}^{t} dt \quad \ldots\ldots 2.2,$$

and,

$$\ln C = \ln C_1 - k(t - t_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.3$$

This is an exponential relationship which can also be generalized as follows:

$$C = C_1 e^{-k(t-t_1)} \quad \text{.....2.4,}$$

where e = 2.714. If $t_1 = 0$ at the start of the storage experiments, then the above equation can be written simply as:

$$C = C_o e^{-kt} \quad \text{.....2.5,}$$

Where C is the vitamin content at time t and C_o is the initial content. Thus, if the degradation of the vitamin in storage is a first order reaction, then the changes monitored over a given storage duration should be describable by a mathematical relationship of the above (Equation 2.5) form.

The reaction constant, k is dependent on the storage temperature and this dependence is often described by the Arrhenius relationship of the form:

$$K = Se^{-Ea/RT} \quad \text{.....2.6,}$$

Where S is the frequency factor, Ea the activation energy, R the gas constant and T the absolute temperature (Lund, 1975). Taking logarithms for the above equation, it becomes:

$$\ln K = \ln S - Ea/RT \quad \text{.....2.7}$$

The Arrhenius equation assumes only one reaction responsible for the loss. For vitamin C, it would be

the oxidative degradation. In order to predict changes in storage, it is necessary to determine the activation energy and frequency factor for the reaction as given in the Arrhenius equation. The frequency factor represents the total frequency of encounters between molecules irrespective of whether they posses sufficient energy or not for the reaction (Charm, 1971). The activation energy is necessary for the colliding molecules to enter into reaction and the probability that a molecule will posses energy in excess of the activation energy per mole at a given temperature, T is given by $e^{Ea/RT}$ in the Arrhenius equation (Charm, 1971). For most chemical reactions the activation energy lies between 50,000 - 250,000 kJ/kmol which implies a rapid increase in rate constant with temperature.

2.5.6.4 CHANGES IN PROTEINS OF STORED SWEET POTATO ROOTS

Purcell et al., (1978) have reported a decrease in protein content during storage of some sweet potato cultivars. The rate of decrease in protein content was approximately half as much as for dry matter over the storage duration. However, in the earlier part of storage, these authors reported an increase in percent protein for three cultivars tested. The non-protein nitrogen (NPN) decreased during 14 - 15 weeks of

storage and thereafter increased. Purcell and Walter (1980) have also reported some small changes in amino-acid content for sweet potato roots stored at 13°C for 281 days. There was no reference to likelihood of protein synthesis during storage and these increases might only be apparent due to changes in dry matter content.

3 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 SWEET POTATO CULTIVARS

Three sweet potato cultivars, namely Nyakura, Nyeri and KSP20 were planted at the Field Station, Faculty of Agriculture, University of Nairobi between 15th - 23rd November, 1989. All varieties were planted on manually prepared mounds spaced approximately 0.7m apart using vine cuttings procured from an experimental nursery plot at the station and from the sweet potato germplasm collection maintained at Katumani Dryland Research Station in Machakos district. Weeding was carried out about 4 weeks after planting and no fertilizer application was done.

The sole purpose of planting these cultivars was merely to provide a consistent and reliable supply of raw materials of known history for subsequent laboratory experimentation. Field experimental design procedures were therefore overlooked as there were no field treatments whose effects were to be investigated. Nor was the concern of the study to measure vegetative growth of the various cultivars *per se*. The only parameters of a vegetative nature that were monitored over the growing period were root weight and dry matter accumulation only in so far as they were to be used as indices to help decide on the appropriate dates to start harvesting.

Roots were considered mature for harvesting when they attained a mass of 100g (Ojijo, 1990). To ascertain this, roots from a sample of 20 plants were periodically harvested, washed and weighed; then the average mass was obtained. On this basis, the Cv.KSP 20 was the earliest maturing in about 4 months after planting. This cultivar also proved to be of prolific root setting characteristics. The other cultivars Nyeri and Nyakura proved to be late maturing in about 6.5 months with very low number of roots per plant. Due to its early maturity, ease of harvest and high yielding ability, Cv. KSP 20 was selected for further experimentation on a simulated sequential harvesting regime typical of the prevalent mode of harvesting sweet potatoes among traditional farmers.

The sweet potatoes are usually left out in the field even if mature and only harvested as needed (Ojijo, 1990). The aim of the simulated sequential harvesting regime was to ascertain the possible extent of loss in root composition when so delayed out in the field. A random sample of 10 roots were selected from the roots obtained from 20 harvested plants and used for analysis of root composition in relation to the time of harvest.

3.1.2 CURING STRUCTURES

A sun curing procedure was used. This method had been employed in storage trials carried out at the Coast Agricultural Research Station in Mtwapa (Ojijo, 1990). The tubers were wrapped in black polythene sheets and exposed to full sunshine for upto 5 days. Temperatures achieved were expected to be sufficiently high, 30 - 35°C, with high retained relative humidity due to moisture released by the respiring tubers.

When adequate sunshine was not available, the freshly harvested tubers were wrapped in black polythene sheets and placed in a laboratory incubator maintained at 31°C.

3.1.3 STORAGE STRUCTURES

3.1.3.1 CONSTANT TEMPERATURE STORAGE STRUCTURES

Special storage cabinets - Roland, Model Jumo Lan M, West-Germany, were used to maintain temperature conditions within ±2°C. These cabinets had sufficient capacity to store an adequate number of tubers to be used over the intended storage duration.

3.1.3.2 STORAGE SYSTEMS WITH SOIL AND SAW-DUST

Wooden structures measuring approximately 90cm x 90cm x 30cm were fabricated in the Department of Food Technology and Nutrition Workshop. Roots were ar-

ranged in these structures and then completely buried in dry soil or dry saw-dust. The structures were then overlaid with polythene sheets to help in minimizing ambient temperature fluctuations, and to check moisture loss.

It should be realised that the relevant effect here is the storageability of the sweet potato roots buried either in soil or saw-dust. The wooden structures were purposely for containment and are assumed to have no effect on the storage aptitude of the roots.

3.1.3.3 AMBIENT STORAGE

Sweet potato tubers were carefully arranged in a soft sisal sack placed in a dark chamber at ambient conditions. Wet and dry bulb thermometers were also set at a representative place to monitor ambient variations in the room. Dry and wet bulb temperatures were recorded daily throughout the storage duration early in the morning and late in the evening.

3.1.3.4 DESIGN OF STORAGE EXPERIMENT

Roots (Cv. KSP 20) were harvested after about 5 months growing period. A minimum of 120 roots were randomly selected using Random Number Tables (Steel and Torrie, 1980) and subjected to the various storage

conditions after sun-curing.

The storage treatments were 5°C, 10°C, 15°C, 20°C, 29°C, ambient, soil and saw-dust. At selected time intervals, 10 roots were drawn from each of the above storage conditions and analysed for vitamins, sugars and textural properties. In addition, visual assessment of general root appearance and enumeration of sprouted tubers were also used to evaluate storage success. This set-up was preferred to be a complete randomized design and analysis of variance involved one-way technique.

3.1.4 TEXTURE MEASURING INSTRUMENT

Universal texture testing machine - Instron model 1122, with a tension - compression load cell type 2511-312, model No. A217-12, England, was used for texture measurement of sweet potato dices using back - extrusion and puncture test techniques.

3.2 METHODS

3.2.1 AVERAGE ROOT WWEIGHT

The total number of roots obtained as in 3.1.1 above were washed of adhering earth, counted and weighed in bulk using a spring balance (±0.05kg). The average root weight was then calculated as below:

$$\text{Average root weight} = \frac{\text{Total weight of roots (g)}}{\text{Total No. of roots}}$$

3.2.2 SPECIFIC GRAVITY OF ROOTS

The specific gravity of sweet potato roots was obtained by a displacement method adapted by Ben Gera et al. (1974) for potatoes.

The freshly harvested roots were washed free from adhering earth. A plastic string bag was then suspended from a spring balance and its weight recorded (W_1). A suitable number of sweet potato roots were then inserted into the bag and the combined weight recorded (W_2). The bag plus roots was then wholly immersed in water and the apparent weight recorded (W_3). After removing the roots from the bag, a sinker was inserted into the bag and the apparent weight when suspended in water was recorded (W_4). Finally, the sinker alone was suspended in water and its apparent weight recorded (W_5). The specific gravity was then calculated as below:

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_2 + W_4) - (W_1 + W_3 + W_5)}$$

The calculations were performed to the nearest 0.0001

specific gravity unit so as to allow for correction to a standard temperature (10°C) using the correction table shown in Table 3.1.

3.2.3 CHEMICAL ANALYSES

3.2.3.1 SAMPLE PREPARATION FOR CHEMICAL ANALYSES

Ten tubers were randomly selected from the batch of sweet potatoes. After washing, the selected tubers were cut into half, longitudinally. One half was discarded and the remaining half portions were peeled and manually comminuted to give a suitable blend. Appropriate sample portions were then weighed out of the blend for chemical analyses.

3.2.3.2 RELATIONSHIP BETWEEN ROOT WEIGHT AND COMPOSITION

Sweet potato (Cv. KSP 20) of varying sizes were sorted into five different groups on the basis of weight. All roots in each group were weighed out and the average weights for the groups obtained. After segregating the roots thus, an appropriate number (10 roots) were sampled out using Random Number Tables for each weight group and analysed for physical and chemical composition. The data was treated as a complete randomized design in the statistical analyses.

Table 3.1: Temperature Correction to be Added for Specific Gravity of Sweet Potatoes (Corrected to 10°C)

	Water temperature (°C)										
4	6	8	10	12	14	16	18	20	22	24	26
-0.0017	-0.0016	-0.0015	-0.0015	-0.0017	-0.0019	-0.0022	-0.0026	-0.0031	-0.0037	-0.0045	-0.0050
-0.0012	-0.0010	-0.0009	-0.0009	-0.0012	-0.0013	-0.0015	-0.0020	-0.0025	-0.0031	-0.0038	-0.0044
-0.0006	-0.0005	-0.0004	-0.0004	-0.0005	-0.0007	-0.0010	-0.0014	-0.0020	-0.0026	-0.0033	-0.0039
-0.0003	-0.0001	0.0000	0.0000	-0.0001	-0.0003	-0.0006	-0.0010	-0.0017	-0.0023	-0.0029	-0.0035
+0.0001	+0.0002	+0.0003	+0.0003	+0.0002	0.0000	-0.0003	-0.0007	-0.0014	-0.0020	-0.0026	-0.0033
+0.0003	+0.0004	+0.0005	+0.0005	+0.0004	+0.0003	0.0000	-0.0005	-0.0011	-0.0018	-0.0024	-0.0031
+0.0004	+0.0006	+0.0007	+0.0007	+0.0006	+0.0004	+0.0002	-0.0003	-0.0010	-0.0016	-0.0022	-0.0029
+0.0005	+0.0007	+0.0008	+0.0008	+0.0007	+0.0005	+0.0003	-0.0002	-0.0009	-0.0015	-0.0021	-0.0028
+0.0005	+0.0008	+0.0009	+0.0009	+0.0008	+0.0006	+0.0003	-0.0001	-0.0008	-0.0014	-0.0020	-0.0027
+0.0007	+0.0008	+0.0009	+0.0009	+0.0008	+0.0007	+0.0004	0.0000	-0.0007	-0.0013	-0.0019	-0.0027
+0.0008	+0.0009	+0.0010	+0.0010	+0.0009	+0.0008	+0.0004	+0.0001	-0.0006	-0.0012	-0.0019	-0.0026
+0.0008	+0.0010	+0.0011	+0.0011	+0.0010	+0.0008	+0.0005	+0.0001	-0.0005	-0.0012	-0.0018	-0.0025
+0.0009	+0.0011	+0.0012	+0.0012	+0.0010	+0.0009	+0.0006	+0.0002	-0.0004	-0.0011	-0.0017	-0.0024
+0.0010	+0.0012	+0.0012	+0.0012	+0.0011	+0.0010	+0.0007	+0.0003	-0.0003	-0.0010	-0.0016	-0.0024
+0.0011	+0.0012	+0.0013	+0.0013	+0.0012	+0.0010	+0.0007	+0.0003	-0.0003	-0.0009	-0.0016	-0.0023
+0.0012	+0.0013	+0.0014	+0.0014	+0.0013	+0.0011	+0.0008	+0.0004	-0.0002	-0.0008	-0.0015	-0.0022
+0.0012	+0.0013	+0.0014	+0.0014	+0.0013	+0.0011	+0.0008	+0.0004	-0.0002	-0.0008	-0.0015	-0.0022
+0.0013	+0.0014	+0.0015	+0.0015	+0.0014	+0.0012	+0.0009	+0.0005	-0.0001	-0.0008	-0.0014	-0.0021

Source: Lon Cera et al., (1974)

3.2.3.3 TOTAL DRY MATTER

About 10g sample of tubers prepared as in 3.2.3.1 was weighed out in an aluminium dish previously dried, cooled and weighed. The weight of sample and dish was taken. Drying was then carried out in a vacuum oven at 65°C until constant weight was achieved. The dried weight of sample was obtained by difference and total dry matter calculated (Ranganna, 1977).

3.2.3.4 REDUCING SUGARS

From the sample prepared in 3.2.3.1, 150g was weighed and blended with 150 mls distilled water in a Warring blender for 1 minute. The slurry was filtered through Whatman No. 41 filter paper and the filtrate used for analyses of reducing sugars by the non-Stoichiometric volumetric method detailed by Folkes and Brookes (1984).

Equal volumes of Fehlings I solution (69.3g copper sulphate pentahydrate dissolved in 1 liter distilled water) and Fehlings II (100g Sodium and 345g Sodium potassium tartrate per liter) were mixed together. Twenty milliliters of this mixture were pipetted into a 500 ml conical flask and 15 ml distilled water added. Thirty-nine ml of 0.25% pure anhydrous dextrose (previously dried in a vacuum oven at 100 °C for 2 hours) were then run in from a burette and the content of flask heated to boiling on a hot

plate. After about 2 minutes boiling, 3-4 drops of 1% aqueous methylene blue indicator were added and the solution titrated with standard dextrose solution until the blue colour disappeared. The titre, (V_s) obtained was recorded.

The burette was rinsed and filled with the sample solution after which titration was repeated as before. If no blue colour was observed on addition of the methylene blue, a smaller sample volume was used and if the volume of sample originally added to the Fehlings solution was too small, appropriate additions of the sample solution were made until the blue colour disappeared. The final accurate titration, (V_t) was then carried out after adding from the burette the volume, less 1 ml, of the sample solution and appropriate amount of water to give a final volume of 75 ml (including 20 ml Fehlings solution). The percentage reducing sugars as dextrose in the sample was then calculated as:

$$\% \text{ Reducing Sugars} = (V_s \times 0.25)/V_t$$

3.2.3.5 TOTAL SOLUBLE SUGARS

A sample of 150g was weighed out from 3.2.4.1 and blended with 150 mls distilled water in a Warring blender for 1 minute. The slurry obtained was then used for analysis of total soluble sugars according to

a modified procedure of Dubois et al. (1956).

About 2g of slurry, weighed into a plastic centrifuge tube, was vigorously agitated with 30 mls of 80% hot ethanol. The tube was then centrifuged at 2500 r.p.m. for 15 minutes and the resulting supernatant transferred into a conical flask containing boiling chips. The residue was extracted three times with hot alcohol each time centrifuging and transferring the supernatant into the conical flask. The combined extract was then evaporated on a hot plate until it turned turbid to ensure complete removal of ethanol. The remaining aqueous phase was then transferred into a 100 ml volumetric flask and made to volume with distilled water.

An aliquot of 0.1 ml was then transferred into a test-tube and 0.9 ml of distilled water added to make upto 1 ml. This was followed by addition of 1 ml 5% phenol and 5 ml of 96% sulphuric acid respectively, upon which a golden yellow colour developed. After cooling for 15 minutes, the absorbance was read at 490 nm on a Beckman, Model 25, spectrophotometer, U.S.A., against reagent blank. A glucose standard curve was also prepared from graded concentrations of 10 - 60 mg/ml to aid in calculation of total sugars (Appendix I).

3.2.3.6 VITAMIN C (ASCORBIC ACID)

Vitamin C content was determined by the selective oxidation of ascorbic acid by N-bromosuccinimide, a method attributed to Barakat et al. (1955).

From the sample prepared as in 3.2.3.1, 50g was weighed and blended with 150 ml of 10% Trichloroacetic acid (TCA) for 1 minute. After filtration through Whatman No. 41 filter paper, 5 mls of the filtrate was pipetted into a small, 100 ml conical flask. To this portion, 5 ml of 4% potassium Iodide solution was added followed by 1 ml starch indicator solution. The mixture was then titrated against 0.01% N-bromosuccinimide solution (freshly prepared) in a micro-burette to a faint violet or blue end point which persisted on thorough agitation. The vitamin content was then calculated as below:

Vit. C, mg/100g, FWB = V x C x 150/5 x 176/178 x 2

Where: V is the volume of N-bromosuccinimide and
C is its concentration (%)

In using this method, it was assumed that Vit. C in sweet potatoes occur mostly as ascorbic acid; the level of dehydro-ascorbic acid (its oxidation product) being comparatively low (Cooke, 1974).

3.2.3.7 β-CAROTENE

A rapid method of carotene assay based on that of Astrup et al. (1971) and used by Gomez (1981) for green leafy vegetables was used.

According to this procedure, 20g of sample prepared as in 3.2.4.1 above was transferred into a mortar with a pestle. The sample was then extracted with small portions of acetone, each time transferring the extract through glass wool into a 100 ml round bottomed evaporating flask, until no more colour was imparted to the acetone when added to the residue. The total extract was then evaporated to dryness under vacuum in a rotary evaporator at 60°C. The extract was then solubilized in about 4 ml petroleum ether (b.p. 40 - 60°C) and transferred to an alumina column. The column was prepared from a slurry of alumina (activity grade 11) in 8% ethanol in petroleum ether, made to a height of 3-4 cm and topped with about 1 cm high plug of anhydrous sodium sulphate. After washing the column thoroughly with petroleum ether, the extract was transferred to the top of the column and eluted with pet-ether. The eluate was collected in 25 ml volumetric flask as a distinct yellow band and made to volume with pet-ether. Absorbance readings were taken at 450nm on a Beckman Model 25 spectrophotometer, U.S.A., and the β-carotene content read off from a

standard curve previously prepared from fresh commercial β-carotene (Appendix II).

3.2.4 TEXTURE OF SWEET POTATOES

3.2.4.1 COOKING OF SWEET POTATO DICES

Selected roots were sliced 3cm in thickness. Dices 4cm in diameter were then gored out of the flesh from the slices. These were placed in wire baskets and cooked in boiling water at 94°C for predetermined time intervals. The temperature was presumed not to vary as the water was kept boiling throughout the heating period. The cooked dices were then segregated for sensory and instrumental evaluations of cookedness and textural alterations.

According to Earle (1983), the thermal conductivity, K and the specific heat, C of foodstuffs can be estimated if the percentage of water in the foodstuff is known. If this percentage is P, then:

$K = 0.55P/100 + 0.26\ (100 - P)/100\ JM^{-1}S^{-1}\cdot C^{-1}$ ..3.1

and,

$C = 4.19P/100 + 0.84(100-P)/100\ KJ\ Kg^{-1}\cdot C^{-1}$ ...3.2

above freezing and assuming minimal fat content in the foodstuff. Also another parameter, the thermal diffusivity, D can be derived from the specific heat and thermal conductivity according to the following equation:

$$D = K/C\sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.3$$

where σ is the specific weight of the material in Kg M^{-3} (Charm, 1971). Further, the thermal diffusivity is related to the Fourier number, Fo which is an important parameter in unsteady state heat transfer situation typical of food processing operations like cooking, as below:

$$F_o = Dt/R^2 \text{..... .....} 3.4$$

Where t is the processing (cooking) time and R is the characteristic dimension, in this case the radius of the cylindrical sweet potato dices.

3.2.4.2 INSTRUMENTAL (OBJECTIVE) TEXTURE EVALUATION

3.2.4.2.1 BACK EXTRUSION TEST

Cooked sweet potato dices weighing 320g were stacked in a back-extrusion test cell. The test cell had a diameter of 10.16 cm while the diameter of the piston was 9.35 cm giving an annular clearance of 0.81cm. The stroke depth was 3 cm and the stroke rate or cross-head speed was 100 mm/min. Chart speed was also set at 100 mm/min. Maximum force required to accomplish extrusion was recorded as indicated on the chart. Five replicate tests were performed at room temperature. This is a modification of the method

used by Kozempel (1988) for cooked potatoes.

3.2.4.2.2 PUNCTURE TESTS

Cooked sweet potato dices were allowed to cool to room temperature. A cylindrical loading indenter of diameter 0.75cm was driven at a constant cross-head speed of 100cm/min into the dice mounted on the stage to a depth of 0.7cm at the geometric centers. Twenty dices were tested and the yield point force as recorded on a force-time chart, moving at 100mm/min, was recorded.

3.2.4.3 SENSORY EVALUATION

Sensory responses were used to determine the optimal cooking times for three varieties of sweet potatoes (KSP20, Nyeri and Nyakura). The method used was adapted from that employed by Harada et al. (1985) for determination of texture in cooked potatoes.

A special nine point category scale (see Appendix III) was used to assess the degree of cookedness of the sweet potato dices. The total number of panelists was 15. Each panel member recorded his numerical responses to 3 dices per sample. Water was available for panelists to rinse particulate matter from their mouths between tests. The judgments for each given sample were averaged and used for regression analysis

of cooking time against numerical sensory scores. According to the category scale, a numerical judgement of 5 corresponded to an optimally cooked sample. The time required to reach this value was taken as the optimal cooking time as determined from the regression equation.

3.2.5 PROXIMATE COMPOSITION OF SWEET POTATOES

3.2.5.1 TOTAL ASH

The total ash content was determined on pre-dried sweet potato samples (used in determination of total dry matter) by a dry ashing technique outlined by Pearson (1970).

About 2g of the sample was accurately weighed into a porcelain dish which had been previously heated and cooled before weighing. The dish and contents were then ignited, first gently on a hot plate and then at 500°C until a light grey or white ash of constant weight was obtained. The dish and contents were then cooled in a dessicator and weighed. Total ash was calculated on a dry weight basis. Duplicate samples were determined.

3.2.5.2 CRUDE FAT

Crude fat content was determined by extracting predried and ground sweet potato samples with petroleum spirit in a soxhlet extractor as detailed by Ran-

ganna (1977).

About 5g of sample was accurately weighed into an extraction thimble. The sample was then covered with cotton wool and placed into the soxhlet extractor. A tared flat bottomed flask previously dried, cooled and weighed was placed on a heating mantle and connected to the soxhlet extractor. Fat was extracted for 8 hours under reflux. The solvent was then evaporated in a rotary evaporator and the remaining residue dried in an air oven at 105°C for 1 hour. The flask and contents were then cooled in a dessicator and weighed. Crude fat was calculated on dry weight basis for duplicate samples.

3.2.5.3 CRUDE FIBER

The procedure outlined by Lees (1975) was followed in the determination of crude fiber.

About 2g of sample was accurately weighed into a graduated 600 ml beaker. Extraction was carried on for 30 minutes with boiling 2.04N sulphuric acid with adequate additions of boiling distilled water to maintain the total volume at 200 ml. The contents of the beaker were then filtered through a Buchner funnel packed with glass wool and the residue rinsed three times with boiling distilled water. After washing, the residue and glass wool were returned to the flask

and extracted for a further 30 minutes with boiling 1.78 N potassium hydroxide with additions of appropriate volumes of boiling distilled water to maintain the volume at 200 ml. The contents of the beaker were then filtered and washed as before. Finally, the residue was washed three times with small amounts of ethanol and then quantitatively transferred (together with glass wool) to a porcelain dish. Drying was done at 105°C for 1 hour in an air oven after which the dish and contents were cooled and weighed. After weighing, the dish and contents were ignited at 550°C to constant weight, cooled and weighed. Crude fibre content was calculated on dry weight basis.

3.2.5.4 CRUDE PROTEIN

The macro-Kjeldhal method outlined by Pearson (1970) was used with modifications in the analytical reagents.

About 1g of dried sample was accurately weighed on a N-free filter paper. The paper was then carefully introduced into a Kjeldhal flask containing anti-bumping pumice, one Kjeldhal catalyst tablet and 20 ml of concentrated sulphuric acid. The flask was heated gently in an inclined position in a fume chamber until frothing ceased. Stronger heating was then applied to maintain moderate boiling of the liquid until it turned clear. After sufficient cool-

ing, water was added to the digest until flask was almost three quarters full. Some drops of phenolphthalein indicator were added and the flask connected to a distillation unit. Sufficient amount of 40% sodium hydroxide solution was added to make the digest alkaline. Distillation was then carried out and the distillate collected into a 400 ml conical flask containing 50 ml of 0.1N Hydrochloric acid and some drops of methyl orange indicator. After the distillation was completed, the distillate was back titrated with 0.1N sodium hydroxide solution. A blank was run alongside the samples and crude protein calculated as below:

Crude Protein = N x 6.25, where N was obtained by suitable stoichiometric factor.

3.2.5.5 TOTAL CARBOHYDRATES

The total carbohydrates excluding crude fibre was obtained by difference.

3.2.5.6 MINERALS

Mineral analysis was carried out on a Perkin-Elmer, Model 2380 Atomic Absorption Spectrophotometer, U.S.A, according to the following procedure:

About 2g of dried and ground sample was digested in a Kjeldhal flask by adding 20 mls mixture of conc.

nitric acid and 70% perchloric acid (3:1). Heating was applied on a mantle until the digestion mixture became clear. After cooling, the digest was transferred into a 100 mls volumetric flask and made to volume with distilled water. Appropriate dilutions were made and sample portions introduced into the spectrophotometer.

Approved analytical methods for atomic absorption spectrophotometry compiled in the manual of analytical methods by Perkin-Elmer (1982) were followed. Standard conditions for atomic absorption for each of the respective metals analysed are reproduced in Table 3.2.

Table 3.2: Standard Conditions for Atomic Absorption

Element	(nm)	SBW (nm)	Flame Gases	Sensitivity Check
Ca	422.7	0.7	A - Ac	4.0
Fe	248.3	0.2	A - Ac	5.0
K	766.5	1.4	A - Ac	2.0
Mg	285.2	0.7	A - Ac	0.3
Na	589.0	0.4	A - Ac	0.5
Zn	213.8	0.7	A - Ac	1.0
Cu	324.8	0.7	A - Ac	4.0

A - AC : Air-Acetylene SBW : Slit width

4.0 RESULTS AND DISCUSSION

4.1 CHANGES IN ROOT COMPOSITION UNDER SEQUENTIAL HARVESTING REGIME

4.1.1 WEIGHT, SPECIFIC GRAVITY AND DRY MATTER

Average root weight increased with harvest date in a pattern typical of biological growth progression (Figure 4.1). The curve tends to level off at about 180 days after planting indicating maximum attainable root weight of 310g. Using a computer program, this increase could be described by an exponential equation of the form:

$$Y = 18.65e^{1.53x10^{-2}x} \quad \text{.....4.1}$$

where Y is average root weight at harvest time X days and e = 2.714, with a correlation coefficient, r = 0.947.

The changes in specific gravity of roots with harvest date also followed a similar pattern of increase (Figure 4.2) culminating in a maximum value of 1.039 in 184 days after planting. Mathematical modeling of this growth pattern yielded low correlation coefficients.

Fig. 4.1. Average root weight at different harvest dates

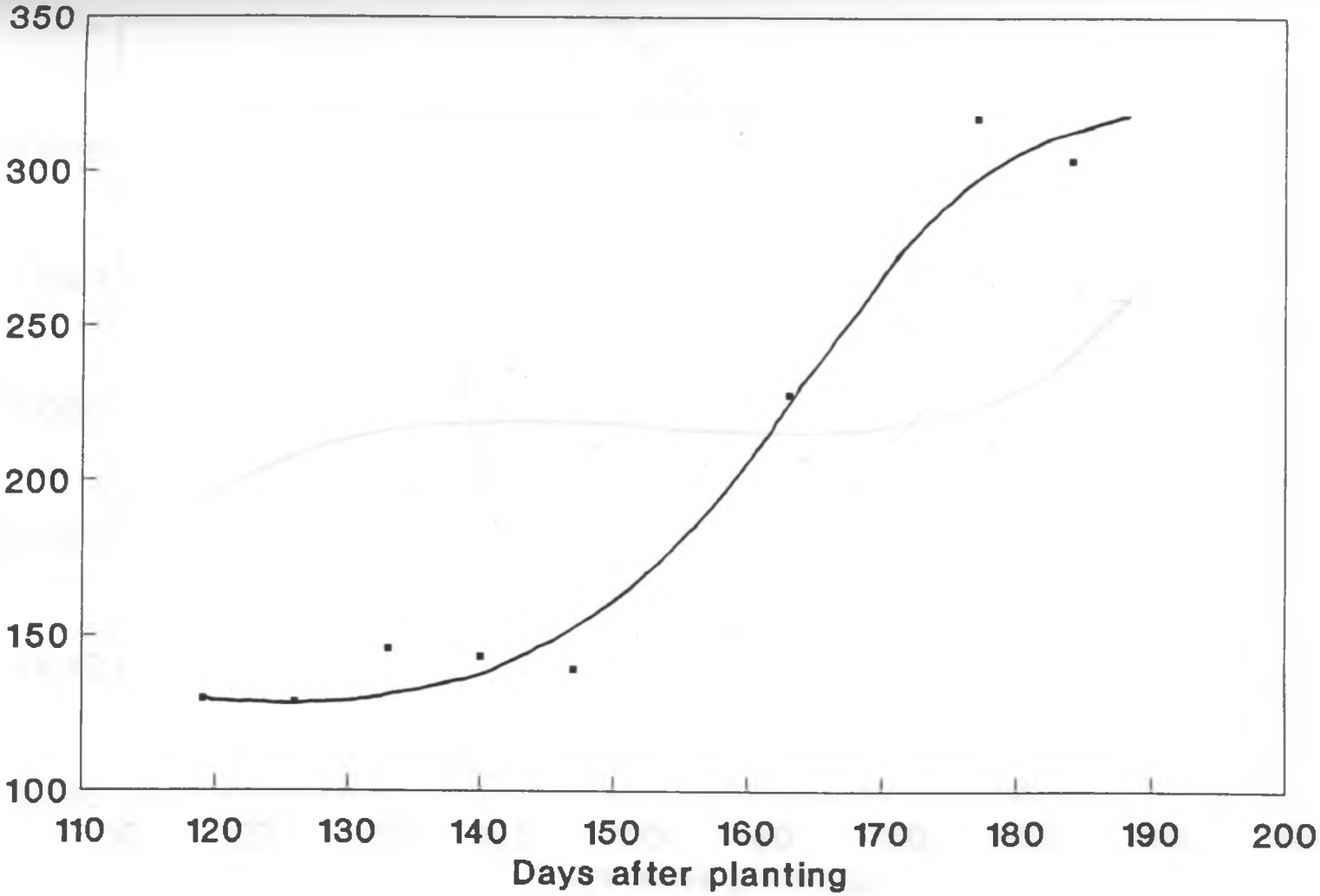
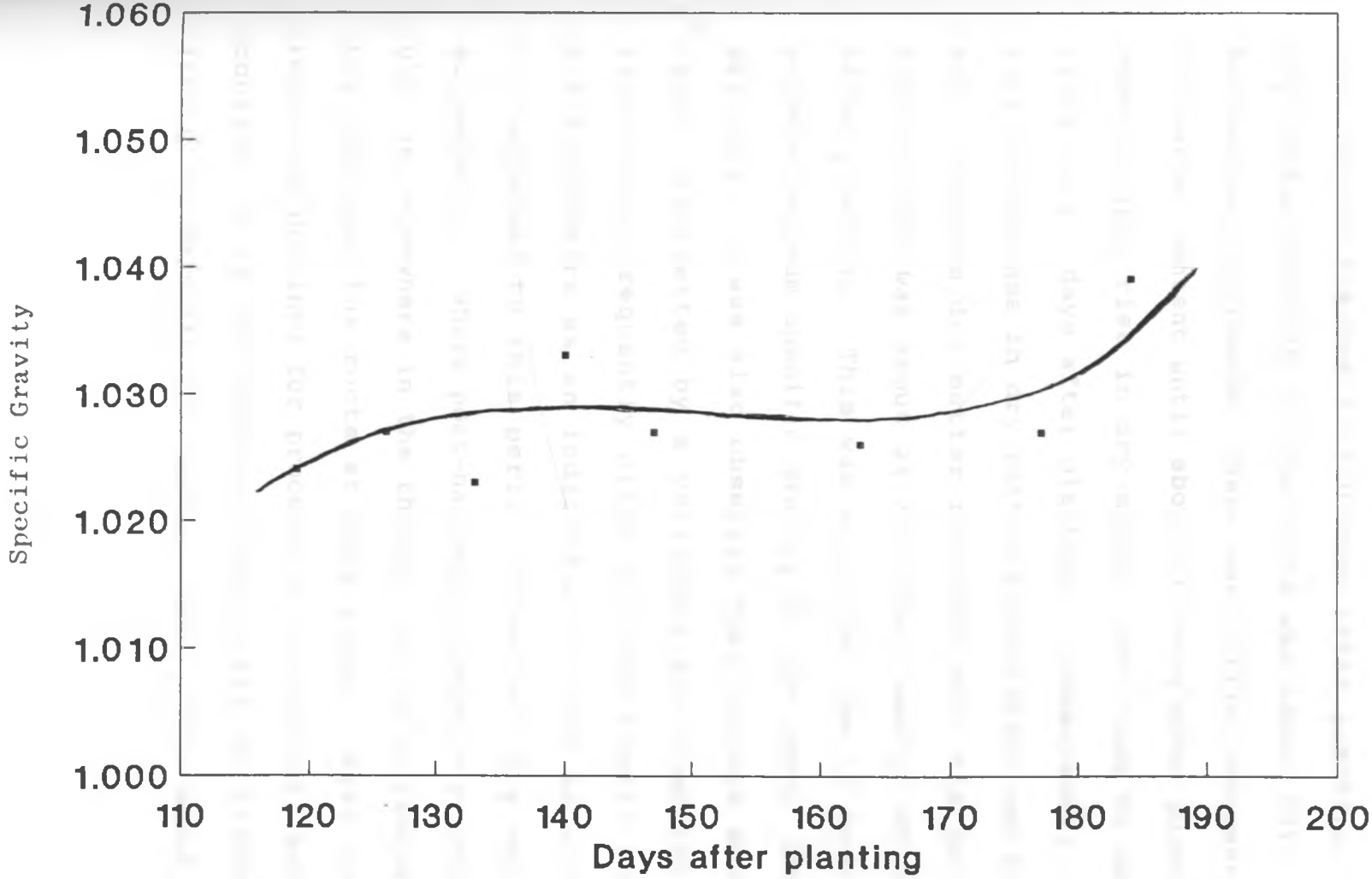
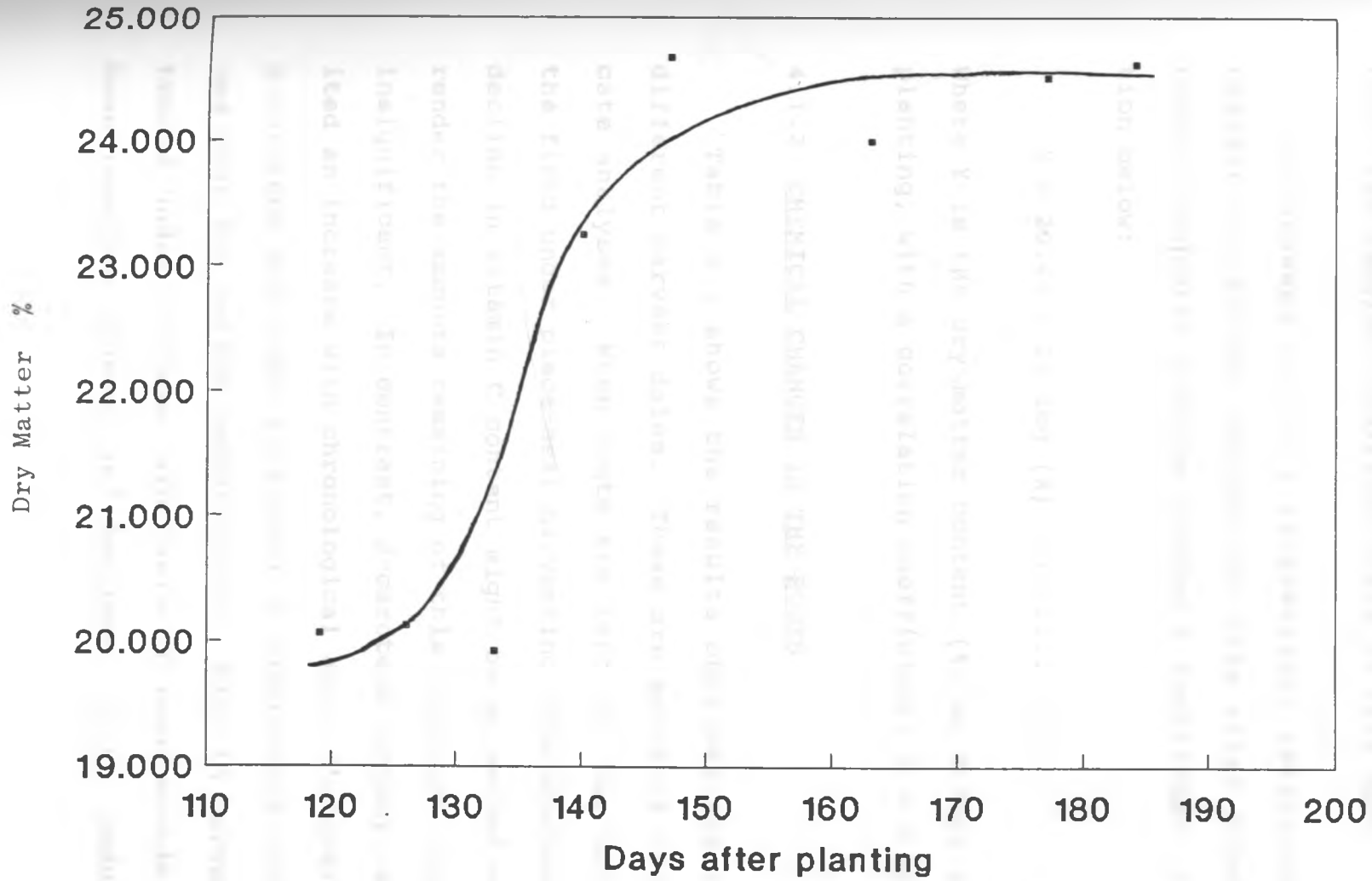


Fig.4.2. Specific gravity of roots at different harvest dates



Dry matter accumulation in the roots also displayed a similar pattern with that of specific gravity and root weight (Figure 4.3). Originally, when harvesting was started at 120 days after planting, the dry matter content of the roots was about 20%. As harvesting progressed, there was little increase in dry matter content until about 135 days after planting when a rapid rise in dry matter continued to about 24.5% in 150 days after planting. Subsequently, the rate of increase in dry matter accumulation was minimal. Maximum dry matter recorded over the period investigated was about 24.75% after nearly 185 days after planting. This was also the time it took to achieve maximum specific gravity of the roots. Interestingly, it was also observed that foliage senescence, manifested by a yellowing and dropping of leaves and frequently cited by traditional sweet potato farmers as an indication of root maturity, corresponded to this period of maximum dry matter accumulation. Where post-harvest storage is practicable (see elsewhere in the thesis), it is advisable to bulk harvest the roots at this stage. Also where roots are destined for processing in which dry matter content is of influence on the yield of products (Smith, 1977; Smith and Davis, (1968), this would be

Fig. 3.6. Percent dry matter of roots at different harvest dates



the right stage to harvest. In this case, about 180 days after planting would be suitable for Cv. KSP 20 under the growing conditions cited in this work.

An attempt to fit a mathematical relationship between dry matter content and days after planting using a computer program yielded a logarithmic equation below:

$$Y = 20.43 + 10 \log (X) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.2$$

Where Y is the dry matter content (%) at X days after planting, with a correlation coefficient, r = 0.663.

4.1.2 CHEMICAL CHANGES IN THE ROOTS

Table 4.1 shows the results obtained for five different harvest dates. These are means of triplicate analyses. When roots are left out too long in the field under piece-meal harvesting, the progressive decline in vitamin C content might be so marked as to render the amounts remaining of this important vitamin insignificant. In contrast, β-carotene content exhibited an increase with chronological age. Synthesis of β-carotene and other provitamin A carotenoids continued over the period investigated. Even in harvested tubers under storage, synthesis of carotenoids has been reported (Edmond and Ammerman, 1971). Reducing

Table 4.1: Vitamin and Sugar Content of Sweet Potato (Cv. KSP 20) Roots at Harvest

Days after planting	Vitamin C mg/100g	β-Carotene μ/100g	Reducing Sugar %
126	25.35	23.75	0.20
133	17.26	23.44	0.35
140	20.84	26.50	0.38
163	14.85	26.75	0.42
177	19.10	28.75	0.57

sugars showed an increase over the period investigated. Accumulation of reducing sugars in the roots is due to action of amylolytic enzymes which degrade the starch polymer. As reducing sugars are possible precursors for sucrose synthesis in the roots (Sistrunk et al., 1954), accumulation of reducing sugars should favour formation of sucrose. As this is the major sugar responsible for sweetness in sweet potatoes, the roots should therefore increase in sweetness with chronological age.

4.2 RELATIONSHIP BETWEEN ROOT WEIGHT AND COMPOSITION

4.2.1 TOTAL SOLIDS

Means of root composition for the various root weight categories are presented in Table 4.2. The superscripts denote weight categories with significant differences at $\alpha = 0.05\%$ using Duncan's Multiple Range Test (DMRT). Means of total solids bearing different letters are significantly different from each other while those bearing similar letters are not significantly different at this level of significance.

According to Table 4.2, the dry matter increases

Table 4.2: Means of root composition for various root weigh

Group Number	Range of Weights in group (g)	Mean of Weights in group (g)	Total Solids %	Specific Gravity	Ascorbic Acid, mg/100g
1	10- 30	21.97	22.59^{a}	1.0461^{a}	31.72^{c}
2	50- 90	70.39	24.25^{b}	1.0497^{b}	28.75^{a}
3	120-150	133.41	25.41^{c}	1.0555^{c}	30.33^{b}
4	300-400	339.38	26.70^{d}	1.0650^{d}	28.79^{a}
5	400-500	439.12	27.21^{d}	1.0685^{d}	32.45^{d}

NB: Superscripts indicate significance of difference betwee
$\alpha = 0.05\%$, using DMRT

with root weight apart from groups 4 and 5. That there were no significant differences in dry matter between root weight groups with means 339.38g and 439.12g shows that there were no significant increases in dry matter content of roots falling within this range of weights. This is supportive of the findings in Section 4.1 where it was found out that dry matter rapidly increases with root weight until a point when further increases in root weight only results in minimal accumulation of dry matter.

Using a computer program, a logarithmic relation (Fig. 4.4) was obtained between total solids and average tuber weight as below:

$$Y = 17.818 + 1.537 \log (X) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.3,$$

where Y is % total solids and X is average root weight (g) and r = 0.998.

4.2.2 SPECIFIC GRAVITY

Significant differences (Table 4.2) were obtained at $\alpha = 0.05\%$ for means of specific gravity for the various root weight categories. It can also be seen from Table 4.2 that the higher the root weight the higher the specific gravity upto the root weight mean of 339.38 g beyond which there was no further increase in specific gravity.

Figure 4.5 shows a linear relationship between specific gravity and weight of sweet potato roots. Using a computer program, an exponential equation was found to best describe this relationship as given below:

$$Y = 1.0459\ e^{5.065 \times 10^{-5}\ x} \quad \ldots\ldots\ldots\ldots\ 4.4,$$

where Y is the specific gravity, X is root weight (g), e = 2.714 and r = 0.975.

4.2.3 TOTAL AND SPECIFIC GRAVITY

The relationship between the specific gravity and dry matter is important because when it exists, the former affords a quick and reliable means of estimating the latter.

Figure 4.6 shows the positive relationship between specific gravity and dry matter content of sweet potato roots. Using a computer program the best equation that could describe this relationship was exponential as given below:

$$Y = 0.936e^{4.796 \times 10^{-3}x} \quad \ldots\ldots\ldots\ldots\ldots 4.5,$$

Fig. 4.4 Relationship between weight and dry matter of roots

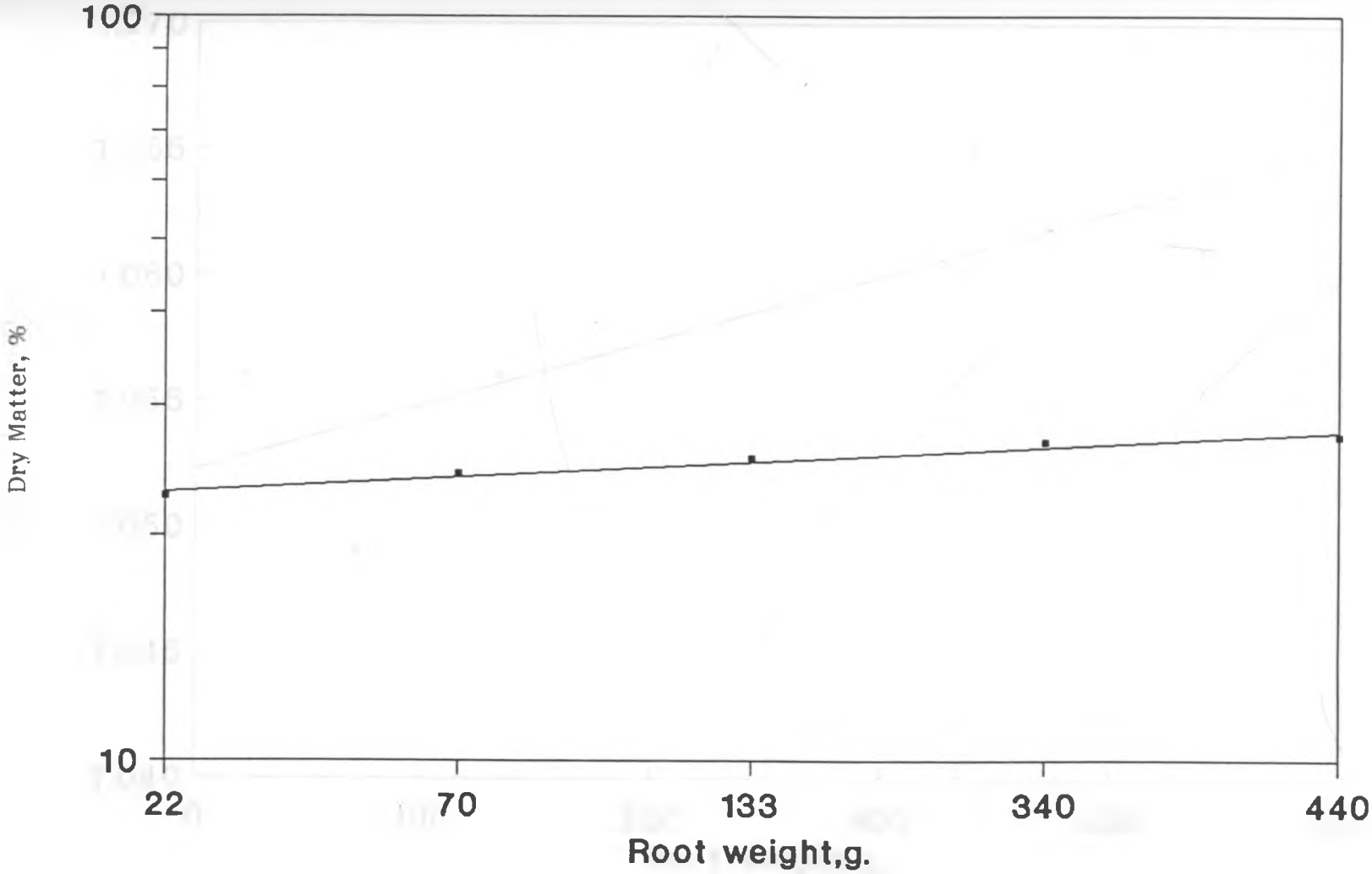
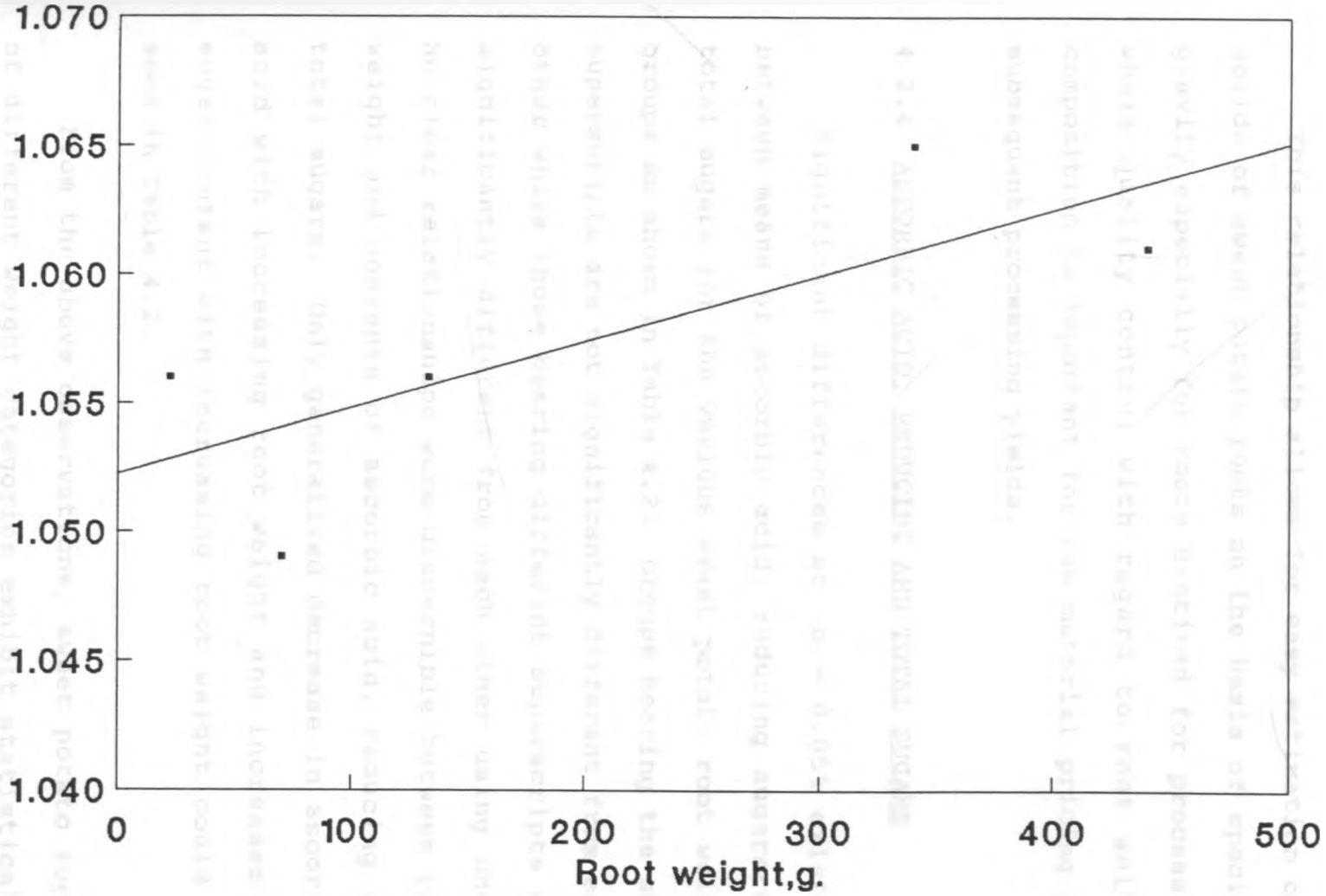


Fig.4.5 Relationship between weight and specific gravity of roots



where Y is specific gravity, X the corresponding dry matter content (%), e = 2.714 and r = 0.936.

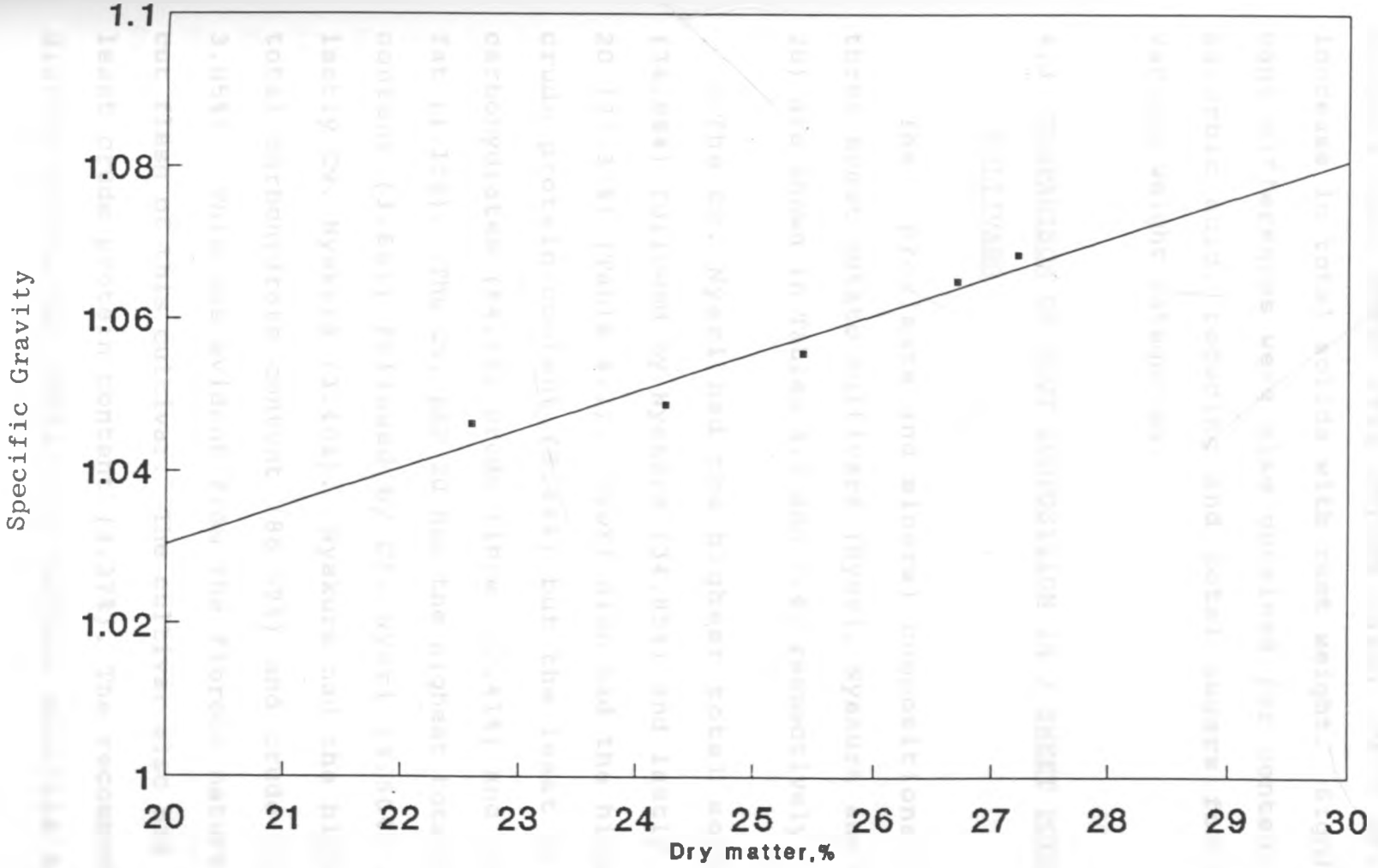
This relationship allows for easy estimation of % solids of sweet potato roots on the basis of specific gravity especially for roots destined for processing where quality control with regard to root solids composition is important for raw material pricing and subsequent processing yields.

4.2.4 ASCORBIC ACID, REDUCING AND TOTAL SUGARS

Significant differences at $\alpha = 0.05\%$ existed between means of ascorbic acid, reducing sugars and total sugars for the various sweet potato root weight groups as shown in Table 4.2. Groups bearing the same superscripts are not significantly different from each other while those bearing different superscripts are significantly different from each other using DMRT. No clear relationships were discernible between root weight and contents of ascorbic acid, reducing and total sugars. Only generalized decrease in ascorbic acid with increasing root weight and increases in sugar content with increasing root weight could be seen in Table 4.2.

From the above observations, sweet potato roots of different weight categories exhibit statistically

Fig. 4.6. Relationship between specific gravity and dry matter



significant (α = 0.05%) differences in root contents of total solids and specific gravity for average root weights upto about 340g beyond which there was no increase in total solids with root weight. Significant differences were also obtained for content of ascorbic acid, reducing and total sugars for the various weight categories.

4.3 COMPARISON OF ROOT COMPOSITION IN 3 SWEET POTATO CULTIVARS

The proximate and mineral compositions for three sweet potato cultivars (Nyeri, Nyakura and KSP 20) are shown in Tables 4.3 and 4.4, respectively.

The Cv. Nyeri had the highest total solids (34.98%) followed by Nyakura (34.85%) and lastly KSP 20 (23.32%) (Table 4.3). Nyeri also had the highest crude protein content (8.44%) but the least total carbohydrates (84.5%) crude fibre (2.41%) and crude fat (1.15%). The Cv. KSP 20 had the highest total ash content (3.66%) followed by Cf. Nyeri (3.50%) and lastly Cv. Nyakura (3.40%). Nyakura had the highest total carbohydrate content (88.59%) and crude fibre 3.05%). This was evident from the fibrous nature of cut flesh of this cultivar. The cultivar also had the least crude protein content (3.37%). The recommended dietary allowances (RDAs) for various minerals have

been compiled by the Food and Nutrition Board, USA (1974) for various age groups, physical states and sex. The table is reproduced in Appendix IV. Assuming minimal loss of calcium during processing of sweet potato roots, about 1.5 kg of the roots would be needed daily to supply the RDA for children, males from 19 years and females from 19 years who are neither pregnant nor lactating. About the same quantity on the average for the three cultivars would be required to satisfy the RDA for Iron and Magnesium for the entire age groups, sex and physiological states specified in Appendix IV, except for infants and children who may not be able to consume the whole bulk. All the three cultivars are also good sources of sodium and potassium. Zinc content, however, appears to be low.

Table 4.5 shows the specific gravity, reducing sugars and vitamin contents for the three cultivars after a growing period of 6 months. The specific gravity was highest in Cv. Nyeri which also had the highest total solids content (Table 4.2), and lowest in Cv. KSP 20 which had the lowest solids content. This confirms the earlier observation (section 4.2) that specific gravity and total solids are positively related.

In section 4.1.2, it was shown that reducing

Table 4.3: Proximate Composition of Cvs. Nyeri, KSP 20, and Nyakura, after 6 Months of Growth from planting

Cultivar	KSP 20	Nyeri	Nyakura
Solids, %	24.32	34.98	34.75
Crude protein, % DM	3.95	8.44	3.73
Crude fat, % DM	1.35	1.15	1.20
Crude fibre, % DM	2.65	2.40	3.05
Total ash, % DM	3.66	3.50	3.40
Total carbohydrates, % DM	88.39	84.51	88.95

Table 4.4: Mineral Composition of Cvs. Nyeri, KSP 20 and Nyakura (mg/100 DM)

	KSP 2	Nyeri	Nyakura
Na	44	9	12.3
K	1400	1250	14.0
Mg	160	210	160
Fe	5.6	4.4	5.6
Zn	1.2	1.3	1.0
Ca	100	80	150

Table 4.5: Specific Gravity, Reducing Sugars and Vitamin Contents of Cvs. KSP 20, Nyeri and Nyakura after 6 Months of Growth

	KSP 20	Nyeri	Nyakura
Specific gravity	1.041	1.066	1.056
Reducing sugars, % DM	2.34	Trace	Trace
Ascorbic acid, mg/100g Dm	84.17	74.18	44.12
β-Carotene, /100g DM	109.99	14.29	57.00

sugars increased with harvest date of roots for Cv. KSP 20. Indeed, as shown in Table 4.5, it has increased to 2.35% after a growing period of 6 months. However, even after 6 months, there were no quantifiable amounts of reducing sugars in the roots of Cvs. Nyeri and Nyakura. The presence of reducing sugars (mainly glucose and fructose) in the storage roots of sweet potatoes may be attributed to similar processes as in the tubers of the white potato (S. tuberosum). According to Van Es and Hartmans (1981), the presence of reducing sugars in the tubers of potatoes is due to their reformation from translocated sucrose, the transport sugar formed in the photosynthetic leaves, in the cytoplasm on the boundary of the membrane surrounding the incipient starch grain. The sucrose is split into glucose and fructose by the enzyme sucrose synthetase. The fructose is transformed into glucose inside the starch grain and is then polymerized to starch - the storage carbohydrate. Apart from the above process, reducing sugars in the roots of sweet potatoes may also be due to the breakdown of the starch polymer by the amylolytic enzymes notably α -amylase. The increase in reducing sugars in the roots of Cv. KSP 20 must be due to starch amylolysis, and the absence of reducing sugars in Cvs. Nyeri and Nyakura shows that these cultivars have negligible amylolytic activity. If the presence of reducing

sugars in sweet potato (Cv. KSP 20) roots was solely due to their reconversion from translocated sucrose, then, as shown by van Es and Hartmans (1981), the reducing sugar level of the roots would decrease progressively with chronological age. These authors showed that sucrose and reducing sugar levels decrease constantly with increasing maturity in white potato (S. tuberosum). In contrast, however, as there are significant levels of certain starch degrading enzymes in the roots of sweet potato (Deobald et al., 1969), there seems to be an opposing process in the formation of reducing sugars which, as it is, is responsible for their increase in Cv. KSP 20.

After 6 months' growing period, ascorbic acid and β-carotene contents were highest in Cv. KSP 20. Nyeri also had appreciable amounts of ascorbic acid (74.18 mg/100g), but as expected from the whiteness of its root flesh, it had the least amount of provitamin A carotenoids (14.29 g/100g) compared to Cv. Nyakura (57 g/100g) or Cv. KSP 20 (109.0 g/100g). From Appendix IV, the RDA for vitamin C for most adults is about 45 mg per day, increasing to 60 mg and 80 mg in pregnant and lactating mothers, respectively. According to Bradbury and Singh (1986a), the loss of vitamin C can be upto 65% on boiling if water is discarded and 20% if water is retained. If losses pertaining to cooked roots (water discarded) is taken as a basis for

estimating the approximate quantities of sweet potato roots that would provide sufficient RDA of vitamin C, then for Cv. KSP 20, about 120g would be required for most adults, about 120g for pregnant mothers and about 180g for lactating mothers. For Cv. Nyeri, most adults would need about 300g, 390g for pregnant mothers and 570g for lactating mothers. In the case of Cv. Nyakura, the requisite quantities for the various dietary groups would be about twice as much as for Cv. KSP 20. It is known (Appendix IV) that, the RDA for vitamin A is generally 800 retinol equivalents (RE) for adult females, 1000 RE for adult males and pregnant women, and 1200 RE for lactating mothers. But 1 RE is equivalent to 6 μg β-carotene. This means that adult females would require about 20 kg, adult males and pregnant women about 24 kg, and lactating mothers about 28 kg of Cv. KSP 20 to satisfy the RDA requirements of vitamin A. The figures are even larger for Cv. Nyakura or Cv. Nyeri. These are enormous quantities that may not be practicable in reality and these cultivars cannot be said to be good sources of vitamin A.

4.4 COOKING CHARACTERISTICS FOR Cvs. KSP 20, NYERI AND NYAKURA

A computer program was used to obtain regression outputs of sensory score on cooking time as shown in

Table 4.6. On the basis of the regression constants and the coefficients for cooking time in Table 4.6, three linear equations were constructed for the respective cultivars as follows:-

$$R_1 = 0.257t + 1.029 \quad \text{---------- 4.6}$$

$$R_2 = 0.207t + 1.293 \quad \text{---------- 4.7}$$

$$R_3 = 0.196t + 1.330 \quad \text{---------- 4.8}$$

where R_1, R_2 and R_3 are the sensory scores for Cvs. KSP 20, Nyakura and Nyeri, respectively and t is the cooking time in minutes at 94°C.

According to the category scale in Appendix III, the sensory score of 5 corresponds to an optimally cooked sample. When this value is substituted in equations 4.6, 4.7 and 4.8 above, values of 15.5, 18 and 18.7 minutes are obtained as the optimal cooking times for Cvs. KSP 20, Nyakura and Nyeri, respectively. Nyeri which had the highest total solids content (Table 4.3) also had the longest cooking time while KSP 20 which had the least total solids also had the shortest optimal cooking time. Optimal cooking time for all the cultivars in boiling water at 94°C is therefore dependent on their dry matter content. This dependence of cooking time on dry matter can be explained in terms of certain thermal properties of foodstuffs.

Table 4.6: Regression outputs for Sensory Scores on Cooking Cvs. KSP 20, Nyakura and Nyeri

Cultivar	Regression constant	Std. Error of R estimate	Regression coefficient	t coefficien
KSP 20	1.02857	0.333	0.980	0.257
Nyakura	1.29286	0.327	0.971	0.207
Nyeri	1.33000	0.314	0.970	0.196

t = Cooking time, Minutes
R = Average sensory score for degree of cookedness

Table 4.7 shows some pertinent physical properties and thermal data calculated for the three sweet potato cultivars.

It can be seen that Cv. KSP 20 which had the highest thermal conductivity (0.4794 J m^{-1} $S^{-1} \cdot C^{-1}$) also had the least optimal cooking time (15.5 minutes), while Nyeri which had the least thermal conductivity also had the longest optimal cooking time. Thermal conductivity is inversely related to total solids and specific weight, but the higher the thermal conductivity the lesser the resistance to heat transfer and hence the shorter the cooking time. According to Table 4.7, Cv. KSP 20 which had the lowest thermal diffusivity (1.364×10^{-4} m^2 S^{-1}) also had the shortest cooking time (15.5 minutes). The values for the thermal diffusivities for Cvs. Nyeri and Nyakura are comparable as are their respective optimal cooking times. The thermal diffusivities for the three cultivars seem to be directly related to the puncture force (yield point force) of raw samples. Nyakura which had the highest thermal diffusivity also had the highest puncture force, while KSP 20 which had lowest thermal diffusivity also had the least puncture force. It should be noted that the optimal cooking time was determined subjectively as the time required for sufficient cookedness as perceived in the mouth by the panelists while the yield point force (which is

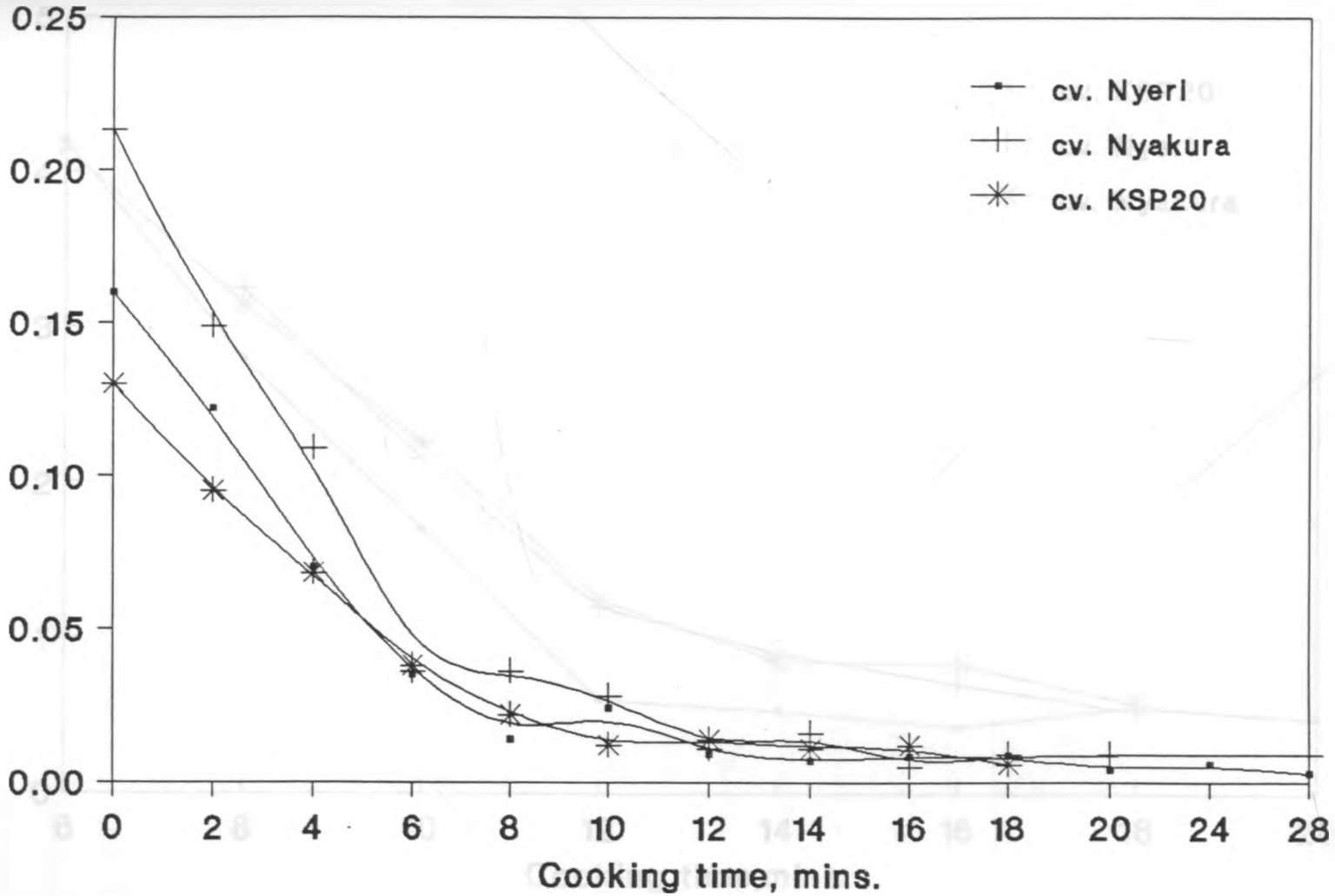
Table 4.7: Physical and Thermal Properties of Sweet Potato Cultivars

Cultivar	% Moisture	% Solids	Thermal Conductivity, K	Specific Heat ($Jm^{-1}s^{-1}$ $^{o}C^{-1}$)	Specific Weight ($Kg\ M^{-3}$)	Thermal Diffusivity $D(M^2S^{-1})$	Optimal Cooking Time, Mins	Yield Point At T = 0 Mins
KSP 20	75.68	24.32	0.4794	3.3753	1.041	$1.364x10^{-4}$	15.5	0.13
Nyakura	65.25	34.75	0.4493	3.0259	1.056	$1.406x10^{-4}$	18.0	0.21
Nyeri	65.02	34.98	0.4485	3.0181	1.066	$1.394x10^{-4}$	18.9	0.16

necessarily a measure of raw firmness of the dices) was gauged objectively by instrumental means. Firmer roots do not necessarily require a longer cooking time and other root constituents may play a major role in the rate of thermal penetration of the dices.

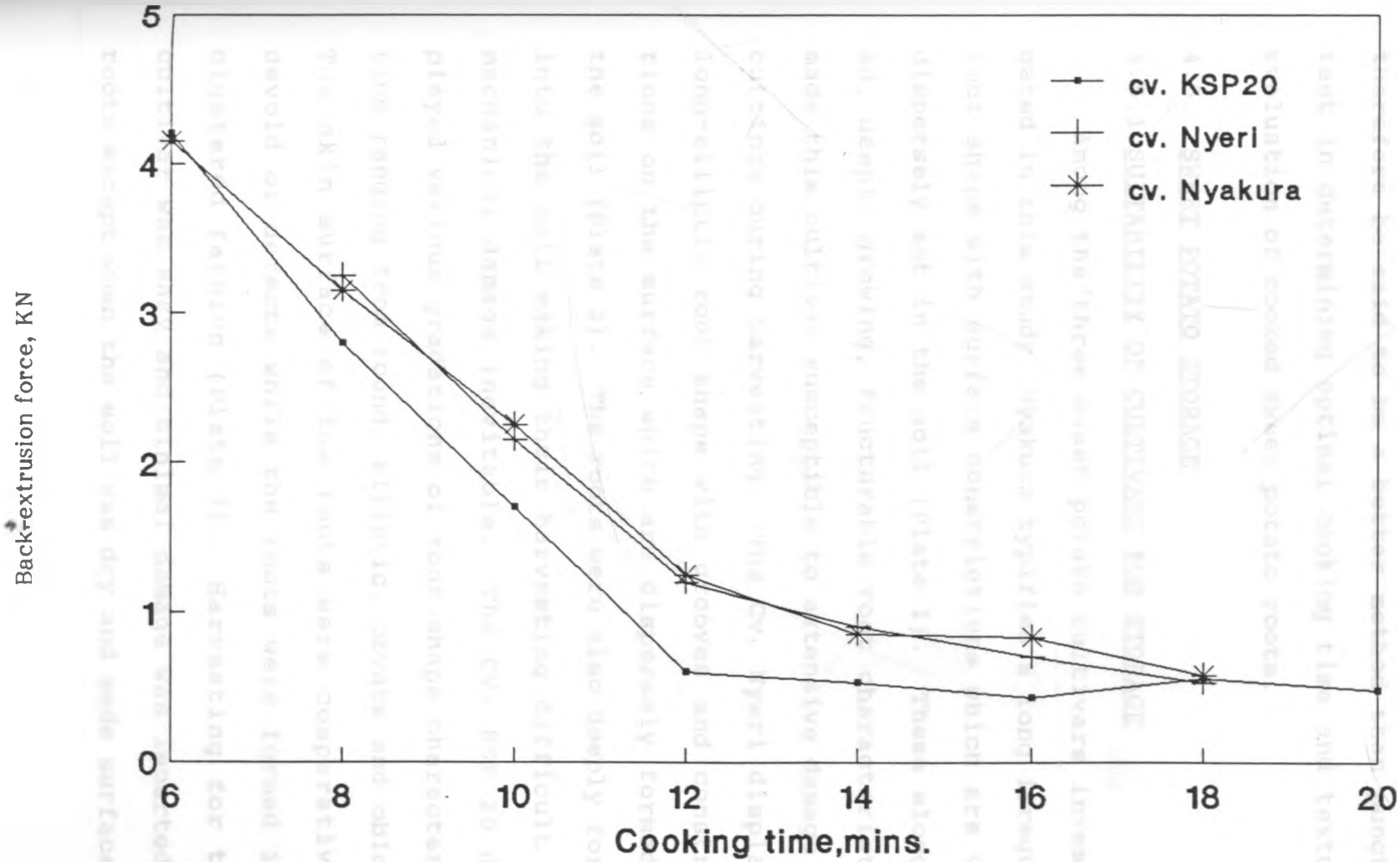
Two techniques of objective textural evaluation were applied to gauge the extent of cookedness of sweet potato dices. The techniques used were back-extrusion and puncture tests. Figures 4.7 and 4.8 show the puncture force and back-extrusion force, respectively of sweet potato dices cooked for various time intervals in boiling water at 94°C. The puncture force decreased with cooking time upto about 14 minutes for Cv. KSP 20 and about 16 minutes for both Cvs. Nyeri and Nyakura. Any further supply of heat was unnecessary after these times as the rigidity as well as the strength of the dices did not change any more. Similarly, back-extrusion force decreased with cooking time upto about 15 minutes for Cv. KSP 20, and about 18 minutes for Cvs. Nyeri and Nyakura, beyond which the force necessary to accomplish extrusion did not increase any further with added cooking time. The optimal cooking times as gauged by sensory evaluation for all the cultivars were similar to the respective times when there were no further decreases in back-extrusion force. Cooking times as gauged by puncture technique were lower than the corresponding optimal

Fig. 47. Puncture force vs. cooking time for sweet potato dices



Cooking in boiling water at 94 C

of sweet potato dices



Dices cooked in boiling water at 94 C

cooking times as determined by sensory evaluation. This means that back-extrusion technique as an objective method relates better to sensory values and can therefore be said to be a better method than puncture test in determining optimal cooking time and textural evaluation of cooked sweet potato roots.

4.5 SWEET POTATO STORAGE

4.5.1 SUITABILITY OF CULTIVARS FOR STORAGE

Among the three sweet potato cultivars investigated in this study, Nyakura typifies a long irregular root shape with surface constrictions which are very dispersely set in the soil (Plate 1). These elongated, deeply growing, fructurable root characteristics made this cultivar susceptible to extensive damage and cuttings during harvesting. The Cv. Nyeri displayed long-elliptic root shape with grooves and constrictions on the surface which are dispersely formed in the soil (Plate 2). The roots were also deeply formed into the soil making their harvesting difficult and mechanical damage inevitable. The Cv. KSP 20 displayed various gradations of root shape characteristics ranging from round, elliptic, obvate and oblong. The skin surface of the roots were comparatively devoid of defects while the roots were formed in a clustered fashion (Plate 3). Harvesting for this cultivar was easy and minimal damage was imparted to roots except when the soil was dry and made surface

Plate 1: Cultivar Nyakura

NB: Notice the irregularly elongated nature of the roots; they are deeply permeating in the soil rendering them susceptible to extensive mechanical injury during harvesting.

Plate 2: Cultivar Nyeri

NB: The roots are typical of long elliptic shapes with grooves and constrictions on the surface. Mechanical injury is evident

Plate 3: Cultivar KSP 20

NB: These roots were formed in a clustered fashion near the surface of the soil and were easily removable. There is minimal mechanical injury on the surface of the roots.

bruising inevitable.

On the basis of degree of mechanical damage imparted to the roots at harvest, the cultivar KSP 20 was selected for storage studies. In addition, this cultivar was the highest yielding of the three and could therefore provide sufficient roots for storage experimentation. Of no lesser significance was the fact that ascorbic acid and β-carotene which were used as quality indicators in stored roots occurred in superior quantities in this cultivar.

4.5.2 DRY MATTER AND CARBOHYDRATE CHANGES IN STORED ROOTS

After 4 weeks of storage, there was an enormous accumulation of reducing, non-reducing and total sugars in the roots under all the storage conditions (Table 4.8). Roots stored in saw-dust however exhibited maximum content of reducing and total sugars. Roots stored in soil had least total and reducing sugars. Sprouting was most marked in roots stored in saw-dust after 4 weeks storage. During sprouting there is enzymatic breakdown of reserve carbohydrates in the roots to nourish the emanating shoots. This process might account for the high rise in reducing and total sugars in these roots. The important storage carbohydrate in sweet potato roots is starch; this

Table 4.8: Changes in Total Solids and Sugars in Stored Sweet Potato Roots

	% Solids	% Total sugars (DMB)	% Reducing sugars (DMB)	% Non-reducing sugars (DMB)	% Sprouted Roots
	0 Weeks				
	24.68	1.35	0.57	0.78	0
	4 Weeks				
15°C	25.88	22.10	7.57	14.53	0
20°C	25.61	22.53	6.99	15.54	7.0
Soil	25.96	21.84	6.51	15.33	5.0
Saw-dust	24.60	32.05	8.09	14.96	12.10
Ambient	25.85	19.14	6.69	12.45	10.0
	12 WeekS				
15°	26.68	14.99	7.46	7.53	0
20°C	26.52	11.43	6.41	5.02	53.30
Soil	27.88	14.17	5.92	8.25	45.0
Saw-dust	25.66	12.63	6.78	5.85	55.56
Ambient	30.42	17.39	5.85	11.54	56.25

undergoes hydrolytic degradation by α-amylase when roots are in storage resulting in an increase in reducing and non-reducing sugars (Walter et al., 1975).

The dry matter content was also least in roots stored in saw-dust after 4 weeks storage indicating that some dry matter constituents for example minerals and sugars were used in nourishing the sprouts. Sprouting could therefore have a depletive effect on the nutritional composition of the stored roots and should be minimized by the application of sprout suppressants.

After 12 weeks storage, total sugars decreased generally for all the storage conditions while dry matter continued to increase in all cases. Non-reducing sugars also decreased after this storage duration in all the storage conditions. Maximum dry matter increase occurred in roots stored at ambient temperatures indicating maximum moisture loss under these fluctuating conditions. Although dry matter had been used up during sprouting, roots stored in saw-dust registered a net dry matter increase indicating that the rate of dry matter increase due to moisture loss was greater than dry matter utilization by growing sprouts. Even after 12 weeks storage, roots stored at 15°C did not show any sprouting, but reduc-

ing sugar accumulation was now highest in these roots.

During sweet potato storage, starch conversion into sugars has been reported to be rapid at first, especially during curing and to gradually slow down to an equilibrium during subsequent storage duration. This has been attributed to a reformation of starch from sucrose (non-reducing sugars) involving two sequential enzyme systems - sucrose synthase and starch synthase, respectively (Picha, 1986a). The decrease in total reducing and non-reducing sugars in stored roots of Cv. KSP 20 may be due to this cyclic enzymatic process. Sugar accumulation in stored roots may lead to unpleasant sweet taste especially in boiled roots and a dark colouration especially in fried processed products (Woolfe, 1987). However, in a baked potatoes, sugar accumulation is desirable ...ffer- developing flavour (Hamann, et al., 1980).

...here were Due to excessive moisture loss, roots ...roperties of ambient temperature were characteri... ...ions using back- shriveling and internal breakdown. were no significant of overall root appearance in o... various storage condi- were generally better eve... technique. The differences period.

... force using DMRT for the var- ...ctions after 12 weeks are shown in ... means bearing the same letters are not ...y different from each other at α = 0.05%, ...ey are significantly different from those

4.5.3 CHANGES IN TEXTURAL PROPERTIES OF STORED ROOTS

Changes in textural properties were quantified by instrumental techniques in roots of Cv. KSP 20 cooked in boiling water at 94°C for about 15 minutes (Section 4.4). The means for five values of instrumental forces (textural indices) are shown in Table 4.9.

Textural properties as indicated by puncture and back-extrusion forces of roots stored under various conditions for a duration of 4 weeks revealed no significant differences at α = 0.05%. Textural properties as indicated by puncture and back-extrusion forces of roots stored under various conditions for a duration of 4 weeks revealed no significant differences. However, after 12 weeks of storage, there were significant differences in textural properties of roots for the various storage conditions using back-extrusion technique while there were no significant differences observed for the various storage conditions using puncture test technique. The differences in mean back-extrusion force using DMRT for the various storage conditions after 12 weeks are shown in Table 4.9. The means bearing the same letters are not significantly different from each other at α = 0.05%, while they are significantly different from those

Table 4.9: Changes in Textural Properties of Stored Sweet Potato Roots

	Average Back-extrusion force, KN	Average Yield point force, KN
	0 Weeks	
	0.58	0.0185
	4 Weeks	
15°C	0.68	0.0175
20°C	0.61	0.0189
Soil	0.81	0.0181
Saw-dust	0.72	0.0155
Ambient	0.74	0.0200
	12 Weeks	
15°C	1.300^{c}	0.0224^{ns}
20°C	1.047^{b}	0.0161^{ns}
Soil	0.658^{a}	0.0084^{ns}
Saw-dust	0.682^{a}	0.0126^{ns}
Ambient	0.582^{a}	0.0153^{ns}

Key: α = 0.05%; DMRT;
ns = not significantly different

bearing different letters; thus roots stored at ambient, in soil and in saw-dust did not register significant differences in textural properties as gauged by back-extrusion force. Textural properties of roots stored at 15°C and at 20°C were significantly different from each other and also from those stored at ambient, in soil and in saw-dust. Maximum average back-extrusion force was recorded at 15°C and minimum at ambient temperature. Decrease in textural force should be due to hydrolytic changes in carbohydrate constituents such as starch, pectic substances and hemi-celluloses (Picha, 1986a; Walter et al., 1975).

Table 4.9 shows a general increase in back-extrusion for all the five different storage conditions after 4 weeks storage when compared to the original instrumental force at the beginning of storage. This increase in back-extrusion force was sustained in roots stored at 15 and 20°C, while there was a general decrease in instrumental force for roots stored in soil, saw-dust and at ambient conditions, stabilizing after 12 weeks' storage at about the original value. The changes in back-extrusion force for roots stored in soil, saw-dust and at ambient tend to follow the same pattern as the corresponding changes in non-reducing sugar content (Table 4.9). Non-reducing sugar in sweet potato roots is essentially composed of sucrose. As has been discussed

elsewhere in the present study, sucrose level at first increases when sweet potato roots are stored but eventually starts to decrease due to its use in starch resynthesis later on in storage (Picha, 1986a). This shows that the changes in textural properties of roots stored at ambient, in soil and in saw-dust are occasioned by the corresponding enzymatic modification of carbohydrate constituents notably starch.

The increase in back-extrusion force of roots stored at 15 and 20°C can be explained in terms of certain physiological disorders. At 15°C, the roots developed black surface pittings indicative of chilling injury. This led to hardcore formation in cooked roots and eventually the enormous increase in back-extrusion force. Roots stored at 20°C were shriveled on the surface and had indications of internal breakdown. This may account for the apparent anomalous increase in textural force. Therefore, apart from the enzymatic modifications of structural constituents in sweet potato roots in storage, certain temperature dependent physiological disorders such as chilling injury and internal breakdown are determinant on the resultant textural properties of the cooked roots.

From the above observations, it can be said that back-extrusion is a better method of determining changes in textural properties of stored roots than

puncture test. Also changes in textural properties can be attributed to the corresponding enzymatic modifications on carbohydrate constituents, especially starch and development of physiological disorders in the stored roots. Among the five different storage conditions, storage in soil and in saw-dust seem to be the most viable with respect to extent of textural alteration and modification of structural constituents as well as the general root appearance for the storage period investigated in the present study.

4.5.4 CHANGES IN COMPOSITION OF ROOTS STORED AT VARIOUS TEMPERATURES

Table 4.10 shows the composition of fresh roots and roots stored for various periods upto 10 weeks without curing at various temperatures chosen arbitrarily.

Roots stored at 5°C and 10°C could be stored only for a maximum period of three weeks when most roots had shown manifest chilling injury, extensive mould development and loss of integrity of root tissue. At 15°C, there was a remarkable contrast in that the roots were still preserved after 3 weeks with no indication of spoilage. However, at 20°C some roots had started sprouting although tuber flesh and skin were still presentable. Sprouting was more pronounced at 25°C and 29°C. Also, at 29°C the roots presented a

Table 4.10: Changes in Root Composition During Storage at Various Temperatures (Cv. KSP 20)

Temp. °C	Time Weeks	% Solids	Vitamin C (mg/100g) DMB	β-Carotene (µg/100g) DMB	Reducing Sugars, %
5	0	21.410	184.34	25.56	0.98
	1	20.920	155.96	26.15	3.15
	2	20.060	118.30	27.25	3.79
	3	20.040	105.92	28.75	7.80
10	0	21.410	184.34	25.56	0.98
	1	20.920	109.05	24.72	3.29
	2	20.970	97.62	23.75	4.15
	3	21.710	95.12	24.60	4.79
15	0	21.410	184.34	25.56	0.98
	1	22.08	134.33	33.75	4.44
	2	22.81	114.32	30.00	8.51
	3	21.96	129.14	23.75	10.06
	4	20.74	116.01	23.50	12.30
	5	20.99	94.57	16.25	12.10
	10	23.24	53.96	7.50	9.29
20	0	21.41	184.34	25.56	0.98
	1	22.59	170.74	21.34	8.50
	2	21.20	64.34	20.00	11.18
	3	22.41	52.88	20.00	9.59
	4	19.73	72.33	19.00	12.82
	5	22.10	69.28	22.50	9.82
	10	22.87	46.00	8.75	8.74

Table 4.10 Cont'd

Temp. °C	Time Weeks	% Solids	Vitamin C (mg/100g) DMB	β-Carotene (µg/100g) DMB	Reducing Sugars, %
29	0	21.41	184.34	25.56	0.98
	1	22.84	94.97	24.73	7.36
	2	24.61	82.37	28.75	6.71
	3	26.83	52.89	25.00	5.26
	4	25.48	47.73	23.00	5.34

shriveled appearance. Sprouting started as early as after only 2 weeks in storage at this temperature. There were also evident manifestations of internal breakdown and loss of tuber firmness.

Earlier in the storage period, there was a general increase in total solids which was more marked the higher the storage temperature. The reducing sugar content remained appreciably low at 5, 10 and 15°C, although it increased generally as compared to the fresh roots (Table 4.10). At 20, 29°C and ambient temperature, the increase in reducing sugars was more marked. This sudden change from 15 to 20°C means that the critical temperature for sweet potato storage (Cv. KSP 20) lies near 15°C. This fact can also be appreciated from the relative length of time that roots were storable at this temperature (10 weeks). Subsequently, as the storage period progressed, the reducing sugar content decreased for all the storage temperatures indicating that they were used up in respiratory and other physiological processes occurring in the roots.

The degradation of ascorbic acid was higher the higher the storage temperature with the highest rate of loss occurring under the fluctuating ambient temperature conditions.

From the data of Table 4.10, a computer program

was used to investigate the best mathematical relationship between vitamin C content of sweet potato roots (Cv. KSP 20) with storage time at the various temperatures. It was necessary to exclude errant data points in order to facilitate meaningful interpretation. Except for the data obtained for roots stored at 10°C, the degradation of vitamin C with time at various storage temperatures could be best described by first order relationship. Predicted values of initial vitamin C content using the various equations, the reaction rate constants at the various storage temperatures and the regression coefficients are given in Table 4.11. First order equations for vitamin C degradation at the various storage temperatures could be constructed as follows:

at 5°C, $C = 184.26\ e^{-0.194t}$ -------- 4.9

at 15°C $C = 165.87\ e^{-0.108t}$ -------- 4.10

at 20°C $C = 128.88\ e^{-0.124t}$ -------- 4.11

at 29°C $C = 157.69\ e^{-0.329t}$ -------- 4.12

It is clear from Table 4.11 that the rate constant, K varies positively with the storage temperature T. Using the data of Table 4.11, a computer program was used and an exponential equation of the Arrhenius type obtained between the rate constant and storage temperature. The values of the frequency factor and the coefficient, E_a/R were calculated from

Table 4.11: Rate Constants and Predicted Initial Vitamin C Content for First Order Degradation Kinetics at Various Storage Temperatures

Storage Temp. T (K)	1/T (K^{-1})	Predicted initial vitamin C content C_1 (mg/100g Dm)	Rate Constant, K ($Week^{-1}$)	ln K	Regression-Coefficient
278	3.597×10^{-3}	184.26	0.194	1.639	0.976
288	3.472×10^{-3}	165.87	0.108	2.226	0.957
293	3.413×10^{-3}	128.88	0.124	2.087	0.540
302	3.311×10^{-3}	157.69	0.329	1.112	0.930

the equation as 4.30×10^9 per week and 7056.17, respectively. Since R = 8.314 JK^{-1} $mole^{-1}$, the activation energy E_a was obtained as 5.87×10^4 J $mole^{-1}$.

Thus, the oxidative degradation of vitamin C in sweet potato roots stored at various temperatures is a first order reaction characterised by a definite frequency factor and activation energy. Using these kinetic parameters, the extent of vitamin C loss in storage can be predicted using appropriate equations as discussed in detail by Charm (1971).

The β-carotene content in stored roots showed erratic trends over the storage period at various temperatures, although there was a general decrease. It seems that β-carotene synthesis occurs in the earlier part of storage as shown by increases during this period. However, when storage is prolonged, there is a net degradation, especially at higher temperatures.

Even though synthesis of β-carotene is implied in storage which tends to offset the loss due to degradation, the author attempted to investigate the kinetic parameters for the net loss in this vitamin using the data in Table 4.11. As shown above for vitamin C, a computer program was used to find the relationship between change in β-carotene with storage time and to verify whether this relationship conforms to the

general first order equation. This method was preferred to the manual plot of the logarithm of residual vitamin content against time of storage. Except for the data at 10°C, the rest of the storage temperatures showed that the changes in β-carotene content with time could best be described by an exponential relationship of the form $C = c_0 e^{-kt}$. This is the first order reaction relationship and the degradation equations at the various temperatures are presented below:

at 5°C, $C = 25.36 e^{-3.94x10^{-2}t}$ -------- 4.13

at 15°C $C = 35.06 e^{-0.14t}$ -------- 4.14

at 20°C $C = 26.28 e^{-9.45x10^{-2}t}$ -------- 4.15

at 29°C $C = 26.38 e^{-2x10^{-2}t}$ -------- 4.16

The relationship had appreciably high correlation coefficients, of 0.97, 0.89 and 0.80 for 5, 15 and 20°C respectively, except for 29°C which had r = 0.15. It can be seen that values of the reaction constants, K (coefficients of t in the equations) do not follow a distinct pattern with storage temperature and the dependence of K on temperature could not be conclusively said to obey Arrhenius relationship. This could be attributed to sampling problems and experimental errors. Alternatively, there could be changes in the kinetic order of β-carotene loss at different storage temperatures.

5. CONCLUSIONS AND RECOMMENDATIONS

This study has concerned itself with the pertinent physical and chemical changes in sweet potato roots with growing period and various traditional and conventional storage conditions. In addition, nutritional constitution and cooking characteristics are considered in three selected cultivars. The following conclusions have therefore been deduced and appropriate recommendations made where necessary.

Increases in weight, specific gravity and dry matter content in sweet potato (Cv. KSP 20) roots with chronological age could be described by mathematical relationships. Weight and specific gravity exhibited an exponential fashion of increase while the increase in dry matter was logarithmic. Maximum dry matter accumulation occured in 160 days after planting. This was also the time of onset of foliage senescence. This time was recommended as the best for bulk harvesting for storage or processing as the high dry matter would ensure maximum processing yields. Specific gravity and dry matter were found to be positively correlated and this relationship was describable by an exponential equation.

Reducing sugar and total sugar both increased with chronological age of roots but there was a pro-

gressive decrease in ascorbic acid content. Total carotenoids also increased with harvest date. There exist significant differences in composition with regard to root sizes and sampling for analysis of root composition embraced all roots of possible sizes in the batch to obtain representative results.

The cultivar Nyeri had maximum total solids and specific gravity followed by Cv. Nyakura and lastly Cv. KSP 20. Nyeri also had almost twice as much crude protein as Cvs. Nyakura or KSP 20. Total carbohydrates were comparatively higher in Cvs. Nyakura and KSP 20 but least in Cv. Nyeri. All varieties were found to be good sources of sodium, potassium and magnesium. Vitamin C occurs in good quantities in all the cultivars sufficient for all dietary groups except children. These cultivars were however not good sources of provitamin A carotenoids.

The cultivar KSP 20 had least cooking time followed by Nyakura and lastly Nyeri. It was concluded that the higher the dry matter content, the longer the cooking time. Cooking time could also be explained in terms of certain derived thermal properties of sweet potato roots. Thus, the higher the thermal conductivity the lower the cooking time. Optimal cooking times as gauged by sensory evaluation were also the times when there were no further decrease in back-extrusion

force and not puncture force. It was therefore concluded that back-extrusion as an objective method for measuring textural properties of cooked sweet potato roots was better than puncture test technique.

Sweet potato (Cv. KSP 20) roots stored in soil or saw-dust were just as good and could store for just as long as at the conventional 15°C, save for sprouting. It is recommended that if suitable sprout suppresants are used, then these traditional storage practices would prove cheap and viable storage alternatives especially for small scale farmers.

Alterations in textural properties of sweet potato roots under various storage conditions were objectively quantifiable by back-extrusion technique, especially after 12 weeks storage. Changes in textural properties of roots stored at ambient, in soil and in saw-dust were due to corresponding enzymatic modifications of root carbohydrate constituents especially starch. Development of physiological disorders was the over-riding factor for textural changes in roots stored at the fluctuating temperatures of 15 and 20°C.

For roots stored without curing at various temperatures, manifest chilling injury occured after only 3 weeks at 10°C and below. Sprouting and internal breakdown were also observed at 20°C and above. It was therefore concluded that the critical temperature

for Cv. KSP 20 lies in the neighbourhood of 15°C. Increases in total solids and reducing sugars occur with storage time, being higher the higher the storage temperature. Degradation of vitamin C was also accelerated at higher temperatures. This rate of degradation was described by first order reaction kinetics with a frequency factor and an activation energy. Similarly, the net degradation of β-carotene in storage could be described by first order reaction kinetics.

REFERENCES

Adam, M.; J. Celba and Z. Havlicek (1980). Texture of Some Solid and Semi-Solid Foods. In: Food Process Engineering, Vol. 1, Food Processing Systems. Eds., P. Linko, Y. Malkki, J. Olkku, and J. Larinkari. Applied Science Publishers Ltd., London. pp. 265 - 273.

Agata, W. (1982). The Characteristics of Dry Matter and Yield Production in Sweet Potato Under Field Conditions. In: Sweet Potato: Proceedings of the First International Symposium, Shanhua, Tainan, Taiwan, China, Eds., R.L. Vallereal and T.D. Griggs. Assian Vegetable Research and Development Centre (AVRDC) pp. 119 - 128.

Agrawal, V.P. and P.E. Kolattukudy (1977). Biochemistry of Suberization. Plant Physiology, 59: 667 - 672.

Ajlouni, S. and M.K. Hamdy (1988). Effect of Combined Γ-irradiation and Storage on Biochemical Changes in Sweet Potato. J. Food Science, 53 (2): 477 - 481.

Alvarez, S.J. and S. Thorne (1988). The Effect of Temperature on the Deterioration of Stored Agricultural Produce. In: Development in Food Preservation-1. Ed., S. Thorne. Applied Science Publishers, London and New Jersey. pp. 215-237.

Alvarez, M.N. (1987). Sweet Potatoes and the African Food Crisis. In: Tropical Root Crops: Root Crops and the African Food Crisis. Eds., E.R. Terry, M.O. Akoroda and O.B. Arene, International Development Research Centre (IDRC), Ottawa - Canada.

Arinze, A.E. and I.M. Smith (1982). Effect of Storage Conditions on the Resistance of Sweet Potato Tissues to Rotting by Botryodiplodia theorbromae (Pat.) and Other Fungi. J. of Stored Products Research, Vol. 18 (2): 37 - 41.

Astrup, H.N.; E.S. Halvorsen; P. Linstad; Y. Entwistle and J.C. Mathers (1971). Publication No. 373, Institute of Animal Nutrition, Agriculture Institute of Norway.

Austin, M.E. and L.H. Aung (1973). Patterns of Dry Matter Distribution During Development of Sweet Potato. J. Hort. Science 48 (1): 11

Baba, T. and K. Kainuma (1987). Partial Hydrolysis of Sweet Potato Starch with β-amylase. Agricultural and Biological Chemistry 51 (5): 1365 - 1371.

Baba, T.; H. Nakama; Y. Tamaru and T. Kano (1987). Development of Snack Foods Produced from Sweet Potatoes V. Changes in Sugar and Starch Contents during Storage of New Type Sweet Potato (Low β-amylase activity in roots).

Barakat, Z.M.; M.F.A. El-Wahab; M.M. El-Sadr (1955). Action of N-Bromosuccinimide on Ascorbic Acid: A New Titrimetric Method for Estimation of Vitamin C. Analytical Chemistry 27 (4): 536 - 540.

Ben-Gera, I.; H. Weisslowitz; P. Shalom and D. Basker (1974). Uniform Methods for the Laboratory Examination of Potatoes. Agricultural Research Organization, The Volcani Centre, Special Publication No. 33. Bet. Dagan, Israel.

Booth, R.H. (1974). Post-Harvest Deterioration of Tropical Root Crops. Tropical Science 16: 149 - 163.

Bourke, R.M. (1985). Influence of Nitrogen and Potassium Fertilizer on Growth of Sweet Potato in Papuas New Guinea. Field Crops Research, 12: 363 - 375.

Bourne, M.C. (1979). Theory and Application of the Puncture Test in Food Texture Measurement. In: Food Texture and Rheology. Ed., P. Sherman. Academic Press. London, New York, San Francisco. pp. 95 - 142.

Bourne, M.C. (1982). Food Texture and Viscosity: Concept and Measurement. Academic Press, New York and London.

Bouwkamp, J.C. (1985). Sweet Potato Production Requirements. In: Sweet Potato Products. A Natural Resource for the Tropics. Ed., J.C. Bouwkamp, Ed. CRC Press, Inc., Boca Raton, Florida. pp. 9 - 34.

Bouwkamp, J.C. and J.G. Kantzes (1977). Carotene Content of Sweet Potato Roots as a affected by Various Nematicide Treatments. HortScience 12 (2): 167.

Boyd, T.J. and A. Wilson (1972). Isolation and Characterization of 4-ipomeanol, a Lung Toxic Furanoterpenoid Produced by Sweet

Potato. J. Agric. Fd. Chem. 20: 426 - 430.

Bradbury, J.H. and U. Singh (1986a). Ascorbic Acid and Dehydroascrobic Acid Contents of Tropical Root Crops from the South Pacific. J. Food Science 51 (4): 975 - 978.

Bradbury, J.H. and U. Singh (1986b). Thiamin, Riboflavin, and Nictotinic Acid Contents of Tropical Root Crops from the South Pacific. J. Food Science 51 (6): 1563 - 1564.

Bradbury, J.H. and W.D. Holloway (1988). Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific. Australia Centre for International Agricultural Research (ACIAR), Canberra, Australia.

Bueschar, R.W.; W.A. Sistrunk and A.E. Kassaian (1976). Induction of Textural Changes in Sweet Potato Root by Chilling. J. Amer. Soc. Hort. Science 101: 516 - 519.

Burton, W.G. (1982). Post-Harvest Physiology of Food Crops. Longman, London and New York. P. 5.

Chang, L.A. and S.J. Kays (1981). Effect of Low Oxygen Storage on Sweet Potato Roots. J. Amer. Soc. Hort. Sci. 106 (4): 481 - 483.

Charm, S.E. (1971). The Fundamentals of Food Engineering. The AVI Publishing Company, Inc. Westport, Connecticut, 2nd Edition. pp. 119 - 188.

CIAT - CIP -IITA (1987). Recommendations of the Workshop on Sweet Potato Improvement in Africa, held from 28 September - 2 October, 1987 in Nairobi, Kenya.

Coates, M.E. (1983). Germ-free Animals in Studies of the Nutritional Importance of the Gut Micro-flora. In: Dietary Fibre. Eds., G.G. Birch and K.J. Parker. Applied Science Publishers, London and New York. pp 275 - 283.

Collins. W.W. (1987). Improvement of Nutritional and Edible Quantities of Sweet Potato for Human Consumption. In: Exploration, Maintanance and Utilization of Sweet Potato Genetic Resources. Report of the First Sweet Potato Planning Conference, CIP-Lima, Peru. pp. 221 - 226.

Constantin, R.J., T.P. Hernandez and L.G. Jones (1974). Effects of Irrigation and Nitrogen Fertilization on Quality of Sweet Potatoes.

J. Amer. Soc. Hort. Sci. 99 (4): 308 - 310.

Constantin, R.J.; L.G. Jones and T.P. Hernandez (1975). Sweet Potato Quality as Affected by Soil Reaction (pH) and Fertilizer. J. Amer. Soc. Hort. Sci. 100(b): 604 - 607.

Constantin, R.J.; L.G. Jones; T.P. Hernandez (1977). Effects of Potassium and Phosphorus Fertilization on Quality of Sweet Potatoes. J. Amer. Soc. Hort. Sci. 102 (6): 779 - 781.

Cooke, J.R. (1974). The Chemical Estimation of Vitamin C. In: Vitamin C. Eds., G.G. Birch and K.J. Parker. John Wiley and Sons, New York and Toronto.

Cottle, W. and P.E. Kolattukudy (1982). Abscisic Acid Stimulation of Suberization. Plant Physiology, 70: 775 - 780.

Data, E.S.; J.C. Diamente and P.S. Eronico (1987). Postharvest Handling and Storability of Sweet Potato Roots. International Sweet Potato Workshop, Visayas State College of Agriculture, Phillipines. pp 19.

Deobold, H.J.; V.C. Hasting and E.A. Catalano (1971). Variability of Increases in α-amylase and Sugars during Storage of Goldrush and

Centennial Sweet Potatoes. J. Fd. Sci. 36: 413 - 415.

Deobald, H.J.; V.C. Hasting; E.A. Catalano, and T.A. McLemore (1969). Relationship of Sugar Formation and Sweet Potato α-amylase Activity during Processing for Flake Production. Food Tech. (Campaign) 23 (6): 826 - 829.

Dickey, L.F. and W.W. Collins (1984). Cultivar Differences in Trypsin Inhibitors of Sweet Potato Roots. J. of American Society of Horticultural Science 109: 750 - 754.

Dubois, M.; K.A. Gilles; J.K. Hamilton; P.A. Rebers and F. Smith (1956). Calorimetric Method for Determination of Sugars and Related Substances. Analytical Chemistry 28(3): 350 - 356.

Earle, R.L. (1983). Unit Operation in Food Processing. Pergamon Press. Oxford. New York. Toronto. Sydney. Paris. Frankfurt. 2nd Edition pp. 46 - 63.

Edmond, J.B. and G.R. Ammerman (1971). Sweet Potatoes: Production, Processing, Marketing. AVI Publishing Co., Estport, CT, USA. PP. 334.

Elkins, E.R. (1979). Nutrient Contents of Raw and Canned Green Beans, Peaches and Sweet Potatoes. Food Technology 33 (2): 66 - 70.

El-Tamzini, M.I. (1976). Post-Harvest Physiological Studies on Sweet Potato Cultivars. Dissertation Abstracts International, B 37, 550.

Van Es, A. and K.J. Hartmans (1981). Sugars and Starch during Tuberization, Storage and Sprouting. In: Storage of Potatoes. Eds., A. Rastovski and A. Van Es. Centre for Agricultural Publishing and Documentation. Wageningen. pp. 82 - 98.

Ewell, P.T. (1988). Tentative Agenda for Research on Sweet Potatoes in Kenya. CIP Region III - Nairobi, Kenya.

Ewell, P.T. (1989). Report on a Workshop on Sweet Potato Germplasm in Kenya. Paper Presented at the KARI and CIP Sponsored Workshop held from July 5 - 7, 1989 in Nairobi. CIP Region III - Nairobi - Kenya. .pa

Ewell, P.T. and J. Mutuura (1990). Sweet Potatoes in the Food Systems of Eastern and Southern Africa. A Poster Presented at the 2nd Triennial Conference of the African Potato

Association, Mauritius. CIP - Region III, Nairobi.

FAO (1987): World Crop and Livestock Statistics (1948 - 1985). Rome, Italy. pp. 169

FAO (1989a): Utilization of Tropical Foods: Roots and Tubers. Rome - Italy. pp. 43 - 46.

FAO (1989b): Production Yearbook Vol. 42 (1988): Rome - Italy. pp. 134 - 140.

Folkes, D.J. and A. Brookes (1984): Analysis and Characterization of Glucose Syrups. In: Glucose Syrup: Science and Technology, Dziedzic, S.Z. and M.W. Kearsley, Eds. Elsevier Applied Science Publishers. London and New York. pp. 197 - 245.

Food and Nutrition Board (1974). Recommended Daily Allowance (RDA) for some Vitamins and Minerals. National Academy of Sciences. U.S.A

Fujimoto, S.; T. Nagahama and M. Karice (1972): Changes in Content and Chain Length of Amylose in Sweet Potato Starch with the Development of Starch Granules J. Agric. Chem. Soc. of Japan, 46 (ii): 577 - 583.

Gracza, R. (1965). Minor Constituents of Starch. In: Starch: Chemistry and Technology, Vol. 1. Eds., R.L. Whistler and E.F. Paschall. Academic Press, New York and London. p. 289 - 307.

Gomez, M.I. (1981). Carotene Content of Some Green Leafy Vegetables of Kenya and Effects of Dehydration and Storage on Carotene Retension. Journal of Plant Foods 3: 231 - 244.

Gor, C.O. (1989). Literature Review and Baseline Statistics on Sweet Potatoes in Kenya. CIP Region III, Nairobi - Kenya.

Hamann, D.D.; N.C. Miller; and E.A. Purcell, (1980). Effects of Curing on the Flavour and Texture of Baked Sweet Potatoes. J. Food Science 45: 992 - 994.

Hinton, W.L. (1973). Economic Aspects of Vegetable Storage. Acta Horticulturae Vol. 2 No. 38, P. 531 - 560.

Hodge, J.E. and E.M. Osman (1976). Carbohydrates. In: Principles of Food Science, Part I, Food Chemistry. Eds., O.R. Fennema. Marcel Dekker, Inc., New York and Basel. p. 41-137.

Hong, E.H. (1982). The Storage, Marketing and Utilization of Sweet Potatoes in Korea. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwan, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). p. 421 - 428).

Horton, D. (1989). Constraints to Sweet Potato Production and Use. In: Improvement of Sweet Potato (Ipomoea batatas) in Asia. International Potato Centre, , CIP. Lima, Peru. p. 219 - 223.

Hozyo, Y. and S. Kato (1976). Thickening Growth Inhibition and Re-thickening Growth of Tuberous Roots of Sweet Potato Plants (Ipomoea batatas). Proc. Crop Sci. Soc. Japan, 45: 131 - 138. .PA

Huaman, Z. (1987). Descriptors for the Characterization and Evaluation of Sweet Potato Genetic Resources. In: Exploration, Maintenance, and Utilization of Sweet Potato Genetic Resources. CIP, LIMA, Peru.

p. 331 - 335.

Huaman. Z. and H. De la Puente (1988). Development of a Sweet Potato Gene Bank At CIP. CIP Circular Vol. 16, No. 2.

Huang, P.C. (1982). Nutritive Value of Sweet Potato. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwan, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). P. 35 - 36.

Jellinek, G. (1985). Sensory Evaluation of Food: Theory and Practice. VCH Germany and Ellis Horwood Ltd. England. p. 156.

Jenkins, P.D. (1982). Losses in Sweet Potatoes (Ipomoea batatas) Stored Under Traditional Conditions in Bangladesh. Tropical Science 24 (1): 17 - 28.

Junek, J. and W.A. Sistrunk (1978). Sweet Potatoes High in Vitamin Content but Content is affected by Variety and Cooking Method. Arkansas Farm Research 27 (5): 7

Karel, K. (1975). Carbohydrates. In: Enzymes in Food Processing. Ed., G. Reed. Academic Press, New York, San Francisco and London. P. 53 - 122.

Kay, D.E. (1973). Crop and product Digest 2: Root Crops. Tropical Products Institute, London. p. 245.

Kolattukudy, P.E. and B.B. Dean (1974). Structure, Gass Chromatographic Measurement and Function of Suberin Synthesized by Potato Tuber Tissue Slices. Plant Physiology. 54: 116 - 121.

Kozempel, M.F. (1988). Modelling the Kinetics of Cooking and Precooking Potatoes. J. of Food Science 53 (3): 753 - 755.

Kramer, A. (1973). Food Texture - Definition, Measurement and Relation to Other Food Quality Attributes. In: Texture Measurements of Foods. Eds., A. Kramer and A.S. Szczesniak. D. Reidel Publishing Company. Dordrecht - Holland and Boston - USA p. 1 - 8.

Kwapata, M.B. (1984). Effect of Sun Curing Time and Application of Ash on Storability of Sweet Potato (Ipomoea batatas). Research Bulletin, Bunda College of Agric. 12: 171 - 180. Lilongwe, Malawi.

Lanier, J.J. and Sistrunk, W.A. (1979). Influence of Cooking Method on Quality Attributes and Vitamin Content of Sweet Potatoes. J. Fd. Sci. 44 (2): 324 - 376

Leach, H.W. (1965). Gelatinization of Starch. In: Starch: Chemistry and Technology, Vol. I Eds., R.L. Whistler and E.F. Paschall. Academic Press, New York and London. p 289 - 307.

Lee, K. and S.R. Lee (1972). A Study of the Systematic Analysis of Lipids from Sweet Potatoes. Korean Journal of Food Science and Technology, 4 (4): 309 - 316.

Lees, R. (1975). Food Analysis. Leonard Hill Books. London.

Leveille, G.A. (1977). The Role of Dietary Fibre in Nutrition and Health. In: Carbohydrates and Health, Eds. L.F. Hood; E.K. Wardrip and G.N. Bollenback. AVI Publishing Co., Inc., Westport, Connecticut. p. 84 - 93.

Lund, D.B. (1975). Interaction of Heat Energy and Food Components. In: Principles of Food Science, Part II. Eds. M. Karel, O.R. Fennema and D.B. Lund. Marcel Dekker, Inc.

New York and Basel. P. 38 - 52.

McKenna, B.M. (1980). Mechanical Properties of Fruits and Vegetables. In: Food Process Engineering, Vol. I; Food Processing Systems. Eds. P. Linko, Y. Malkki, J. Olkku and J. Larinkari. Applied Science Publishers Ltd. London. P. 274 - 279.

Meyer, L.H. (1960). Food Chemistry. AVI Publishing Co. Inc., Westport, Connecticut.

Ministry of Agriculture (1984 - 1987). Provincial Annual Reports for Western, Nyanza, Coast, Central, Eastern and Rift Valley. Kenya.

Ministry of Agriculture and Livestock Development (1986). Report of the Kenya National Agriculture Research Project. Government of Kenya, Nairobi.

Murata, T. and T. Akazawa (1968). Enzymatic Mechanism of Starch Synthesis in Sweet Potato Roots. I. Requirement of Potassium Ions for Starch Synthatase, Arch. Biochem. Biophys. 126: 873.

Ndolo, P.J. (1989). Root and Tuber Crops Survey Report on Western Kenya. Western Agricultural Research Centre - KARI. Kenya.

Ojijo, N.K.O. (1990). Preliminary Survey on Sweet Potato Production, Utilization, Storage and Processing in Kenya, Carried out by the Author in Nyanza, Western, Eastern and Coast Provinces and CIP.

Oliver, M. (1967). Occurrence of Vit. C in Foods. In: The Vitamins, Vol. 1., 2nd Edition. Eds. W.H. Sebrell and R.S. Harris. Academic Press New York and London. pp. 359 - 367.

Onwueme, I.C. (1982). The Tropical Tuber Crops: Yams, Cassava, Sweet Potato and Cocoyams. English Language Book Society and John Wiley and Sons. Chichester, Britain. pp. 189 - 190.

Ontani, K. and A. Mizaki (1985). An In Vitro Study of the Effects of Cell Wall Polysaccharides of Potatoes on Digestibilities of their Starches. J. Japanese Society of Nutrition and Food Science, 38(5): 363 - 370.

Palmer, J.K. (1982). Carbohydrates in Sweet Potato. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). P.135 - 140.

Pearson, D. (1970). The Chemical Analysis of Foods. 6th Edition. J. and A Churchill. London.

Perkin-Elmer (1982). Manual of the Analytical Methods for Atomic Absorption Spectrophotometry. Perkim-Elmer Company, U.S.A.

Pesek, C.A. and Warthesen, J.J. (1988). Characterization of the Photodegradation of β-Carotene in Aqueous Model System. J. of Food Science, 53 (5): 1517 - 1520.

Picha, D.H. (1986a). Post-Harvest Storage Characteristics of Sweet Potatoes. Lousiana Agriculture 30 (9): 12 - 13.

Picha, D.H. (1986b). Weight Loss in Sweet Potatoes during Curing and Storage: Contribution of Transportation and Respiration. J. of the American Society for Horticultural Science III (6): 889 - 892.

Picha, D.H. (1987). Carbohydrate Changes in Sweet Potatoes during Curing and Storage. J. of the American Society for Horticultural Science 112 (1): 89 - 92.

Pol, F.V.D.; S.V. Pummo and H.A.V. Rosmalen (1988). Trans-Cis Isomerization of Carotenes and its Effect on the Vitamin A Potency of Some

Common Idonesian Foods. Nutritional Reports International 37 (4): 785 - 793.

Purcell, A.E.; W.M. Walter Jr. and F.G. Giesbrecht (1978a). Changes in Dry Matter, Protein and Non-protein Nitrogen during Storage of Sweet Potatoes. J. Amer. Soc. Hort. Sci. 103 (2): 190 - 192.

Purcell, A.E.; W.M. Walter Jr. and F. Giesbrecht (1978b). Protein and Amino Acid of Sweet Potato Fractions. J. Agric. Fd. Chem. 26 (3): 699 - 701.

Purcell, A.E. and W.M. Walter (1980). Changes in Composition of the Non-protein Nitrogen Fraction of `Jewel' Sweet Potatoes during Storage. J. Agric. Fd. Chem. 28: 842 - 844.

Purcell, A.E.; D.T. Pope and W.M. Water Jr. (1976). Dry Matter and Proteins in Sweet Potatoes. Hort. Science 11(1): 31.

Ranganna, S. (1977). Manual of Analysis of Fruit and Vegetable Products. Tata McGraw-Hill Publishing Company Ltd. New Delhi, India.

Ryall, A.L. and W.J. Lipton (1979). Handling Transportation and storage of Fruits and Vegetables. Vol. 1, 2nd Edition. AVI Publishing Col, Inc. Westport, Connecticut.

Sclimme, D.V. (1966). Anatomical and Physiological Aspects of Sprouts Initiation and Development in Sweet Potato Storage Roots, Diss. Abstracts 26(9): 4947.

Scott, L.E. and J.C. Bouwkamp (1975). Effect of Chronological Age on Composition and Firmness of Raw and Processed Sweet Potatoes. Hort. Science 10 (2): 165 - 168.

Shanmugavelu, K.G.; S. Thamburaj; A. Shanmugam and N. Gopalaswamy (1972). Effect of Time of Planting and Type of Planting Material on the Yield of Sweet Potato (I. batatas), South India Horticulture, 20: 55 - 58.

Sistrunk, W.A. (1971). Carbohydrate Transformations, Color and Firmness of Canned Sweet Potatoes as Influenced by Variety, Storage, pH and Treatment. J. Food-Sci. 36: 39 - 42.

Sistrunk, W.A. (1977). Relationship of Storage, Handling and Cooking Method to Colour, Hardcore Tissue, and Carbohydrate Composition in Sweet Potatoes. J. Amer. Soc. Hort. Sci. 102: 381 - 384.

Sistrunk, W.A., J.C. Miller and L.G. Jones (1954). Carbohydrate Changes During Storage and Cooking of Sweet Potatoes. Food Technology 8: 223 - 226.

Smith, O. (1977). Potatoes: Production, Storing, Processing. 2nd Edition. AVI Publishing Company, Inc. Westport Connecticut.

Smith, O. and C.O. Davis (1968). Potato Processing. In: Potatoes: Production, Storing, Processing, Ed., Ora Smith. The AVI Publishing Company, Inc. Westport, Connecticut. pp. 558 - 602.

Spence, J.A. and J.C. Humphries (1972). Effect of Moisture Supply, Root Temperature and Growth Regulators on Photosynthesis of Isolated Leaves in Sweet Potato. Annals of Botany, 36: 115 - 121.

Splittstoesser, W.E.; F.W. Martin and A.M. Rhodes (1973). The Nutritional Value of Some Tropical Root Crops. Proceedings of the Tropical Region of the American Society for Horticultural Science, 17: 290 - 294.

Splittstoesser, W.E. (1977). Protein Quality and Quantity of Tropical Roots and Tubers. Hort. Science 12 (4): 294 - 298.

Stahmann, M.A.; B.G. Glare and W. Woodbury (1966). Increased Disease Resistance and Enzymic Activity Induced by Ethylene and Ethene

Production by Black-Rott Infected Sweet Potato Tissue. Plant Physiology 14: 1505 - 1512.

Steel, R.G.D. and J.H. Torrie (1980). Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Kogakusha, Ltd. Tokyo - Japan.

Steve, S.M.L.; C. Peet; D. Chen and H. Lo (1985). Sweet Potato Production and Utilization in Asia and the Pacific. In: Sweet Potato Products: A Natural Resource for the Tropics. Ed., J.C. Bouwkamp, CRC Press, Inc., Boca Raton, Florida. p. 139 - 148.

Stino, K.R. and M.E. Lashin, (1953). Effect of Fertilizers on the Yield and Vegetative Growth of Sweet Potatoes. Proc. Am. Soc. Hortic. Sci., 61: 367.

Suguira, M.; T. Ogiso; K. Takeuti; S. Tamura and A. Ito (1973). Studies of Trypsin Inhibitors in Sweet Potato 1. Purification and Some Properties. Biochem. Biophys. Acta 328: 407 - 417.

Ton, C.S. (1978). A Study of High Soil Moisture Levels and Water Submergence on the Sweet Potato (I. batatas (L.) Lam). Dissertation

Abstracts International, B. 38 (7): 2991.

Tsou, S.C.S. and R.L. Vallereal (1982). Resistance to Eating Sweet Potato. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). P. 37 - 44.

Tsou, S.C.S. and Yang, M.H. (1984). Flatulence Factors in Sweet Potato. Acta Horticulturae 163: 197.

Tsou, S.C.S. and T.L. Hong (1989). Digestibility of Sweet Potato Starch. In: Improvement of Sweet Potato (I. batatas) in Asia. CIP - Lima - Peru. pp. 167 - 182.

Tsuno, Y. and K. Fujise (1965). Studies on the Dry Matter Production of the Sweet Potato. VIII. The Internal Factors Influence on Photosynthetic Activity of Sweet Potato Leaf. Proc. Crop Sci. Soc. Japan, 33: 230.

Tsuno, Y. and K. Fujise (1963). Studies of the Dry Matter Production of Sweet Potato: II - Aspects of Dry matter Production in the Field. Proceedings of the Crop Science Society of Japan, 31: 285 - 288.

Uritani, I. (1982). Postharvest Physiology and Pathology of Sweet Potato From the Biochemical Viewpoint. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). p. 421 - 428.

Uritani, I.; E.S. Data and Y. Tanaka (1984). Biochemistry of Post-harvest Deterioration of Cassava and Sweet Potato Roots. In: Tropical Root Crops - Post-harvest Physiology and Processing. Eds., Uritani, I., Reye, E.D. Japan Scientific Society Press, p. 61 - 75.

Walter, W.M. Jr. (1987). Effects of Curing on Sensory Properties and Carbohydrate Composition of Baked Sweet Potatoes. J. Food Science 52 (4): 1026 - 1029.

Walter, W.M. and Catignani, G.L. (1981). Biological Quality and Composition of Sweet Potato Protein Fractions. J. Agric. Food Chem. 29: 797 - 799.

Walter, W.J. Jr.; A.E. Purcell, and A.M. Nelson (1975). Effects of Amylolytic Enzymes on Moistness and Carbohydrate Changes of Baked

Sweet Potato Cultivars. J. of Food Science, 40: 793.

Walter W.M. Jr. and A.E. Purcell (1986). Protein of the Sweet Potato. ACS Symposium Series 312: 234 - 248.

Wanda, W.C. and W.M. Walter Jr. (1985). Fresh Roots for Human Consumption. In: Sweet Potato Products; A Natural Resource for The Tropics. Ed. J.C. Bouwkamp. CRC Press, Inc., Boca Raton, Florida. pp. 153.

Watanabe, K.; K. Ozaki and T. Yashiki (1986). Studies on the Effect of Soil Physical Condition on the Growth and Yield of Crop Plants. 7. Effect of Soil Air Composition and Soil Bulk Density on the Growth of Sweet Potato. Proc. Crop Sci. Soc. Japan, 37: 65 - 69.

West, C.E.; F. Pepping and C.R. Temaliwa (1988). The Composition of Foods Commonly Eaten in East Africa. Wageningen Agricultural University, CTA and ECSA. Wageningen. P. 14 - 15.

Wilson, B.J.; D.T.C. Yang and M.R. Boyd (1970). Toxicity of Mould Damaged Sweet Potatoes (Ipomoea batatas). Nature (Lond.), 227(5): 521 - 522.

Wilson, L.A. (1982). Tuberization in Sweet Potato (Ipomoea batatas (L.) Lam). In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). 79 - 94.

Winarmo, F.G. (1982). Sweet Potato Processing and By-product Utilization in the Tropics. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). P. 373 - 384.

Woolfe, J.A. (1987). The Potato in the Human Diet. CIP-Lima. Cambridge University Press, Cambridge, Britain.

Woolfe, J.A. (1989). Nutritional Aspects of Sweet Potato Roots and Leaves. In: Improvement of Sweet Potato (I. batatas) in Asia. CIP - Lima - Peru. pp. 167 - 182.

Wright, F.S. and W.F. Splinter (1968). Mechanical Behaviour of Sweet Potatoes Under Slow Loading and Impact Loading. Trans ASAE 11:

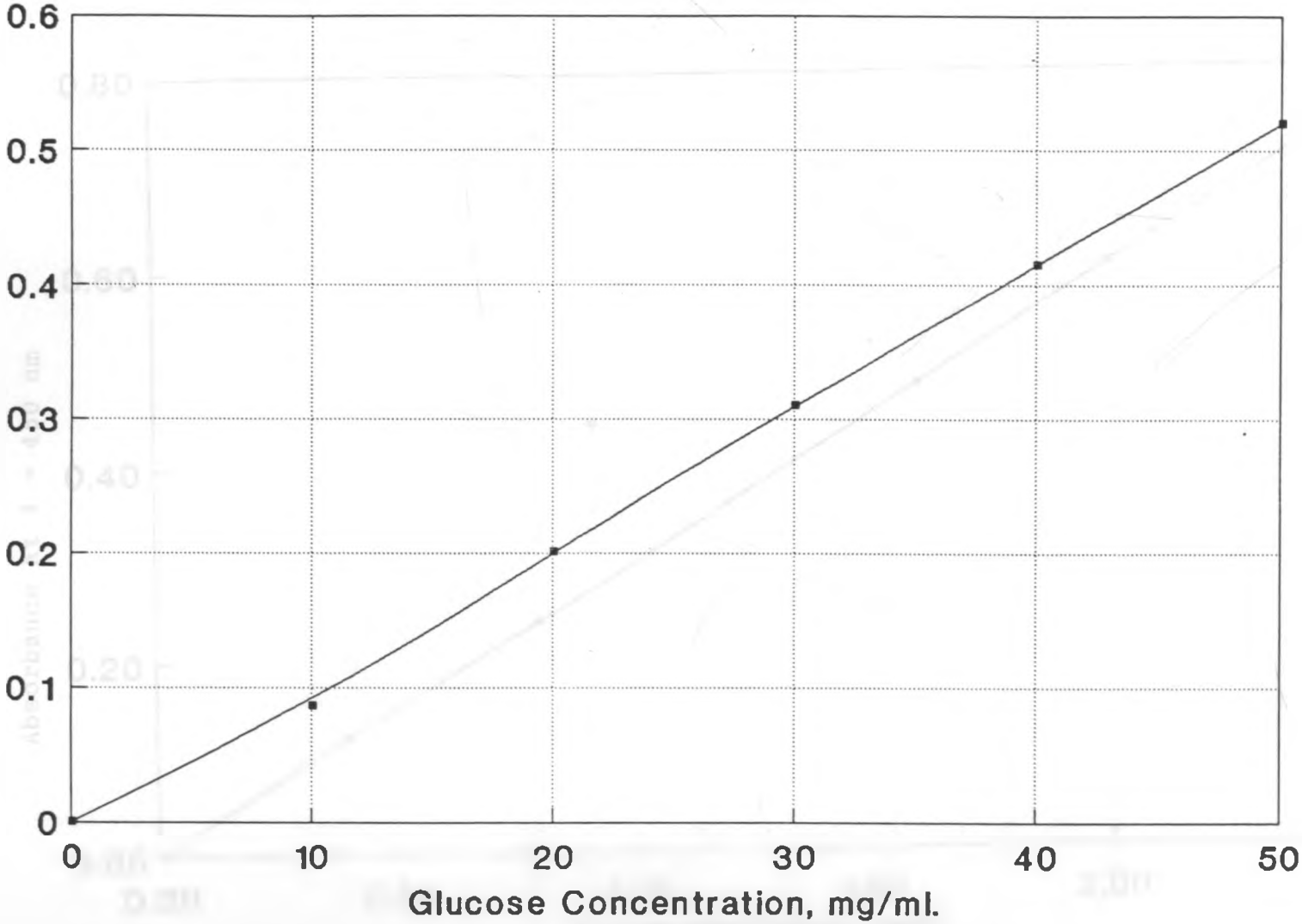
765 - 770.

Wright, F.S.; W.E. Splinter and L.J. Kushman (1968). Influence of Variety, Time from harvest and Storage Conditions on Mechanical Behaviour of sweet Potatoes. Trans ASAE 11: 81 - 85.

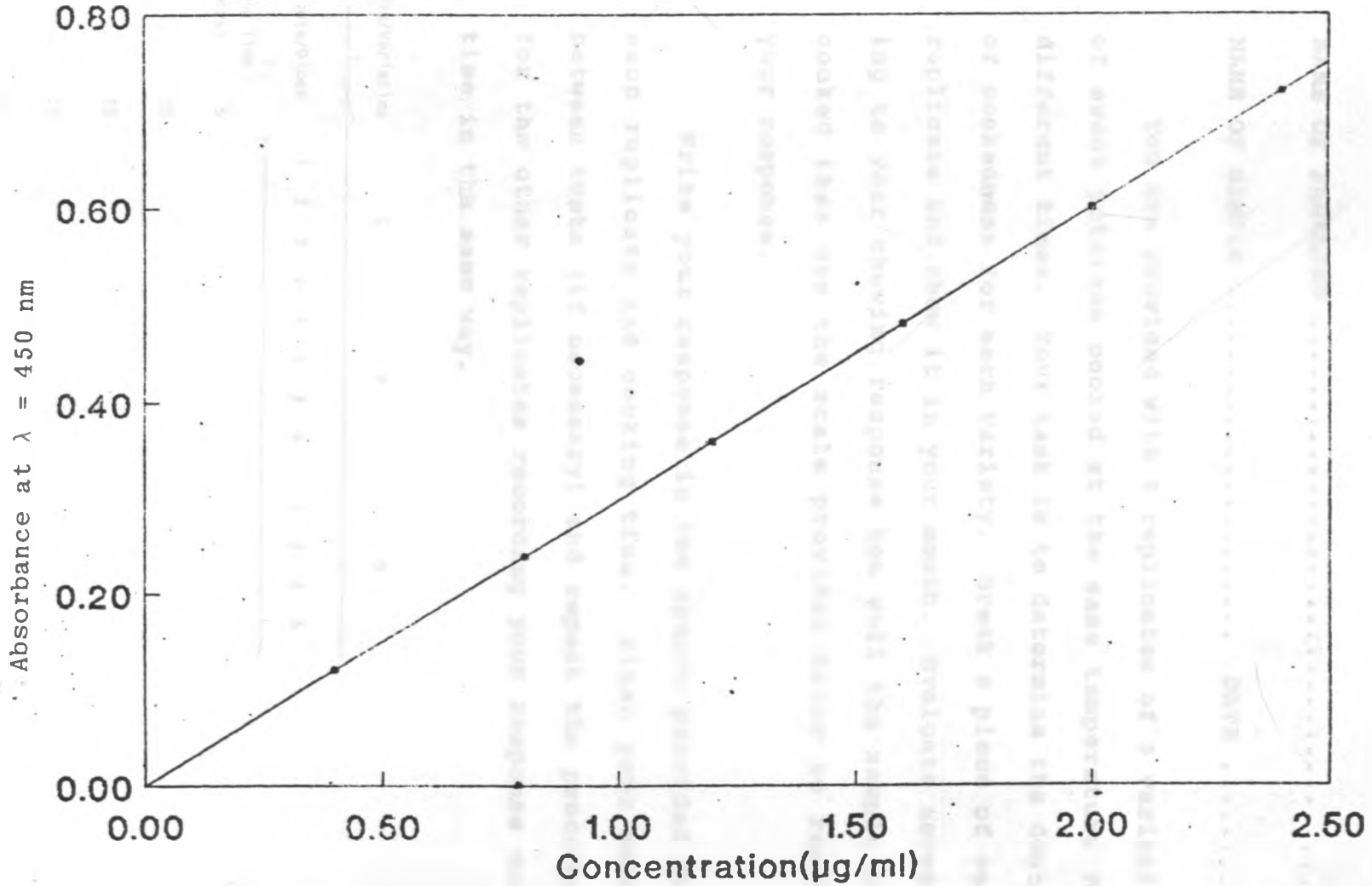
Yang, T.H. (1982). Sweet Potato as a Supplemental Staple Food. In: Sweet Potato, Proceedings of the First International Symposium, Shanhua, Tainan, Taiwanm, China. Eds., R.L. Villareal and T.D. Griggs. Asian Vegetable Research and Development Centre (AVRDC). P. 31 - 34.

Yen, (1982). Sweet Potato in Historical Perspective. In: Sweet Potato, Proceedings of the First International Symposium, AVRDC, R.L. Villareal and T.D. Griggs, Eds. Shanhua, Tainan, Taiwan, China, P. 17 - 30.

App.I Glucose standard curve



Appendix II: β - Carotene standard curve



Appendix III: Sensory Evaluation of Cooked Sweet Potatoes

NAME OF PANELIST .....

NAME OF SAMPLE ..... DATE .....

You are provided with 2 replicates of 3 varieties of sweet potatoes cooked at the same temperature for different times. Your task is to determine the degree of cookedness for each variety. Break a piece of each replicate and chew it in your mouth. Evaluate according to your chewing response how well the sample was cooked then use the scale provided below to record your response.

Write your response in the spaces provided for each replicate and cooking time. Rinse your mouth between tests (if necessary) and repeat the procedure for the other replicates recording your response each time in the same way.

Samples/Varieties		L				P				Q			
Replicats/Dices		1	2	3	4	1	2	3	4	1	2	3	4
Cooking Time (Minutes)	5												
	10												
	15												
	20												
	25												

SCALE:

1 : Extremely raw

2 : Very slightly cooked

3 : Slightly cooked

4 : Nearly cooked

5 : Sufficiently cooked

6 : Very slightly overcooked

7 : Slightly overcooked

8 : Overcooked

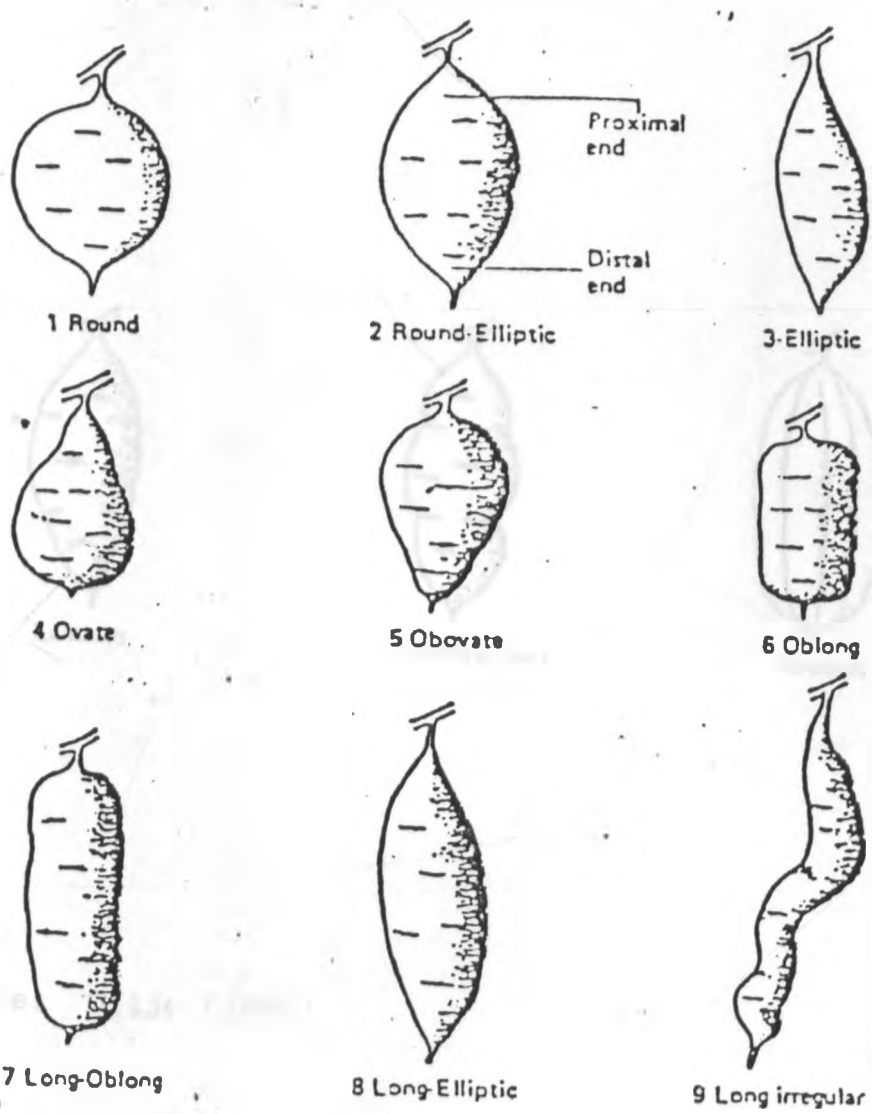
9 : Extremely overcooked

Appendix IV: RDA for Some Minerals and Vitamins

	Age Yrs	Energy (kcal)	Protein (g)	Vitamin A Activity (RE)	Ascorbic Acid (mg)	Calcium (mg)	Iron (mg)	Magnesium (mg)	Zinc (mg)
Infants	0.0-0.5	kgx117	kgx2.2	420	35	360	10	60	3
	0.5-1.0	kgx108	kgx2.0	400	35	540	15	70	5
Children	1-3	1300	23	400	40	800	15	150	10
	4-6	1800	30	500	40	800	10	200	10
	7-10	2400	36	700	40	800	10	250	10
Males	11-14	2800	44	1000	45	1200	18	350	15
	15-18	3000	54	1000	45	1200	18	400	15
	19-22	3000	54	1000	45	800	10	350	15
	23-50	2700	56	1000	45	800	10	350	15
	51+	2400	56	1000	45	800	10	350	15
Females	11-14	2400	44	800	45	1200	18	300	15
	15-18	2100	48	800	45	1200	18	300	15
	19-22	2100	46	800	45	800	18	300	15
	23-50	2000	46	800	45	800	18	300	15
	51+	1800	46	800	45	800	10	300	15
Pregnant		+300	+30	1000	60	1200	18	450	20
Lactating		+500	+20	1200	80	1200	18	450	25

Source: Food and Nutrition Board, National Academy of Sciences, U.S.A (1974).ojon.ls2

Appendix V: Storage Root Shape

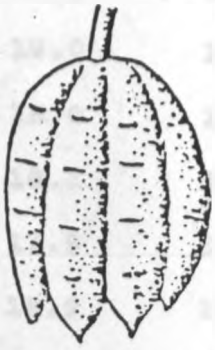


Source: Ojijo (1990)

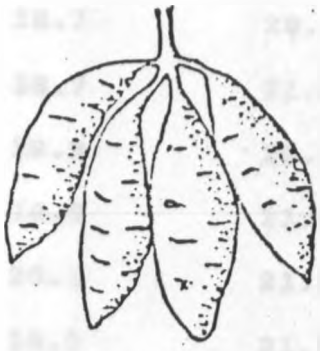
Appendix VI: Storage Root Surface Defects

Source: Ojijo (1990)

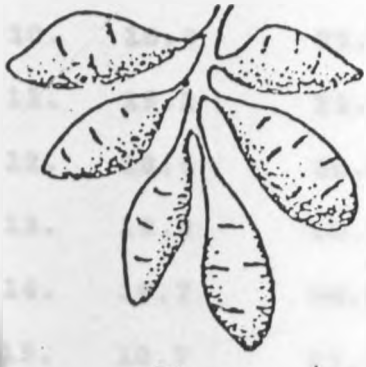
Appendix VII: Storage Root Formation



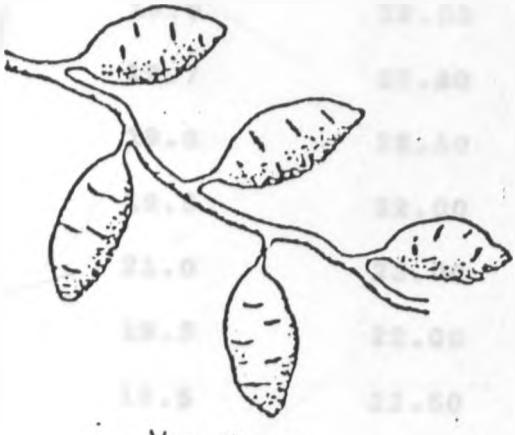
Closed cluster



Open cluster



Disperse



Very disperse

Ojijo (1990)

Appendix VIII: Ambient Temperature Fluctuations

	Wet Bulb		Dry Bulb	
	M	E	M	E
1.	17.9	18.5	18.7	19.10
2.	18.0	19.3	18.7	20.20
3.	18.0	19.9	18.7	21.00
4.	18.1	19.3	18.9	20.30
5.	17.9	19.9	18.8	21.40
6.	18.9	20.0	20.1	21.20
7.	17.8	19.7	18.5	21.10
8.	19.5	20.9	20.5	22.40
9.	18.7	20.9	19.5	22.00
10.	18.9	21.0	19.7	22.20
11.	19.2	21.3	19.8	22.50
12.	18.6	20.2	19.5	22.00
13.	19.9	20.7	21.0	22.00
14.	18.7	20.5	19.5	22.00
15.	18.7	21.0	19.5	22.50
16.	18.4	20.5	19.2	22.20
17.	18.9	20.4	19.9	21.70
18.	20.2	20.5	21.8	22.00
19.	19.3	20.8	20.0	22.20
20.	19.5	20.4	20.2	22.00
21.	19.0	19.80	19.9	21.00

Appendix VIII Cont'd

	Wet Bulb		Dry Bulb	
	M	E	M	E
22.	20.25	21.15	21.25	22.25
23.	18.90	21.0	19.90	22.10
24.	18.70	20.00	19.40	21.20
25.	18.70	19.90	19.40	20.70
26.	17.70	18.80	18.50	19.60
27.	16.90	19.50	17.70	20.50
28.	18.10	19.30	18.80	20.10
29.	17.10	17.70	17.80	18.40
30.	15.80	19.80	16.60	21.20
31.	18.00	20.00	18.90	21.40
32.	19.80	19.80	20.80	21.00
33.	17.80	19.60	18.60	20.30
34.	17.20	18.40	17.90	19.20
35.	16.60	18.80	17.10	19.50

NB: M - Morning

E - Evening