EFFECT OF GAMMA IRRADIATION ON THE KEEPING QUALITY OF TWO CULTIVARS OF THE NIGERIAN YAM DIOSCOREA ROTUNDATA poir

BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN BIOCHEMISTRY.

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D E C L A R A T I O N

I hereby declare that this thesis is a record of my own research and has not been submitted for the award of a degree at any other university. Informations and excerpts from both published and unpublished work of others have been acknowledged in the text.

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C E R T I F I C A T I O N

This thesis entitled:"Effect of gamma irradiation on the keeping quality of two cultivars of the Nigerian yam Dioscorea rotundata" by Owolabi, Olumuyiwa Adeyemi meets the regulations governing the award of the degree of Master of Science (M.Sc.) in Biochemistry of Ahmadu Bello University and is approved for its contribution to knowledge and literacy presentation.

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D E D I C A T I O N

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A B S T R A C T

The effect of gamma irradiation on the keeping quality of yam tuber (Dioscorea rotundata) was investigated. Two cultivars "Amara" and "Chikakwando" harvested 7 days prior to the experiment were cured and then treated at about 25° C with 50, 100 and 180 GY doses of gamma irradiation. The tubers were stored in a well ventilated barn (temp. 22 °C 35 °C and RH 22-78 %) for 40 weeks. The tubers were monitored weekly for sprouting and rotting. The weight proximate composition, reducing sugar, total free amino acid, dietary fibre (cellulose, hemicellulose and lignin) and the carbohydrate profiles were determined every four weeks.

Irradiation completely inhibited sprouting throughout the whole storage period and rotting was significantly reduced ($P<0.05$) in Chikakwando but not in Amara. The rate of weight loss was lecreased significantly ($P<0.05$) by irradiation in both cultivars. Irradiation significantly affected ($P<0.05$) the moisture, protein, total free amino acid, lipid, nitrogen free extractive, starch, reducing sugar, soluble carbohydrate, hemicellulose and Lignin contents of tubers of both cultivars after dormancy breakage. Irradiation at various dose levels did not significantly ($P>0.05$) affect the chemical composition except for the starch and reducing sugar content of Amara.

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CHAPTER ONE

1.0 INTRODUCTION

As the world population grows, increasing the food supply becomes an ever-more-urgent priority. One vital but neglected step toward this end is the reduction of the food losses that occur between harvest and consumption (N.A.S., 1978). A quarter of the world food production is lost after harvesting (N.A.S., 1978). Losses occur where the food is grown, during distribution, storage, processing and marketing and in the home. This is more pronounced in developing countries where transportation and storage system are not efficient, ambient temperature and humidity are high and the need for food is greatest (IAEA, 1984). The availability of food can be increased by reduction in losses, as it is much easier than improving the yield of food crops by a few percent. Indeed most governments now recognise the need to take action and thus have given high priority to programmes that will reduce food losses (IAEA, 1978).

Despite the availability of several methods for food preservation, such as drying, canning, freezing and fermentation, huge losses still occur in many parts of the world, especially in the developing countries where the available technology is not efficient.

Yam is one of the staple foodstuffs in Nigeria and many other tropical and subtropical countries of the

world (Coursey, 1967a). It is only second to cassava (Manihot esculenta) as the principal source of calories for millions of West African people (April, 1974). Yam belongs to the genus Dioscorea, containing about six hundred species, of which ten are edible. Edible yam species cultivated in Nigeria in order of importance are given below (Coursey, 1967a):

Dioscorea rotundata poir - The white Guinea yam

Dioscorea cayenensis lam - The yellow yam

Dioscorea alata linn - The water yam

Dioscorea esculenta Burkill - The Chinese yam

Dioscorea dumetorum pax - The bitter yam.

World annual production of yam is estimated to be approximately 20 million metric tons (Martin and Thompson, 1971); 98 % of this is produced in Africa. Nigeria alone accounts for 78 % of the total yam produced (Coursey, 1971). Yam is also a foreign exchange earner for Nigeria (Okigbo, 1962). 8375 tons of yams was exported to Britain in 1969 with an estimated earning of 500,000 pounds (Bell and Coursey, 1971). Though yam is such an important crop in the food economy of Nigeria, only one crop is grown per year and this is harvested over a limited period of three to four months (FAO, 1967). Yam must therefore be stored for periods of up to six months or longer to make meaningful impact in hunger alleviation of the populace. The most widely used or

perhaps the best type of store for yam in West Africa is the yam barn. Other methods of storage include leaving yam in heaps or ridges until they are required for food or sales (Coursey, 1967a).

Unfortunately, very substantial losses in weight and quality occur during storage in yam barn. A loss of 10-15 % in the first three months and losses approaching 50 % after six months storage have been reported (Coursey, 1967b). Based on storage period of three months, it is estimated that an annual loss of 10 % in Nigeria is worth approximately 13 million pounds (Hayward and Walker, 1962). The losses in yams during storage have been attributed to physical, metabolic and microbiological factors and to insects, nematodes and rodents attack, with the metabolic and microbiological factors being the two most important (Adesuji and Mackenzie, 1973). The decay caused by fungi in stored yams is effected through wounds and natural openings (Ogundana et al, 1970a; 1970b). This therefore suggests that if yams are carefully harvested and handled before storage, microbiological losses could be substantially reduced or prevented.

Metabolic factors include respiration and sprouting. Respiration accounts for about 10 % loss in dry matter over 5 months. Sprouting which involves formation and growth of new bud from tuber with accompanying depletion of stored

food material, contributes immensely to metabolic losses and dehydration; it accounts for about 20 % of weight loss over 5 months period (Onwueme, 1973).

Despite the potential benefit of solving the storage problems of yam urgently, the level of research investment in the post harvest storage of yam does not appear to reflect this. If yam is to retain its position as mass consumed staple food, certain fundamental changes must occur in its production and utilization, especially in form of increased research efforts into its post-harvest storage problems.

Once harvested, the yam tuber quickly goes into dormancy, a period of metabolic quiescence during which the rate of respiration may drop to as low as 20 % of the pre-harvest value and remain at this level until sprouting (Ikediobi, 1985). Dormancy is a necessary and unavoidable stage in the life cycle of the yam tuber and it is precisely because of it that the tuber must be stored before it can be used as planting material. Because of the potential benefits, the temptation to successfully manipulate dormancy is very great.

Unfortunately, attempts to do this by application of some synthetic sprout suppressants and plant hormones have not yielded much dividend. From available information, it is discouraging to note that of all the chemical tested, only isopropyl N-(3-chlorophenyl) carbamate (ICPC) was found to exhibit any positive effect (Passam, 1978a). Of the hormones

examined, only gibberellic acid appeared to offer the promise as a practical means of prolonging dormancy and extending storage life. Passam (1978a) explained the ineffectiveness of sprout suppresant chemicals when used on yams as being due to the fact that, they seem to act on the meristematic cells of the sprouting loci. Unlike in potatoes, where these loci are well formed at the time of harvest and are superficially located, they appear just before breakage of dormancy in yams and are usually buried beneath the periderm (Onwueme, 1973).

Storage at low temperature could be a practical alternative with regard to the elongation of the dormancy period of the tuber. However, this method is beset with difficulties which range from its not being cost effective coupled with the erratic nature of our power supply here in Nigeria, to the little understood phenomenon of chilling injury.

A very promising, though largely unexploited method of yam storage involves the exposure of tubers to a range of doses of gamma radiation prior to storage. In pioneer studies by Adesuyi and Mackenzie (1973) and Adesuyi (1975b and 1976) it was observed that treatment of tubers with 125 Grays of gamma radiation was most suitable in inhibiting sprouting in Dioscorea rotundata for about six months, these workers were mostly interested in inhibition of sprouting by gamma irradiation and the organoleptic quality of the

irradiated yams. Literature is scanty on some important nutritional changes associated with gamma radiation inhibition of sprouting compared with what is available on potatoes, sweet potatoes and onions, hence acceptability and wholesomeness are not yet completely elucidated (Nair et al, 1973; Roushdy et al, 1973; Agbaji, 1980; Agbaji et al 1981). Incidentally, Gregory (1968) and Martins et al (1974) reported stimulation of sprouting of yam tuber by gamma irradiation. Hence, there is need for clarification.

This research work attempts to correlate the inhibition of sprouting in gamma irradiated yam tuber to the nutritional changes associated with it. Therefore, the specific objectives this study are to:

i) Delay sprouting and prolong the storage life of different cultivars of yams.

ii) Determine the optimal irradiation dosage suitable and economical for various cultivars of D. rotundata.

iii) Determine the effect of various doses of gamma radiation on the weight losses.

iv) Determine the effect of various doses of gamma radiation on the keeping qualities and nutrient composition of yam tuber during storage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Nature of the Tuber:

Yam plants are monocotyledon belonging to the family Dioscoreaceae within the order Dioscoreales (Ayensu, 1972) although there is some evidence of the existence of a second cotyledon (Lawton and Lawton, 1969).

The yam tuber has conventionally been classified as a stem structure (Waitt, 1961a). Burkhill (1960) and Njoku (1963) have advanced strong organographic evidence to show that it is a stem and not a root structure. However, several characteristics of the yam tuber tend to suggest that it is not a stem tuber in the classical sense that an irish potato tuber or a cocoyam would be. Firstly, the yam tuber lacks any scale leaves on its surface that might identify nodal positions. Secondly, no buds or "eyes" are present on the surface of the yam tuber, nor are any preformed ones concealed beneath the surface (Onwueme, 1973). Thirdly, the growing point of the yam tuber is not marked by a terminal bud. Fourthly, most yam tubers, with the exception of some varieties of D. esculenta (U.S.D.A., 1974) exhibit strong positive geotropism.

The yam tuber is probably neither a root nor a stem structure. Rather, it is a structure that originates from the hypocotyl, the transition zone between the stem and the

root. This is supported by several morphogenetic studies which suggest that the yam tuber is a lateral outgrowth from the hypocotyl region of the plant axis (Martin and Ortiz, 1963; Lawton and Lawton, 1969).

2.2 Yam Growth Cycle:

Four different phases are identifiable in a generalised growth cycle of yam plant (Sobulo, 1972a; Njoku et al, 1973). For D. rotundata, the first phase lasts from the time of sprouting until about six weeks later. During this time, the plant growth almost exclusively entails developing a profuse root system, and elongating the vine. Since leaf growth is negligible at this stage, the plant remains incapable of large scale photosynthesis and must sustain itself by absorbing the food material stored in the parent sett.

The second phase is characterised by development of the foliage. Leaf expansion commences at about the sixth week. By the tenth week, the canopy is fully formed, and by the thirteenth week, little or no further increase in leaf area occurs. Root growth continues into this second phase, but by the tenth week, further net increase in root length are negligible. This second phase with its characteristic increase in plant leaf area marks the transition of the plant from dependence on the sett to self-sufficiency (autotrophy). The latter part of this phase is a period of carbohydrate excess for the plant; and not suprisingly, tuber initiation occurs by the tenth or eleventh week (Onwueme, 1975a and

1975b).

The third phase of growth is characterised by increase in tuber bulk; this continues until very close to the end of the season.

At this time, the fourth and the final phase of yam plant growth cycle sets in. Large scale senescence of the shoot begins and according to Sobulo (1972b) this is accompanied by a decrease in dry weight of the tuber. Senescence and drying back of the shoot at the end of the season are probably under photoperiodic control. Onwueme (1977) has reported that D. rotundata plots planted in November and in February senesced at approximately the same time.

After shoot senescence, the tuber enters into a period of dormancy, and will not normally sprout again until two or three months later (Adesuyi, 1975a).

2.3 Curing of Yams for Storage:

Ideally, before yam tubers are stored by whatever method, they should be properly cured. The term curing as applied to root and tuber crops is their controlled exposure to relatively high temperature of about 29-40 ^{o}C and relative humidity of about 90-95 % for about 5-7 days after harvest with the intention of improving their subsequent storage life (Adesuyi, 1973). Curing was originally developed for potatoes (Priestley and Woffenden, 1923) and sweet potatoes (Artschwager and Starrett, 1931). It has now been

successfully applied to yams (Gonzales and de Rivera, 1972; Thompson, 1972; Thompson et al, 1973; Martin, 1974; Adesuyi, 1973, 1974; Been et al, 1977).

The purpose of curing is to provide suitable environmental condition to promote the process of wound healing at those sites on the tuber where mechanical cuts and bruises have been inflicted during harvesting and subsequent transportation and handling. Wound healing or wound repair involves the formation of suberin at wound sites followed by development of a periderm or cork layer. This protective layer of dead cell is known to inhibit excessive water loss, infection by wound pathogens and subsequent rot during storage (Been et al, 1977; Noon, 1978).

The promotion of suberization and of wound periderm formation form the basis of curing of root and tuber crops. Histological studies using bisected D. rotundata tubers or whole tubers artificially cut with knife (Noon, 1976; Passam et al, 1976a, 1976b) indicate that within 5-10 hours of mechanical injury on a tuber, migration of starch molecules to the surface of the injured tissue occurs, followed by the formation of suberized layer within the starch containing layer of cells after 2-3 days and after 5 days there is formation of periderm or cork/dead cell which acts as a tough protective coat over the wound site. Suberin is an ergastic highly polymerised substance, fatty in nature and generally occurring together with waxes and cutin as protective

substances in and on plant cell walls (Rawnsley, 1969). Suberin is known to occur in association with cellulose (Coursey, 1967b; Booth, 1974). These histological changes are similar to those observed in potatoes and sweet potatoes (Weimer and Harter, 1921; Artschwager, 1927; Artschwager and Starrett, 1931).

Concurrent with these structural changes are some subtle but interesting physiological and biochemical changes. Firstly, there is a loss of moisture which leads to a corresponding loss in weight of the yam tuber (Passam et al, 1976a). Secondly, there is an increase in the rate of respiration of the tuber (Kahl, 1974; Passam et al, 1977) and a rapid synthesis of RNA and protein (Click and Hackett, 1963). This enhanced respiration is called "Induced" or "Wound" respiration and is believed to be brought about by increased respiratory activity of the starch/suberin and periderm zone of the tuber (Passam et al, 1976a). The induced respiration which is largely insensitive to potassium cyanide is attributed to the synthesis of new mitochondria possessing an active cyanide-insensitive oxidase which are synthesized only after the wounding process (Less and Chasson, 1966; Sakano et al, 1968; Nakano and Asahi, 1970). Thirdly, there is an increased activity of certain enzymes, notably phosphorylase, alpha-amylase and invertase (Bacon, 1961; Kahl, 1974). The induction of the three enzyme

activities coupled with the increase in respiration is an essential process for mobilization of carbohydrate reserves for use in cell division and laying down of new cell wall substances that are associated with suberization and periderm formation.

2.4 Dormancy of Yam Tuber:

Dormancy as applied to yams is a state in which the tuber cells are metabollically quiescent and spans the period between harvest and sprouting (Campbell et al, 1962). Dormancy is critical to yam storage for two reasons. Firstly, it determines the length of storage life of tuber, since sprouting marks the beginning of tuber senescence which inevitably leads to tuber tissue necrosis and disintegration. Secondly, the suppression of endogenous metabolism during dormancy reduces the rate of loss of storage carbohydrate.

Little is known of the mechanism of dormancy in yam tuber. Campbell et al (1962) have suggested that dormancy is associated with low levels of glutathione in the tuber and that glutathione level is high when the dormancy level is low. Many attempts have been made to break dormancy artificially and thereby cause dormant tuber to sprout, and also to increase the level of dormancy in yam tubers in order to prevent their sprouting during prolonged storage. Gregory (1968) and Martin et al (1974) were able to promote the sprouting of yam tubers by means of gamma radiation, although Adesuyi (1975b) reported that gamma radiation had the

opposite effect of inhibiting yam sprouting.

Attempts to manipulate yam dormancy are bound to continue. For an effective, all year round production of yam, commercially feasible methods must be found to break tuber dormancy, so that any tuber used as planting material will sprout readily, irrespective of when it was harvested. Ability to prevent sprouting of tuber during storage will also eliminate one of the major source of dry-matter loss during storage of yam tuber.

2.5 Sprouting of Yams:

Sprouting or germination is characterized by increased metabolic activity in the tuber; it is the visible marker of termination of dormancy (Onwueme, 1973). Once sprouting sets in, it is difficult to halt the biochemical and physiological processes that will eventually lead to the loss of the dry matter of the tuber. Thus, precise control of sprouting is the key to prolongation of the life span of the tuber. Despite its importance to yam storage, the molecular mechanisms of sprouting in yams have hardly been investigated. Onwueme (1973) has however studied the morphological changes that occur during sprouting of yam tuber. He concluded that the sprouting process consists of active cell division by the meristematic cell just beneath the tuber surface to produce a mass of undifferentiated cells which latter develops into a vine which one sees on the

sprouted yams.

How fast a piece of yam sprouts is very much dependent on the part of the tuber from which the piece had been obtained. Planted or stored whole tuber appear to sprout preferentially from the head region of the tuber, and while the head sprout thrives, sprouting in the middle or distal regions of the tuber is invariably suppressed (Onwueme, 1978). Sprouting in yam is thus under the influence of apical dominance. Studies by Coursey (1967c), Onwueme (1973) and Passam (1977) have led to the conclusion that: (a) whole tuber tends to sprout earlier than bisected tubers and the proximal half of the bisected tubers sprouted earlier than the distal half; (b) apical dorminance was retained in cut pieces of yam and (c) in tuber stored for prolonged period after breakage of dormancy, sprout arose along the length of the tuber with one or two sprouts at the head region usually remaining dominant. Passam (1977) suggests that it is unlikely that control of apical dorminance is exerted by a hormone or other chemical substance produced at the apical locus; instead control may likely be present throughout the entire tuber. It is further suggested that the layer of meristematic cells near the tuber surface is directly responsible for the maintenance of apical dominance, but how it accomplishes this function at the molecular level is still very much a matter of speculation.

2.6 Yam Storage Techniques:

2.6.1 Traditional yam storage techniques:

Yams may be stored simply by leaving them in the ground until required for food or sale (N.A.S., 1978). Alternatively, yams may be stored without any special arrangement or precaution in ordinary store rooms or in shed or hut either not in use or specially constructed for this purpose.

By far the most widely used and probably the best traditional storage method for yams in West African is the shaded, well-ventilated outdoor yam barn. The yam barn consists of a framework of vertically arranged poles, each of which is about 3 m high. The vertical poles are spaced about 50 cm apart and held together by rigid horizontal wooden sticks as well as by occasional stout, prefereably live, rooted vertical logs (Onwueme, 1978). Yams are tied individually to the framework in a horizontal position by means of local twines.

2.6.2 Improved yam storage techniques:

Experiments have been conducted on the storage of yams in "clamp" similar to those used for potatoes in temperate countries (Waitt, 1961b). The results of these trials proved rather inconclusive. The Nigerian Stored Product Research institute (NSPRI) has designed a barn which farmers can adopt for more effective storage of yams. The barn consists of open-sided shelves constructed from live poles or bamboo.

The use of shelves ensures a more careful handling of yams. A well ventilated shade is constructed around the shelves to protect yams from rain and sunlight. The barn is protected from rats and other rodents by constructing a barrier with iron sheets one metre high around the barn. The use of catches, traps and rodenticides is recommended in case of heavy rodent attack.

Adesuyi (1974) investigated the manual removal of sprouts at the time of first development as a method for improving small-scale storage of yams. It involved the regular removal of the bud as soon as sprouting of the tuber was noticed. Traditionally, sprouts are checked but not as regular and meticulous as Adesuyi did. This method was found to have significantly reduced loss in weight, losses of moisture and carbohydrate contents and improved palatability after six months in storage.

2.6.3 The importance of good ventilation and shadding in yam storage:

In the tropics, yams are generally stored during the dry season. The avoidance of excessively high temperatures and the provision of ventilation are the factors of greatest importance in yam storage (Coursey, 1967b).

The importance of good ventilation in storage, even under the subtropical conditions of the southern United States, has been emphasized by Coursey and Nwankwo (1968). Ugochukwu and Anosike (1979) stored yam tubers under nitrogen

for seventeen days and obtained alcohol concentration of 25 umole/gm fresh weight of tuber. They pointed out that this was a fairly high level of alcohol, and if yams accumulates such a level under anaerobiosis it may contribute to the rapid spoilage of yams. Alcohol was not detected in white yam tuber stored in air.

2.7 Factors Responsible for Storage Losses of Yams:

The natural function of the yam tuber in the plant is to ensure survival from one season to the next; they are thus inherently well adapted to storage. However, storage losses in yams can often be severe (Coursey, 1967c).

The earliest observation on yam storage losses are those of Williams (1925) made on D. alata grown in Trinidad. It was found that the variety used lost weight to the tune of 14.5 % during about four months of storage. Gooding (1960) working with different varieties of D. alata showed that there was much variation in weight between similar cultivars. In D. rotundata losses may be more than 30 % or even approach 50 % after about six months of storage (Anon, 1937; Coursey, 1967c).

In stored yams, all five types of losses - physical, metabolic, microbiological, insect and rodent damage - occur to some extent. The most important of these are metabolic processes and attack by fungi or bacteria.

2.7.1 Physical factors:

Yam tubers are readily injured during harvesting and transportation. Losses due to mechanical damage are frequently overlooked, and because such damages lead to physiological and pathological losses, are difficult to estimate (Booth, 1974). Dessication caused by evaporation is another important physical changes in yam during storage. Czyhrinciw and Jaffe (1951) working with D. alata reported a reduction in moisture content of 5 % in a month storage.

After prolonged storage, reduction in moisture content of about 8% occurs in D. rotundata, but the corresponding weight losses may be of the order of 30 %. These observations show that although water loss does occur, it is not the major cause of weight loss (Coursey, 1967a and b).

2.7.2 Metabolic factors:

Yam tuber is still living, it is a dormant system in which the basic metabolic processes of the plant continues, although more slowly than in the active growing phases. The most important metabolic process is respiration, resulting in the conversion of the carbohydrate of the tuber into carbon dioxide and water which are lost by evaporation (N.A.S., 1978). Respiration has been more thoroughly investigated in temperate crops such as potato, but little direct respirometric evidence is available in the case of yam. Passam and Noon (1977) have shown variation in respiration pattern during storage, Passam et al (1976a) illustrated the

physiological factors associated with wound repair in yams and the correlation of respiratory changes with carbohydrate loss.

Coursey and Russul (1969) showed respiratory activity corresponding to evolution of between 5 and 20 ml carbon dioxide per kilogramme of fresh weight of tuber per hour in healthy yam tissues (dependent of age and stage of dormancy) whereas decay was associated with rates of over 35 ml carbon dioxide per kilogramme fresh weight per hour. Passam et al (1978b) showed that respiration can account for more than 30 % of the total weight loss during the more metabolically active phases. Adesuyi (1975a) has demonstrated a considerable weekly fluctuation in the total carbon dioxide production when yam tuber went through the phases of dormancy and sprouting, and rotting of the tubers resulted in substantial rise in carbon dioxide output. The smaller tubers were also shown to respire more actively weight for weight than larger ones.

Yam tubers generally remain dormant for about ten to thirteen weeks after harvest and this period changes very little from year to year (Adesuyi, 1975a; Passam, 1978a). On breakage of dormancy, respiration is maximal at the head (proximal end) in which sprouting predominates. Once sprouting starts, the tuber senescences and a rapid deterioration results as the food reserve is utilized for growth and development of the sprout (Hayward and Onyearu,

1962). Adesuyi (1975c) has observed that: (a) under certain conditions smaller tubers may take longer than ten weeks to sprout; (b) there was a total loss of 11.8 % of starch in yams whose sprout were checked for six months in storage and 22.4 % starch loss in those whose sprouts were not checked; (c) sprouting increases the rate of respiration of stored yams thereby increasing the rate of dry matter loss; (d) sprouting causes an accelerated loss of moisture content of stored yams through the permeable surface of the sprouts resulting in wilting of the tuber. Yams that sprouted lost 14 % moisture content over six months storage while those that did not sprout lost 6.5 % moisture. (e) Sprouting of stored tubers resulted in heavy loss of weight. Loss in weight of tubers that did not sprout for six months in storage was 18.6 % while those which sprouted lost 43.0 %. (f) Sprouting reduces the quality and palatability of the tuber in storage. Passam et al (1978) showed that yam tuber respires actively at harvest, while in the dormant state, respiratory activity is reduced. Coursey (1961) showed that sprouting of yams stored in different parts of Nigeria reached 100% in four months of storage.

2.7.3 Microbial Factor:

Attack by microorganisms (fungi, bacteria, and to a lesser extent viruses) is probably the most serious causes of post harvest loss of root crops (Booth, 1974). Microbial

rotting accounts for a substantial proportion of the annual losses in yam produced in Nigeria (Coursey, 1961). Ogundana et al (1970a and b; 1971) attributed storage losses to microbial rotting and asserted that the microorganisms enter through the wounds and natural openings on the tubers. Several fungal species have been identified as associated with tuber rots (Ogundana et al, 1970a and b; 1971; Ogundana, 1972). The symptoms of each type of rot were the same for preharvest and storage diseases.

Arinze et al (1975) have shown that the nutrient in the sweet potatoes diminished after infection by Lasiodioplodis theobromae which is the fungus responsible for the rot of sweet potatoes in storage. The food substance most used up were starch and sugars.

2.7.4 Spoilage by insects, nematode and rodents:

Unlike many food crops, yams are seldom attacked by insects to any serious extent during storage. The only insect which is of any importance is the yam scale insect, Aspidiella hartii ckll (Coursey, 1967a). This insect is most serious as preharvest pest, or in the storage of seed yams. Yam in store is occassionally attacked by various species of termites, especially when they are stacked on the ground.

Nematodes are field rather than storage pests (Coursey, 1967a). Having once invaded a growing yam tuber they can survive in the tissue for long periods after the tuber has been lifted and stored, and during this time contribute to

the destruction of the tissue leading to a substantial weight loss of the tuber. The most important nematode in connection with yam spoilage is Scutellonema bradys. It is the only specie of nematode that persists in stored yam tubers (Caveness, 1967). This nematode is associated with the formation of wet and dry rot in stored yams (Bridge, 1972; Adesiyan et al. 1975). Bridge (1972) reported as many as 62,000 nematodes per gramme of yam tuber. Nematodes, biochemically convert starch to sugar (Adesiyan et al, 1976). The simple sugars are used as food by secondary invaders such as fungi and bacteria, and these pathogens grow and multiply.

Yams are sometimes attacked by rodents during storage, especially if they are stacked in heaps on the ground. In general, losses due to rodent are not very severe (Coursey, 1967a).

2.8 Measures Taken to Control Storage Losses and Improve Storage Life of Yam Tubers:

2.8.1 Suppression of sprouting:

Although research on suppression of sprouting has met with some success, the use of sprout inhibitors holds little promise as an economic means of prolonging storage life of yam tubers (Olorunda and Macklon, 1976). In contrast, the storage behaviour of potatoes and other temperate root and tuber crops can be improved considerably by the use of sprouting or respiratory inhibitors, and some have gained widespread commercial acceptance. Sprouting of potatoes can

also be inhibited by the use of gamma radiation. The materials and techniques adopted with crop have been reviewed by Burton (1948), Perlasca (1956) and Errington and MacQueen (1961).

For the suppression of sprouting for four months, Adesuyi (1975a) applied 2 % maleic hydrazide (MH-30) and 0.7 % naphthalene acetic acid to head of yam tubers. The result of this experiment tends to suggest that chemical sprout inhibitors were effective in controlling sprouting at high concentrations unlike low concentrations previously tried by Hayward and Walker (1961). Isopropyl N-(3-chlorophenyl) carbamate is a mitotic poison and is effective as a sprout suppressant if applied to yams as soon as the tuber starts sprouting (Olorunda et al, 1974). If it is applied to the yam before or just after harvest it will be ineffective because there will be no sprout loci on which the chemical may act (Passam, 1978b). In potatoes these loci are well formed at the time of harvest and are superficially located, but in yams sprout initials are formed just prior to breakage of dormancy and then arise from beneath the periderm. Chemicals such as methy-alpha-naphthalene acetic acid inhibit sprouting although the problem of phytotoxicity occur. The action of gibberelic acid is critically dependent on the time of application: when applied soon after harvest gibberellin delays sprouting but when applied to a latter stage of storage, sprouting is promoted (Passam, 1978b). Preharvest

application of gibberellic acid delays sprouting. Gibberellic acid is known to promote growth and may thus be expected to stimulate sprouting once the sprout initials are formed. It does not produce phytotoxicity when applied because it is a natural plant hormone and low levels (10^{-5} M to 10^{-6} M) are required.

The results of work carried out on the use of gamma radiation for the inhibition of sprouting in nine varieties of D. rotundata showed that, doses of 75 to 150 Grays applied four weeks after harvesting would effectively inhibit sprouting in stored tubers for six months without inducing adverse changes in acceptability or physiological properties (Adesuyi and Mackenzie, 1973; Adesuyi, 1975b; 1976). Radiation doses of 125 Grays was however, found to be most suitable. Radiation dose higher than 150 Grays were effective in inhibition of sprouting but tended to damage the internal tissues of the yam tubers. However doses higher than 50 Grays adversely affected viability of the tuber. This technique cannot therefore be applied to seed yams to suppress sprouting.

Adesuyi (1974; 1975c) found that storage at 15 ^{o}C suppressed sprouting in yam for six months. This temperature also significantly reduced weight losses, reduced moisture loss, respiration rate and maintained good palatability during six months storage. Storage at 15 ^{o}C did not affect the viability of the yams. Storage at lower temperature than

15 ^{o}C may be even more effective (Olorunda and Macklon, 1976). However, yam tubers suffer serious chilling injury below about 10 ^{o}C (Coursey, 1968) and a rapid deterioration sets in on removal of the tissue from the cold store (Olorunda, 1973). Chilling injury is related to changes in cell membrane permeability (Simon, 1974). Storage at low temperatures of between 5 and 10 ^{o}C leads to a reduction in the capacity for chloride, sodium and potassium ion absorption (Olorunda and Macklon, 1976). An increase in cell permeability resulting from exposure to chilling temperature during storage would allow a much increased back-diffusion of the ions which are accumulated against the electrochemical potential gradient between the cell and the bathing solution. After storage at 5 ^{o}C, respiration is barely detected in freshly cut yam discs. This effect has been linked to damage to mitochondria (Minamikawa et al, 1961) and this has been explained by postulating that the fatty acid composition of the mitochondrial membrane becomes altered (Richardson and Tappel, 1962). Perhaps the most apparent symptoms of chilling injury are surface pitting, necrotic areas, and external discolouration (Olorunda and Macklon, 1976). Pitting has been reduced by maintaining a high relative humidity or waxing the material to decrease water loss (Lyons, 1973). Chilling injury can be avoided in many

tissues if they are returned to a warming temperature before degradative changes occur (Lyons, 1973). The basis of this system is the assumption that the cause of chilling injury is the accumulation of a toxic compound which can be metabolised, or depletion of a critical metabolite which can be restored at the warm temperature. Decreased ascorbic acid and increased chlorogenic acid in sweet potato roots during chilling could be reversed by a warm period at 15 ^{o}C following two weeks of exposure to 7.5 ^{o}C, but not four weeks or longer (Lieberman et al, 1968). Czyhrinciw and Jaffe (1951) showed that massive losses in weight accompanied by physiological breakdown of tuber of D. alata took place after three weeks storage at 3 ^{o}C and four weeks storage at 12 ^{o}C.

2.8.2 Anti-microbial measures:

Ogundana (1972) reported that the fungicides benlate and thiabendazole at the level 500 to 1000 ppm controlled soft rot of stored yams for sixteen weeks if applied before storage. Captan was less effective than the other two fungicides. The effect of limewashing has been investigated in Nigeria (Coursey, 1961) where it was found to inhibit weight loss in D. rotundata and D. canyenensis for about three months after harvesting, but not for longer periods. Other fungicidal treatments such as copper 8-hydroxy quanolinate and borax also had some slight effect in reducing storage losses in D. rotundata but not in D. cayenensis. For successful disease control it is necessary to have a thorough

knowledge of the pathogen(s) involved, mode and time of infection, development of the pathogens in the host and the host/pathogen reactions so that control methods may be optimally defined and timed (Booth, 1974).

One of the most effective and simple means of reducing post harvest pathological losses of several roots and tubers crops is by curing (Booth, 1974). Adesuyi (1973) has found that storage conditioning at 25 ^{o}C and 30 ^{o}C with high humidity for five days is most suitable for controlling rot in yams. Gonzalez and de Rivera (1972) has found that curing yam tubers can reduce storage decay considerably. Thompson (1977) found that the only effective curing treatment was at 40$\pm$1 ^{o}C and 98$\pm$2 % relative humidity. Sanner and Fihl (1969) have recommended the use of ionising radiation for the destruction of microorganisms responsible for food spoilage.

2.8.3 Measures against attack by insects, nematode and rodent:

Coursey (1967c) has recommended scrubbing yam tubers in soapy water, followed by dipping in lindane, or heptahlor, as a method for eliminating infesting insects.

Control measures for nematodes includes use of hot water treatment of yam tubers (Adesiyan, 1977) and fumigation of the soil with nemagon before the tubers are harvested. Catches, traps and rodenticides can be used to check a heavy attack by rodents. Barriers of iron sheets built around the

barn checks entry of the rodents into barn.

2.9 Utilization and Economic Importance of Yam:

2.9.1 Chemical composition:

The chemical composition of the tuber varies with species and cultivars; even within the same cultivar, it may vary depending on the environmental conditions under which the tuber was produced (Onwueme, 1978). There are available in literature, inadequate and scattered, data on the chemical composition of yam tubers from various species or varieties (Eka, 1985). The proximate analysis of the various species of yam is given in Table 2.1.

By far the largest component of fresh tuber is water, which accounts for about two-third of the fresh weight. However, the tail end of each tuber has a higher moisture content than the head (Coursey and Walker, 1960), and there is a gradient of increasing percentage of moisture from head to tail.

The percentage of moisture in the tubers is very high during tuber development in the field, but as the tuber approaches maturity, the moisture content begins to decrease. This decrease continues even after the tuber has been harvested, so that during storage, a tuber may lose moisture to the value of 20 % of its original weight.

Table 2.1: Proximate Composition of Yam Tubers of Various Species

(Onwueme, 1978)

	D. rotundata	D. alata	D. cayenensis	D. esculenta	D. dumetorum
Moisture %	60-70	70	80	70-80	80
Starch %	-	28	-	25	-
Sugar %	-	0.5	-	0.6	-
Fat %	0.1	0.1-0.3	0.1	0.1-0.3	0.3
Crude protein %	1.1-2.0	1.1-2.8	1.0	1.3-1.9	2.8
Crude fibre %	0.4-0.8	0.6-1.4	0.4	0.2-1.5	0.3
Ash %	0.7-2.6	0.7-2.1	0.5	0.5-1.2	0.7
Vitamin C (ug/100g)	8000a	2000a	1900a	1700a	21000a
Vitamin B_1 (ug/100g)	120a	90a	85a	80a	140a
Vitamin B_2 (ug/100g)	30a	30a	30a	20a	50a
Vitamin A (ug/100g)	20a	800a	850a	700a	20a

- Not determined.

a = Eka (1985)

Carbohydrates are the major dry matter component of yams. They account for approximately one-quarter of the tuber fresh weight. Most of this carbohydrate is starch. The starch itself is mainly amylopectin and exists in the cells in the form of starch grains. Sugars are present only in minute quantities in yam tubers. For most species, they account for less than 1 % of fresh weight, but in *D. esculenta*, which is sweet, the percentage of sugar may be as high as 2-4 % on a fresh weight basis (Asemota and Osagie, 1988). It seems too, that the sugar content of yam tubers may increase during or just before sprouting. As a result, tubers that have been stored for very long periods may develop a sweetish taste. The sugar present in yams is mostly sucrose, but small traces of glucose and fructose may also occur.

The protein content of yams is rather low, ranging from 1-2 % of fresh weight. Most of the soluble amino acids in yams are lost when the tuber is chilled (Oke, 1973). Mucilage which exude when the yam tuber surface is cut are mostly glycoproteins.

Vitamins and minerals (ash) are also minor component of the yam tuber. Significant amounts of vitamin C are present, with values in the range of 6-10 mg per 100g of the tuber tissue. Traces of vitamins A, B^1, and B^2 are also present Calcium, iron, and phosphorus are among the components of the mineral fraction of the tuber.

Some yams may contain small traces of polyphenolic compounds. These are significant since they are subject to enzymatic oxidation when the tuber is cut. They cause the cut surface of tuber to turn brown (Ikediobi, 1985).

Certain yam species may contain quantities of alkaloids (e.g. dioscorine) and steroid derivatives (e.g. diosgenin). The former may be extracted for use as a poison, while the latter is extracted for pharmaceutical use.

2.9.2 Utilization of yam for food:

By far the largest proportion of yams produced annually is marketed as fresh tubers (Coursey and Aidoo, 1966). Only a very small fraction goes to the market in processed forms.

Boiled yam is the simplest and commonest form in which yam is consumed. It's preparation involves boiling pieces or slices of yam in water.

Pounded yam is perhaps the most popular and most traditional form in which yam is eaten in Nigeria. It is prepared from boiled yam which is pounded in a large mortar until it forms a thick paste of uniform consistency. The exact consistency that results depends on the species or cultivars of yam being used. D. rotundata and D. cayenensis usually make good pounded yam (Onwueme, 1973).

"Amala" is made from yam flour. Amala is brown due to oxidation of phenolics in the yam by o-diphenolase during the preparation of the flour (Onwueme, 1973). Amala is prepared

by stirring the flour in boiling water. Like maize starch, the suspension gradually changes to gel state which is brown. Amala is eaten with a suitable vegetable soup.

Other forms in which yam can be consumed are mashed yam, fried slices,roasted yam, fried yam and yam flakes. The quantity of yam consumed in these processed forms are relatively small, but is expected to continue to increase with time.

Experiments had been conducted on the possible use of yam flour for bread making (Sammy, 1973). Even if these tests are positive, yam flour is probably too expensive to compete with wheat or possibly cassava flour for bread production.

Yam tubers make good feed for livestock, but they are not normally used for that purpose, because of availability of much cheaper alternatives and social-cultural factors. In rural settings, yam peels are often fed to domestic animals such as goats and sheep.

2.9.3 Non-food uses of yam:

'Many species of yam contain small amounts of sapogenins and alkaloids for which various uses have been found. The main sapogenin present is diosgenin which serves as a starting point for the pharmaceutical manufacture of several corticosteroid drugs. The alkaloids present in yams include dioscorine and dihydrodioscorine. Both substances are nerve

poisons and the species that contain them are therefore used as sources of poisons for hunting, fishing and pharmaceutical purposes (Onwueme, 1978). The use of yam as a source of industrial starch is not widespread, probably because cheaper alternative sources exist.

2.9.4 Ethno-agricultural importance of yam:

In many parts of Nigeria, a considerable amount of religious activity has developed around the production and utilization of yams. One of the most important manifestations of this is the New-yam festival. The primary objective of new-yam festival is the religious componenet- to request or thank God for good harvest. Traditional religion was the mode of communication with God but now it is no longer a traditional religion affair. There is a wave of cultural revival involving enlightened people and fetish ceremonied are no longer pronounced. Essentially a date is fixed for the festival, and before that date, no farmer may harvest or consume the new crops of yams. On the appointed day, each farmer harvests several yams from his farms, uses part of the harvest for rituals and to prepare a feast, while the remainder may be used to pay homage to his elders or friends or in-laws. Considerable religious activity and social merry-making often accompany the New-yam festival. After the festival, the farmer may harvest the rest of his crop at his own pace and without further restriction. The fact that yams alone have a festival

indicates that they occupied a singular position in traditional agriculture of earlier times. Yams are regarded as king of crops.

Ritualism in yam production also occurs in other parts of the world, though it does not attain major proportions outside West Africa. In Papua New Guinea, long yam tubers are specially grown for ceremonial purposes (Onwueme, 1973). Such yams are supposedly inhabited by spirits, and are handled with much respect (Coursey, 1967a). A kind of new-yam festival is also celebrated in New Caledonia (Onwueme, 1973).

2.9.5 The Future of Yam:

The problem facing present day yam production are numerous. These include: excessive quantity of planting material, laboriousness of its present day method of production, its long growing season, its low yields, its storage problems, consumer preference for large tubers, difficulties involved in yam improvement and the competition it faces from other crops especially cassava.

With all the foregoing problems, the question might be asked: Will yam survive as a major crop for several decades to come? It seems that with the present method of production and utilisation of yam, the future survival of yam is doubtful. A crop that yield poorly, difficult to produce, difficult to store, and difficult to improve is likely to

continue to increase in price and decrease in quantity to the point where it becomes, simply, a delicacy or luxury food. If yam is to retain its position as a mass-produced mass consumed staple, certain fundamental changes must occur in its production and utilization.

Research into yams is a few decades old, and the crop still remain relatively unimproved. Any major push at improving the crop or its production will certainly yield dividends and increase the likelihood that the crop will survive. "Sentiment" is one major factor which may improve the chances of the future survival of yam. Yam occupies a special place in the hearts and live of West African peoples. As such, its production and utilization will probably continue well beyond the limits dictated by economics. The impetus to improve it may also be generated or sustained by a sentimental reluctance to see the crop disappear. The beneficiary, in each case, is the yam, which may therefore defy predictions and linger on as a major crop.

2.10 Preservation of Food by Irradiation:

The process of food irradiation involves exposing food material to ionizing radiation so that prescribed quantity is absorbed (Gilles et al, 1989). Radiation sources used for food irradiation may be gamma ray from nuclides of ^{60}CO or ^{137}CS, X-ray generated from machine sources operated at or below an energy level of 5 mev, or electron beams generated

from machine sources operated at or below an energy level of 10 mev (Goldblith, 1963; Eisenhower, 1965; Koch and Eisenhower, 1965).

In food irradiation, there are four classes of radiation levels, which are listed below in the order of decreasing dose levels (Goresline et al, 1964).

(i) RADAPPERTIZATION. In this type radiation doses sufficient to reduce the number of viable organisms, so that very few, if any, are detectable.

(ii) RADICIDATION. The radiation doses are sufficient to reduce the number of viable specific, non-spore forming pathogenic microorganisms e.g. Salmonella.

(iii) RADURIZATION. The radiation doses are sufficient to enhance the keeping quality (i.e. extension of shelf-life) by substantial reduction in the number of viable, specific spoilage micro-organisms.

(iv) Radiation doses sufficient to interfere with physiological processes rather than microbiological ones. This includes the sprout inhibition, delay of maturation or ripening of fruits, etc, through relatively small doses of irradiation.

2.10.1 Objectives of Food Irradiation:

Irradiation of food may be used to achieve a variety of desirable objectives including the following (Table 2.2) which are classified according to the average dose required

Table 2.2: Some Possible Applications of Ionizing Radiation to the Treatment of Food (IAEA, 1987)

GROUP	FOOD	DOSE (KGY)	MAIN OBJECTIVE	MEANS OF ATTAINING THE OBJECTIVE
A	Meat, poultry, fish and many other highly perishable foods	40-60	Safe long-term preservation without refrigerated storage	Destruction of spoilage organisms and any pathogen present e.g. botulinum
B	Meat, poultry, fish and many other highly perishable food	0.5-10	Extension of refrigerated storage below 3 ^{o}C	Reduction of population of microorganism capable of growth at this temperature.
C	Frozen meat, poultry, egg and others	3-10	Prevention of food poisoning	Destruction of salmonellae
D	Meat and other food carrying pathogenic parasites	0.1-0.3	Prevention of parasitic diseases transmitted through food	Destruction of parasites e.g. Taenia saginata
E	Cereal, flour, fresh and dried fruits	0.1-0.5	Prevention of loss of stored food or spread of pest	Killing or sexual sterilization of insects
F	Fruits and certain vegetables	1.0-5.0	Improvement of keeping properties	Reduction of population of fungi and/or delay of maturation
G	Tubers, bulbs and other underground organs of plants	0.05-0.15	Extension of storage life	Inhibition of sprouting
H	Spices and other special food ingredients	10-30	To minimise the contamination of food to which the ingredients are added	Reduction of population of microbes in the special ingredient

to achieve the objectives in question.

2.10.2 General Benefits of Food Irradiation:

The general benefits of food irradiation are (i) product improvement (ii) preservation (iii) cost reduction (iv) Increase in trade volume.

Product improvement is not often attained. Usually a food is of good quality initially and irradiation does not make it better (Vakil et al, 1973). There are, however, some instances in which irradiation improves quality characteristics of a food. For example, irradiation can improve the baking qualities of wheat flour, it can tenderise meat, it can reduce the rehydration time of dehydrated vegetables and can increase juice extraction from some fruits (Ogbadu, 1991).

Preservation, because irradiation does not heat the treated materials, food keeps its freshness and its physical state. The unique advantage of radiation for treating package food lies in maintaining hygienic conditions and provided packaging materials are impermeable to bacteria and insects recontamination does not take place.

Cost reduction itself is a sufficient reason to use irradiation. How the cost reduction is obtained ordinarily is specific to the application in question. It can be food loss reduction, or the consequence of an efficient process using less energy. It can be the result of overcoming seasonal variations of supply and prices. In its total

effect, it can result in lower consumer costs.

Increase in Trade Volume. This is probably one of the most significant potential benefits of food irradiation. Many foods are too perishable for reaching long distant market or are carriers of insects and pathogens which are restricted by embargo or quarantine. Irradiation can overcome such obstacles and increase product movement into new market areas.

2.11 Radiation Chemistry of Food and Food Components:

The radiation energy absorbed by irradiated foods causes a variety of physical and chemical reactions to occur in treated food (Elais, 1989). Provided the quantum energy of the radiation used remains below 10 mev, no nuclear reactions can occur which would result in a measurable induced radioactivity. Several studies (SCF, 1986; Elias, 1989) have confirmed that the amount of hypothetical radioactivity produced is below the detection threshhold of the most sensitive instruments and approximately 100,000 fold smaller than those naturally occuring in fresh food.

Irradiation initiates a series of chemical reactions resulting in transient radical intermediates and ultimately in stable new radiolysis products (Elais, 1989). Recent research (Urbain, 1989) has clarified the nature of the radiolytic reactions and products as well as the important parameters controlling radiation induced chemical changes in foods. It has therefore become possible to predict the yield

and the nature of the radiolytic products from a knowledge of the composition of the irradiated foods and the irradiation conditions.

Although, the number of chemical reactions following irradiation is smaller than in corresponding thermal processing, a large number of radiolytic reaction products are generated, albeit almost invariably in very small amounts (Bayer, 1980). The quantities produced depend on a variety of factors such as the applied radiation dose, the water content, and the gaseous environment during treatment (IPFFI, 1981). The nature of these changes and their possible toxic potential, if significantly different from the production of heat treatment, were largely unknown when food irradiation was first carried out in the late 1940s. Only with rapid progress in analytical techniques did it become possible to identify the majority of radiolytic products in irradiated foodstuffs and to assess their toxicological significance from available biological data (Taub et al, 1976; Taub, 1983; Merritt and Taub, 1983).

Merritt and Taub (1983) showed that the volatile radiolytic products in beef, pork, ham and chicken were essentially hydrocarbons and that their formation depended on the fat content of the meat, regardless of origin. The electron spin resonance spectra from the four types of meat, irradiated at -40 ^{o}C were essentially identical, indicating

the production of common free radical intermediates (Merritt and Taub, 1983). The production of radiolysis in irradiated beef have been studied in detail. More than 100 volatile compounds were identified at concentrations ranging from 1 to 700 ug/kg, with a total yield of 9 mg/kg, most of these compounds being innocuous and known to occur also in unirradiated foods (FASEB, 1979).

A similar study (Adam, 1983) showed the radiolytic products from various irradiated starches to be qualitatively identical. The observed small quantitative differences were related to the compositional properties of these starches. Electron spin resonance measurements showed that the nature of the radical intermediates was the same in all irradiated starches.

Using computer methods it has been possible to study the radiation-induced changes in a fruit model and to show that these changes follow well-established laws (Elais, 1989). Predictive calculations of the changes based on reaction probabilities were confirmed subsequently by chemical analyses. The radiolytic products present in greatest yield were derived from the major constituents of the fruit i.e. from sugars, while the minor constituents gave rise to only small amount of radiolytic products (Basson et al, 1983).

There is now considerable evidence (Diehl and Scherz, 1975; Taub et al, 1976) to support the view that similar radiolytic reaction occur with the same constituents of

different foods, and that common radiolytic products are formed in approximately predictable yields on irradiation of these foods. The available evidence also demonstrate that the distribution of radiolytic products are similar for individual members of a given food class. Acceptance of this general principle of radiation-chemical similarity supported the view that information obtained from toxicity tests on one irradiated food could be extrapolated to other foods of similar chemical composition, or from one set of processing conditions to another for the same food. This so-called chemiclearance approach was finally adopted by the Joint FAO/IAEA/WHO Expert Committee in 1980 as one of the arguments on which it based its conclusion that the irradiation of any food commodity up to an overall average dose of 10 KGY presented no toxicological hazard (Loaharanu, 1988).

2.11.1 Radiation chemistry of carbohydrates and carbohydrate containing foodstuffs:

Monosaccharides: Glucose is quantitatively the most important basic unit of food carbohydrates, such as starch and cellulose (Diehl et al, 1978). As most food contain a considerable percentage of water, a detailed study of the radiolysis of glucose in aqueous solution, as published by Dizdaroglu et al (1975), is of particular interest.

Dizdaroglu et al (1975) reported that $OH^{\cdot}$ radicals, hydrated electrons and hydrogen atoms are formed when water

is irradiated, and that of these, OH· radical is of primary importance in reactions with carbohydrates. It abstracts carbon bound hydrogen atoms, forming glucosyl radicals from glucose. The reaction is not very selective and apparently all six possible glucosyl radicals are formed. According to Dizdaroglu et al (1975) these primary glucosyl radicals give rise to a number of free radical reactions. It is important to note that the glucose solution was irradiated in the absence of oxygen, specifically in an atmosphere of N_2O which converts solvated electrons to hydroxyl radicals. With respect to some applications of food irradiation, it is also of interest to know what happens in the presence of oxygen, water elimination and rearrangement processes are suppressed and no deoxy compounds are formed. Instead, the yield of sugar acids and of keto sugars are increased (Dizdaroglu et al, 1975).

Polysaccharides: Irradiation of starch produced lower molecular weight sugars such as glucose, maltose, erythrose, ribose, and mannose in dose dependent yield (Berger et al, 1973). Further radiation - induced breakdown leads to the formation of formic acid (Dauphin et al, 1974), acetaldehyde, methanol, acetone, ethanol, and methyl formate (Berger et al, 1974).

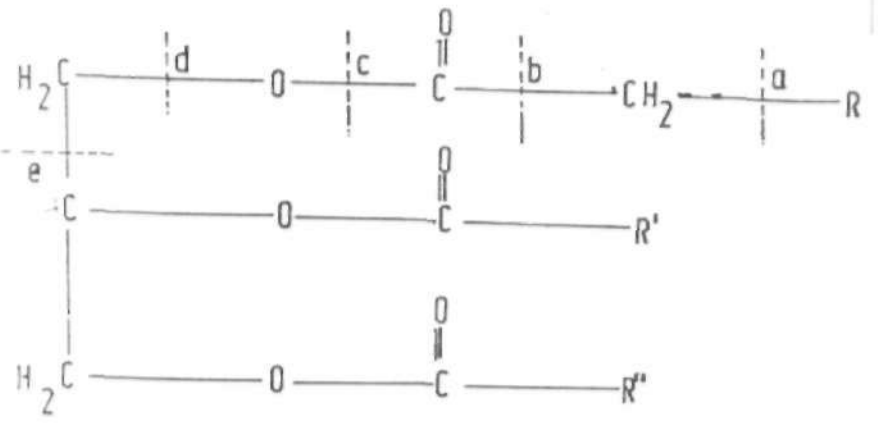
The presence of proteins in wheat flour suppresses product formation from carbohydrates and much higher doses are required to produce measurable breakdown of starch in

flour. Less work has been done on other irradiated polysaccharides such as pectins or cellulose. Basic events must be the same as in the irradiation of starch and the spectrum of reaction products is probably not very different.

2.11.2 Radiation chemistry of fats:

The general mechanism of the radiolysis of fats is thought to involve primary ionisation, followed by migration of positive charges toward the carboxyl groups and the double bonds, and cleavage at preferential positions near the carbonyl group (Nawar, 1978). The resulting free radicals engage in various reactions leading to the formation of stable radiolytic products, which have been classified as primary, recombination and secondary products according to the mode of their formation. In case of unsaturated fatty acids, dimerization reaction appear to be of major importance. The course of radiolysis in fats is significantly influenced by the phase state and temperature (Nawar, 1978).

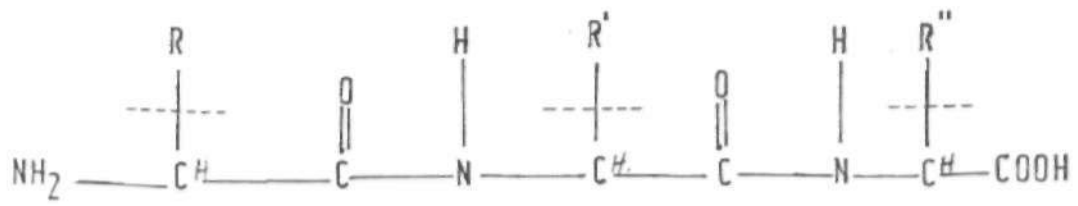
Main reactions which occur are thought to be simple cleavage reactions. For example many of the observed radiolysis compounds can be attributed to cleavage reactions of a triglyceride as follows:



The scission of bonds at a and b results in a series of alkanes, alkene, e.t.c. Scission at c leads to the formation of aldehydes, ketones and diketones from one side and diglycerides, oxy-propanediol diesters, e.t.c. from the other side. If cleavage occurs at d or e, ethane or propane diesters are formed, and recombination reactions can results in a number of compounds which are larger than the parent triglyceride. Cleavage at d or e may also result in the formation of the fatty acids and of a number of corresponding methyl esters (Merritt, 1980).

2.11.3 Radiation chemistry of protein:

Peptide linkage had been found to be relatively stable to radiolytic cleavage (Merritt et al, 1967; Garrison, 1972). The most abundant compounds derived from radiolysis of proteins and peptides appear to be those resulting from cleavage of side groups corresponding to the various amino acids in the peptide chain.



The predominant reaction appears to be decarboxylation of the free carboxyl groups as indicated by the copious evolution of carbon dioxide upon irradiation of protein (Merritt, 1980). The reaction of electrons with proteins lead to deamination, scission of peptide and disulphide bonds, and addition to aromatic and heterocyclic amino acid residues. The extent and ratio of these reactions depend on conditions and the protein systems (Simic, 1978). These reactions are accountable for a variety of radiolytic products found in irradiated foods (Taub et al, 1976).

The reactions of OH· radicals with proteins lead to hydrogen atom abstraction, addition to aromatic, heterocylic, and sulphur containing amino acid residues as well as to oxidation of some of those residues. In frozen systems the OH· radical contribution will be greatly diminished and only a small fraction of OH· radical-induced products will be present in radappertized meats (Simic, 1978).

2.11.4 Radiation chemistry of carbohydrates with proteins and lipids:

The long-range goal of radiation chemistry of the mixture c carbohydrates with protein and lipids is a better understanding of radiation effects on all constituents of complex foodstuffs (Diehl, 1974).

Addition of amino acids to trehalose protects it against radiolytic destruction, with cysteine being most effective (Diehl et al, 1978). Tajima et al (1969) have observed complete suppression of radiation-induced carbonyl formation from glucose by addition of cysteine at one-tenth the concentration of glucose. This may be explained by the higher reaction rate of cysteine as compared with carbohydrate with OH· radicals and by hydrogen donation from cysteine to glycosyl radicals. Obviously, the reaction of proteins with OH· radicals is determined not only by the amino acid composition but also the sequential and also the spatial arrangement in the protein molecule (Diehl et al, 1978).

The observation that the presence of protein or amino acids affects the radiolysis of carbohydrates quantitatively but not qualitatively is in agreement with the notion that radiation-induced changes in aqueous carbohydrate systems are primarily caused by OH· radicals; proteins and amino acids appear to influence carbohydrate radiolysis only or primarily by influencing the availability of OH· radicals (Diehl et al,

1978).

2.12 Nutritional Aspects of Food Irradiation:

2.12.1 Cassava:

Cassava (Manihot esculenta cranz) is eaten in Nigeria mainly in the form of flour known as "gari" (Ogbadu, 1979a). Bassir (1963) prepared a balanced diet by protein enrichment of gari with soya flour. The soya-gari diet was compounded from trace elements, salt mixture, gari, soya flour, methionine and lysine. Irradiation of gari-soya diet with 0.62, 1.25, 2.50 and 5.00 KGY had effect on total protein content. At radiation doses of 1.25 KGY and above, the total protein was reduced by 1 %. The amino acid profile was similarly unchanged although lysine, arginine and phenylalanine increased somewhat at higher irradiation doses. Soluble carbohydrate, hemicelluloses and celluloses decreased slightly with higher irradiation dose (Ogbadu, 1979a).

2.12.2 Potatoes:

The irradiation of potatoes to control sprouting was accepted unconditionally by the WHO/FAO Joint Expert Committee in 1976. No essential change in nutritive value was noted. Baraldi and Muccio (1975) confirm that irradiated and chemically treated potatoes were similar in vitamin C and niacin contents. Azar et al (1980) on the other hand, observed that irradiation with 0.1 KGY increased the normal vitamin C loss on storage by an additional 28 %, 0.15 KGY increased the normal storage loss by as much as an

additional 56 %. Bellomonte et al (1978) using doses of 0.11 and 1.0 KGY found no significant nutritional alteration with respect to amino acid and vitamic C content. Similar finding were reported by Anon (1980).

Further confirmation of loss of vitamin C in relation to storage time and radiation dose was obtained by Ghods et al (1976). The shift to dehydroascorbic acid was partially due to radiation enhanced reactions but this is irrelevant from a nutritional point of view because dehydroascobic acid has practically the same vitamin C activity as ascorbic acid.

2.12.3 Onions:

As noted by the WHO/FAO Joint Expert Committee in 1976, Onions are not nutritionally of any great importance (Murray, 1980). Nevertheless, it has been reported that sprout inhibition with 0.05 KGY induced no compositional change of nutritional significance (Mahmoud et al, 1978). Furthermore, a 56 day feeding trial demonstrated that irradiation of onions caused no difference in food and water intake or weight gain (Seshadri et al, 1979). Irradiation with doses ranging from 0.02 to 0.06 KGY in presence of air, induced increasing loss of ascorbic acid by conversion to dehydroascorbic acid, partially the result of radiation-enhanced reaction without seriously affecting the nutritional value (Ghods et al, 1976). Much larger doses (up to 27 KGY) were used to reduce the microbiological load of

dehydrated onion powder. The treatment was successful and onion powder proved very resistant to chemical changes (Silberstein et al, 1978; Galetto et al, 1979).

2.12.4 Fruits and Vegetables:

The market life of mangoes irradiated with 0.1-0.6 KGY was extended by 4-7 days (Jinavatana et al, 1974). Treated mangoes showed no difference in organoleptic qualities, an observation supported by failure to detect changes in the "volatile" profile of the mangoes irradiated with up to 2 KGY (Blakesley et al, 1979). Losses of ascobic acid and carotene attributable to irradiation were slight (Thomas and Beyers, 1979a; Beyers et al, 1979) especially when compared to the losses accompanying freezing and heat treatment (Thomas and Beyers, 1979b). Also unchanged by irradiation were other constituents namely, fats, ash, protein, sugar, starch, riboflavin, niacin, thiamine, phosphorus, iron, calcium, sodium and potassium (Coelho et al, 1978).

Doses between 0.2-0.4 KGY delay ripening of "Hons Tong" banana for 3-5 days in 17 ^{o}C storage. Nutritional and organoleptic properties were not harmed (Loaharanu, 1971).

Irradiation of tomatoes with 1.5-3.0 KGY had little or no effect on vitamin C content, pH or percent of sugar but decreased resistance to penetration and increased decay (Magaudda et al, 1976; Belli-Donini and Baraldi, 1977).

2.12.5 Cereal and Grains:

The WHO/FAO Joint Expert Committee in 1976 accepted the

irradiation of rice provisionally pending completion of long term studies in rats and monkeys (Murray, 1980). Also mentioned was the need for more data on thiamine loss. In this regard, Azar et al (1980) observed losses of up to 22 % in thiamine as well as riboflavin, niacin and pyridoxine. Also of importance was the observation that irradiation to control insects neither adversely affected aroma, taste, colour or texture (Ismail et al, 1978) nor improved these qualities (El Saadany et al, 1979).

Maize, sorghum and millet irradiated with 0.2 KGY for disinfestation purposes suffered no negative nutritional effects as judged by amino acids, vitamins B_1 and B_2, niacin, and panthothenic acid contents and when fed to rats there were no ill effects (Adrian and Frayssinet, 1975; Chahin et al, 1977).

2.13 Industry and Consumer Acceptance of Food Processed by Ionising Radiation:

One major reason why food irradiation is not in wider commercial use, despite its legal approval in 35 countries is that governments and food industries are concerned about consumer acceptance (IAEA, 1989). Some irradiated foods, including spices, onions and fruits, are already on the commercial market in some countries, including United States, France, Netherlands, Germany and Thailand.

Recent market research of selected products (IAEA, 1989)

further suggests that informed consumers are not reluctant to try or to buy foods identified as being radiation processed. Such trials have been conducted over the past several years in Argentina, Bangladesh, China, France, Hungary, Indonesia, Isreal, Philippines, Poland, Thailand and the United States for specific irradiated foods, including apples, onions, strawberries, pork, sausages, mangoes and papayas.

In most trials, the irradiated product outsold the conventionally treated counterpart, in Thailand, for example, by a margin of 10:1 and in United States by a margin of 11:1, even though the irradiated product was priced higher. In France irradiated strawberries were preferred for reasons of quality despite being priced one-third higher (IAEA, 1989). Whether irradiated food will be accepted here in Africa is a subject of intensive market trial, although a commercial irradiation facility is coming nearer home, as Ivory Coast is already building one in Abidjan (IAEA, 1989).

2.14 Problems of Food Irradiation in Nigeria:

In Nigeria, the status of food preservation by irradiation has been primarily at research level in the area of radiation microbiology and to a lesser extent radiation chemistry/biochemistry. Research on the radiation inactivation of toxins has been on the effect of gamma irradiation on Aspergillus flavus and some of its toxic metabolites (Ogbadu, 1979b, 1980, 1981a). There are a number of factors delaying practical introduction of food

irradiation in Nigeria. These includes: the problem of infrastructure, lack of economic assessment, lack of trained personnel and the fact that building a commercial irradiation plant is a capital intensive project.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Chemicals:

All chemicals were of analytical grade unless otherwise stated and were supplied by the British Drug Houses (BDH), Chemicals Limited, Poole, England, Hopkins and Williams, Chadwell Heath, Essex-England and Sigma Chemical Company, St. Louis, U.S.A.

3.2 Sampling:

Two cultivars of yam (*Dioscorea rotundata*) known in Hausa as "Amara" and "Chikakwando" respectively were used for the experiments. They were grown on a farm located at Dutse Dumbi Village of Igabi Local Government Area of Zaria District of Kaduna State. All the yam seeds from which the tubers were raised had the same agronomic treatment; they were planted on the same day in a single plot weeded traditionally and no fertilizer was applied. At maturity, the tubers were harvested on the same day (Tuesday, 27 November, 1990), washed with water to reduce the load of rot causing microorganisms and cured in the tradi tional way by exposing them to sunlight six hours a day for six consecutive days (29 November - 3 December 1990). The tubers were carefully selected for lack of mechanical injury or disease symptoms, rot, sprouting or other visible damage and for reasonable uniformity in size and shape.

3.3 Radiation Source:

The radiation source was a cobalt 60 Gammacell 220 unit of Atomic Energy Agency of Canada commercial product located at Biological Control Unit of National Veterinary Research Institute, Vom, Plateau State of Nigeria.

3.4 Radiation Treatment:

Sample of each yam cultivar were divided into four groups with 48 tubers per group. Each group was then divided into two subgroups for duplicate studies. The tubers were adequately labelled and then transported by road to Vom for the radiation treatment.

Irradiation was done at ambient temperature and atmospheric pressure. Absorption of radiation was checked with ferrous sulphate and ceric sulphate dosimetry (Weiss, 1952).

The yam cultivars were radiated with doses of 50 Gy, 100 Gy and 180 Gy for group 2, 3 and 4 respectively, group 1 were not irradiated and served as control. The irradiation was done on Tuesday, 4 December 1990; exactly 7 days (a week) after harvest.

3.5 Storage:

After irradiation, the tubers in the various group of each cultivars were stored seperately on gauzed shelves in a well ventilated and shaded barn (Plate 3.1). Storage was at relative humidity of 22-78 %

(mean 54.4±17.71) and temperature of 22 ^{o}C-35 ^{o}C (mean 29.12±3.5) for the duration of the experiment.

3.6 Observations:

In both sub-groups, weekly counts were made of rotten and sprouted tubers (external sprouting). In addition samples were selected monthly from healthy non-sprouted tubers for the chemical analyses.

3.6.1 Criteria for Sprouting and Rotting:

The criteria for determining sprouting was the appearance of external green shoot, while tubers were considered rotten when the tubers became soft and fungi (moulds) were seen growing on it or distinct smelly liquid found flowing out of it.

3.7 Tuber weight losses:

This was done using Metler PC 440 Delta range balance to weigh each tuber in each group of each cultivar every four weeks.

(a)



(b)



PLATE 3.1 (a) PHOTOGRAPH OF THE YAM BARN
(b) A CLOSER VIEW

3.8 Methods:

3.8.1 Sample Preparation:

A healthy yam tuber was randomly selected from each subgroup 2 for chemical analysis. Samples were obtained from the "head", "middle" and "tail" regions of each of the tubers using a number seven cork borer (internal diameter of 1 cm). These were then homogenised in a blender and used for the determination of moisture content, total free amino acid and starch content of the tuber. The rest of the tuber were cut into pieces and dried to constant weight in an oven at 60 ^{o}C (usually for 24 hours). The dried flakes were then ground into a powder which was then sieved using a laboratory test sieve of 850 micrometer aperture size obtained from Endecotts Ltd. England. The resultant yam flour was then transferred into a clean dry sample bottle and stored in a cool, dry place until required.

3.8.2 Determination of moisture content:

This was carried out as specified by AOAC (1980). Procedure: A clean crucible was dried to a constant weight in an air oven at 60 ^{o}C, cooled in a desiccator and weighed. About 2-5 g of the finely ground sample was accurately weighed into a previously labelled crucible. The crucible containing the sample was dried in an oven at 60^{o}C until constant weight was obtained.

Calculation:

$$\% \text{ moisture content} = \frac{\text{loss in weight due to drying}}{\text{Initial weight of the sample}} \times 100$$

% Dry matter = 100 - % moisture content.

3.8.3 Determination of Ash Content:

This was carried out at 550°C with the aid of a muffle furnace (AOAC, 1980).

Procedure: A clean porcelain crucible with lid was heated over a heating mantle in the fume cupboard, and thereafter was cooled in a dessicator and weighed. A known amount of the dry, ground sample (2-5 g) was transferred into the crucible and weighed again. The sample was heated gently on a bunsen burner in a fume cupboard until smoke ceased. The crucible and content were then transferred into a muffle furnace at 550°C and ashed for 24 hours; at this stage, the ash is grey-white with no black specks of carbon. The crucible was removed, covered with lid, cooled in a dessicator and weighed. The heating and weighing procedure was repeated until constant weight was obtained.

Calculation:

$$\% \text{ Ash} = \frac{\text{Weight of Ash (g)}}{\text{Weight of sample (g)}} \times 100$$

$$\% \text{ Organic matter} = \frac{\text{Weight loss (g)}}{\text{Weight of sample (g)}} \times 100$$

3.8.4 Determination of Crude Lipid Content:

The crude lipid content of each sample was determined by a continuous ether extraction method (AOAC, 1980).

Procedure: Two to five grammes of the powdered sample was accurately weighed into a clean dry previously weighed cellulose thimble and weighed again with degreased cotton wool as cover. Two hundred millilitres petroleum ether (b.p. 40-60 ^{o}C) were poured into a clean dry 250 ml round bottom flask. Some antibumping granules were then added while the thimble with its content was placed in a soxhlet extractor fitted to the distillating flask which was placed on a heating mantle. The mantle was heated electrically until the solvent boiled gently. Just before the solvent started boiling, the water source (the tap) was turned on to ensure a adequately cooling of the apparatus. The extraction process was continued for 6 hours after which the process was stopped and left to cool. The thimble and its content was air dried for 10 minutes. It was then transferred to an oven maintained at 60 ^{o}C and dried till constant weight was obtained.

Calculation:

$$\% \text{ Lipid (crude fat)} = \frac{\text{Weight loss (g)}}{\text{Weight of sample (g)}} \times 100$$

3.8.5 Determination of crude protein content:

The micro-kjeldahl method (AOAC, 1980, Oyeleke, 1984) was used. This method uses the estimation of total nitrogen content after conversion of the protein nitrogen to ammonium

salt by digestion involving acid hydrolysis.

(i) Digestion: Protein nitrogen are reduced to ammonium sulphate using a nitrogen-free conc. sulphuric acid.

$$\text{Protein N} + H_2SO_4 \longrightarrow (NH_4)_2SO_{4(aq.)}$$

$$\text{Carbon} \xrightarrow{\text{Oxidation}} CO_2$$

(ii) Distilation: Ammonium sulphate produced during digestion was distilled using 40 % sodium hydroxide to liberate gaseous ammonia.

$$(NH_4)_2SO_{4(aq.)} + 2NaOH_{(aq.)} \longrightarrow Na_2SO_{4(aq.)} + 2H_2O_{(l)} + 2NH_{3(g)}$$

(iii) Titration: Hydrochloric acid in a recieving flask trapped librated ammonia gas. Then excess hydrochloric acid (left in the recelving flask) was titrated with standard sodium hydroxide (0.1 M) solution. This enabled the determination of the amount of the standard acid solution neutralised by ammonia.

Procedure: Dry, powdered sample (0.2 g) was placed in a micro-kjeldahl digesting flask along with antibumping granules, catalyst (a mixture of 9.6 g anhydrous Na_2SO_4, 0.35 g $CUSO_4.5H_2O$ and 0.05g SeO_2; 1 g) and 5.0 ml of nitrogen fre concentrated sulphuric acid. The flask was then heated carefully in a fume cupboard, using 1 ml of liquid parafin to send the froth down the flask. The digestion was carried out on low heat for 30 minutes, continued on medium heat for 30 minutes, then full heat for about two and half hours until completely digested, when a clear solution was obtained, and

then simmered for 45 minutes. The flask and its content were left to cool, particles at the side of the flask were washed down with hydrogen peroxide and the flask left to cool down completely to room temperature.

The content of the flask was washed into a Markham distillation apparatus with 40 % NaOH (12 ml). The distillate was trapped into 0.1 M HCl (15 ml). During distillation, ammonia released from ammonium sulphate condenses and reacts with the standard hydrochloric acid (0.1 M) solution in the receiving flask to form ammonium chloride. The volume of 0.1 M hydrochloric acid neutralised is directly proportional to the amount of incoming ammonia. The excess 0.1 M HCl is estimated by titrating the mixture with 0.1 M NaOH using phenolphltalen (1 % alcoholic solution) as indicator.

Calculation:

Each ml of 0.1 M HCl neutralised by ammonia is equivalent to 1.4 mg nitrogen (Oyeleke, 1984).

1 ml 0.1 M HCl = 1 ml 0.1 M NaOH = 1 ml of 0.1 M NH_3= 1.4mg Nitrogen

V1 = volume of acid neutralised by titration

15.0 ml = initial volume of 0.1 M HCl in the receiving flask

(15-v1)ml = volume of acid neutralised by ammonia.

The nitrogen equivalent of (15-v1) ml = (15-v1) x 1.4

... Total protein (mg) = (15-v1) x 1.4 x conversion

factor. The conversion factor, 6.25 for most foods (Pearson, 1976) was used.

$$\% \text{ Crude protein} = \frac{\text{mg protein}}{\text{mg sample.}} \times 100$$

3.8.6 Determination of Crude Fibre content:

The AOAC (1980) method involving sequential digestion of the sample with dilute acid and alkali solution was used. The residue obtained was ignited to obtain crude fibre.

Procedure: About 3.0 g of the dry, powdered sample was extracted for 6 hours using petroleum ether(b.p.40 - 60 ^{o}C) as solvent. After drying at 60 ^{o}C, about 2 g of the lipid free sample was accurately weighed into a round bottom flask, 100 ml of 1.25 % (0.25 N) sulphuric acid was added and boiled under reflux for 30 minutes. The hot solution was quickly filtered under suction. The insoluble matter was washed several times with hot water until it was acid free. It was then transferred quantitatively into the flask and 100 ml of hot 1.25 % (0.312 N) sodium hydroxide solution was added and boiled again under reflux for 30 minutes and quickly filtered under suction. The insoluble residue was washed with boiling water until it was base free. It was dried to a constant weight at 80 ^{o}C in an oven, cooled in a desiccator and weighed (C_2). The weighed sample was then incinerated in a muffle furnance at 550 ^{o}C for 2 hours, cooled in a desiccator and reweighed (C_3).

Calculation:

The loss in weight on incineration = C_2-C_3

Weight of original sample = W

% Fibre = $\frac{C_2-C_3}{W}$ x 100

3.8.7 Estimation of nitrogen free extractive:

The nitrogen free extractive (N.F.E.) often termed total carbohydrate is not normally directly determined, it is obtained by difference between 100 and the sum of ash, crude protein, crude fat, and crude fibre (Shirlaw, 1967).

Calculation:

% N.F.E. = 100 - (% ash + % protein + % fat + % fibre)

3.8.8 Determination of starch:

The starch content of the yam tuber was determined using the method of McReady et al (1950) as described by Shirlaw (1967).

Procedure: One hundred grammes of yam discs were blended with 200 ml of distilled water for 5 minutes in a Quikie-mini blender and the homogonate transfered quantitatively into a 120-mesh sieve attached to a 5-litre container. The blended material in the sieve was thoroughly washed through the sieve with about a litre of distilled water. The washings were set aside for the starch so extracted to sediment. The starch was recovered after decanting of the supernatant, transferred quantitatively into a weighed, dry evaporating dish.The sample was allowed to stand for sometime to allow

for some draining of water. The percholating water was decanted and the residue was dried in the oven at 105 ^{o} C to constant weight.

The weight of dried starch was taken as the percentage starch of the yam.

3.8.9 Reducing sugars:

The reducing sugar content was determined colorimetrically by the dinitrosalicylate (DNS) method of Clark and Switzer (1964). At alkaline pH (pH>8) and at a temperature of 100 ^{o}C, DNS is reduced to 3-amino-5-nitrosalicylate by reducing sugars. The reduced DNS has maximum absorbance at 540 nm.

Extraction of sugar: A modified method of Bell (1955) was used for the extraction. The extraction was carried out at 84±2 ^{o}C for 6 hours with 80 % ethanol.

Two grammes of dried, powdered sample was weighed into a 500 ml round bottom flask. 200 ml of 80 % ethanol was poured into the flask and the resulting mixture was refluxed for 6 hours at 84±2 ^{o}C. The flask with its contents was cooled and the mixture centrifuged at 4000 g for 20 minutes. This was to remove the solid particles and precipitate protein. The extract was concentrated with rotary evaporator at about 50 ^{o}C. The final solution was diluted with distilled water to a total volume of 1 litre.

Determination of reducing sugar: One ml of the extract was pipetted into each test tube containing 1.5 ml distilled

water and 2 ml DNS prepared by dissolving 1 g of 3,5-DNS in 20 ml of warm 2 M sodium hydroxide. 30 g of potassium tartarate dissolved in 50 ml distilled water. The DNS solution and the potassium tartarate solutions were mixed with stirring and made up to 100 ml with distilled water. The tube with their contents were thoroughly shaken, heated for 5 minutes in a water bath maintained at about 100 ^{o}C and cooled under tap water. The content of each tube was diluted to 20 ml with distilled water and the absorbance of the solution was taken at 540 nm on a SP6-200 spectrophotometer. The calibration curve of absorbance against umole of glucose and fructose was plotted using standard glucose and fructose solution (Appendix 27) (5mM glucose and 5mM fructose = 5 Umole glucose and 5 Umole fructose per ml : prepared by dissolving 90 mg of glucose and 90 mg of fructose in 100 ml volumentry flask and made to mark).

3.8.10 Determination of total free amino acid content:

The total free amino acid content was determined colorimetrically by the method of Osborne and Voogt (1978). Amino acids react with ninhydrin to yield carbon dioxide, ammonia and an aldehyde containing one carbon less than the amino acids. Protein was removed from the extract by precipitation with trichloroacetic acid. Deproteinisation is necessary because protein gives positive ninhydrin reaction.

Procedure: Fresh yam tuber was peeled and blended thoroughly with addition of a little distilled water and the homogenate produced was squeezed through a lession cloth into a centrifuge tubes. The resultant filtrate was centrifuged at 20,000 g for ten minutes and the resulting supernatant was deprotenized with trichloroacetic acid (1.0 gm/20 ml extract). The precipitated proteins were removed by centrifugation at 20,000 g for 15 minutes and the supernatant so obtained was used to assay for the total free amino acids. The final volume of the extract was noted.

4.0 ml of 1 % (w/v) ninhydrin (triketohydridene hydrate) was pipetted into each of five test tube containing the extract (1.0 ml). A blue colour developed on heating the tubes in boiling water bath for five minutes. The absorbance of the blue solution was measured at 420 nm in a spectrophotometer using a 1cm glass cuvette. The control tube contained 4.0 ml ninhydrin and 1.0 ml distilled water. The mean of three absorbance measurements was taken as the absorbance of the coloured solution formed.

The concentration of the total free amino acid in the extract was extrapolated from a standard curve previously prepared with DL-Glutamine (concentration range 1.0 mg/ml to 3.0 mg/ml) as standard (Appendix 28).

3.8.11 Characterization of carbohydrate content:

The calculation of soluble carbohydrate has limited

value in evaluation of carbohydrate based feeding-stuff. In some instances, crude fibre fraction will be as high digestibility as the soluble carbohydrate. In order to gain fuller knowledge of the carbohydrate portion of the diet, it is necessary to divide it into the following fractions (Shirlaw, 1967).

(i) Soluble carbohydrates (mono, di, oligosaccharides and fructosans)

(ii) Hemicelluloses;

(iii) Cellulose;

(iv) Lignin.

3.8.11.1 Extraction of soluble carbohydrates: The soluble carbohydrates are taken as those that are soluble in boiling water.

Procedure: Two hundred mg (0.2 g) of the dry, powdered sample was placed in a 250 ml round bottom flask containing 20 ml of distilled water. A cold finger condenser was placed at the mouth of the flask and the suspension boiled for 30 minutes. After cooling, the contents of the flask are now filtered and 5 ml of the filtrate pipetted into a 50 ml volumetric flask and made up to mark with distilled water. This was labelled solution A and set aside pending quantitation. The residue was subsequently subjected to extraction for hemicellulose.

3.8.11.2 Extraction of hemicelluloses: The hemicelluloses were obtained by boiling in the soluble carbohydrate - free

resdue with 5 % (w/v) sulphuric acid prepared by diluting 2.7 ml of the concentrated acid to 100 ml with distilled water.

Procedure: The soluble carbohydrate-free residue was washed, transferred back to the 250 ml round bottom flask and 20 ml of 5 % sulphuric acid is added. A cold finger condenser was placed in the flask and the suspension was boiled for 3 hours after which the mixture was filtered. Five millilitre of the filtrate were pipetted into 50 ml volumetric flask and made up to mark with distilled water. This was labelled solution B and set aside pending quantitation. The residue was subsequently extracted for cellulose.

3.8.11.3 Extraction of cellulose: Cellulose was obtained by hydrolysing the hemicellulose-free residue with 72 % (w/v) sulphuric acid prepared by diluting 65.1 ml of the concentrated acid to 100 ml.

Procedure: The hemicellulose-free residue was transferred to a 500 ml round bottom flask and 10 ml of 72 % sulphuric acid was added. This was allowed to stand for four hours at room temperature. Then, 235 ml of distilled water was added and the contents of the flask were boiled for four hours with a cold finger condenser in the neck of the flask. Thereafter, the content of the flask were filtered through a sintered glass crucible of porosity 1 and

carefully washed. The filtrate was made up to 500 ml with distilled water. The solution was labelled C and set aside pending further analysis. The cellulose-free residue was used for lignin determination.

3.8.11.4 Determination of Lignin: The cellulose-free residue was carefully washed with 20 ml of methanol and transferred into a crucible which was then dried to constant weight at 100 ^{0}C in an oven. The weight of crucible with its contents were noted and the sample was ignited in a furnance at 450 ^{o}C for four hours. The crucible was allowed to cool and reweighed. The loss in weight is attributable to crude lignin.

3.8.11.5 Colorimetric estimation of soluble carbohydrate, hemicelluloses and cellulose:

The carbohydrate was estimated colorimetrically with anthrone-sulphuric acid reagent (Shirlaw, 1967), each extract being treated identically.

Preparation of Reagents

Anthrone-sulphuric acid: 760 ml of concentrated sulphuric acid were carefully added to 330 ml of distilled water, cooled and made up to 1 litre, 1.0g of thiourea and 1.0g of anthrone were dissolved in the resultant solution (Shirlaw, 1967).

Standard carbohydrate solution: A standard 100 ppm carbohydrate solution was prepared by dissolving 0.100g of glucose in a litre of distilled water.

Procedure: 2 ml of the respective solutions (solution A, B and C) were placed in a test tube and 10 ml of anthrone-sulphuric acid was added. Reagent blanks were prepared in duplicate using 2 ml of distilled water and 10 ml of the reagent; carbohydrate standards were also prepared in duplicate using 2 ml of the respective carbohydrate standard solution and 10 ml of the reagent.

The tubes were stoppered lightly with rubber bungs, were shaken and placed in a water bath at 100 ^{o}C for 20 minutes. The tubes were removed from the water bath and cooled in running water tap. The absorbance of the colour developed was measured against the reagent blank in a spectrophotometer at 625 nm.

3.9 Stastistical analysis:

All result are expressed as mean $\pm$ SD of at least two determinations. The results were statistically tested using the student-t test and Analysis of variance (ANOVA) at 95 % confidence limit.

All graphs are drawn using the mean values. The standard deviation (SD) are shown on table of values in the appendices.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Temperature and Relative Humidity:

The results of the average weekly relative humidity and air temperature of the yam barn during storage is shown in Fig. 4.1.

The temperature in the yam barn fluctuated between 22 ^{o}C and 35 ^{o}C, with an average of 29 ^{o}C. The humidity during the experimental period ranged between 22 % and 78 % with an average of 55 % .

4.2 Sprouting:

Results of the percentage sprouting of irradiated yam tuber ("Amara" and "Chikakwondo") are presented in Figs. 4.2a and 4.2b. Radiation doses of between 50 and 180 Gy were found to be effective in preventing sprouting in the two cultivars throughout the 40 weeks storage period (Plate 4.1 and 4.2). Sprouting started in "Amara" control tubers at about 17th week of storage and reached 100 % by the 21st week. Sprouting started at about 15th week in storage in "Chikakwando" control tubers and reached 100 % also in the 21st week. Sprouting started first in Chikakwando and it took about 6 weeks to be completed, whereas in the case of Amara sprouting started relatively later but was completed in only 4 weeks in Amara.

Adesuyi and Mackenzie (1973) reported that yam

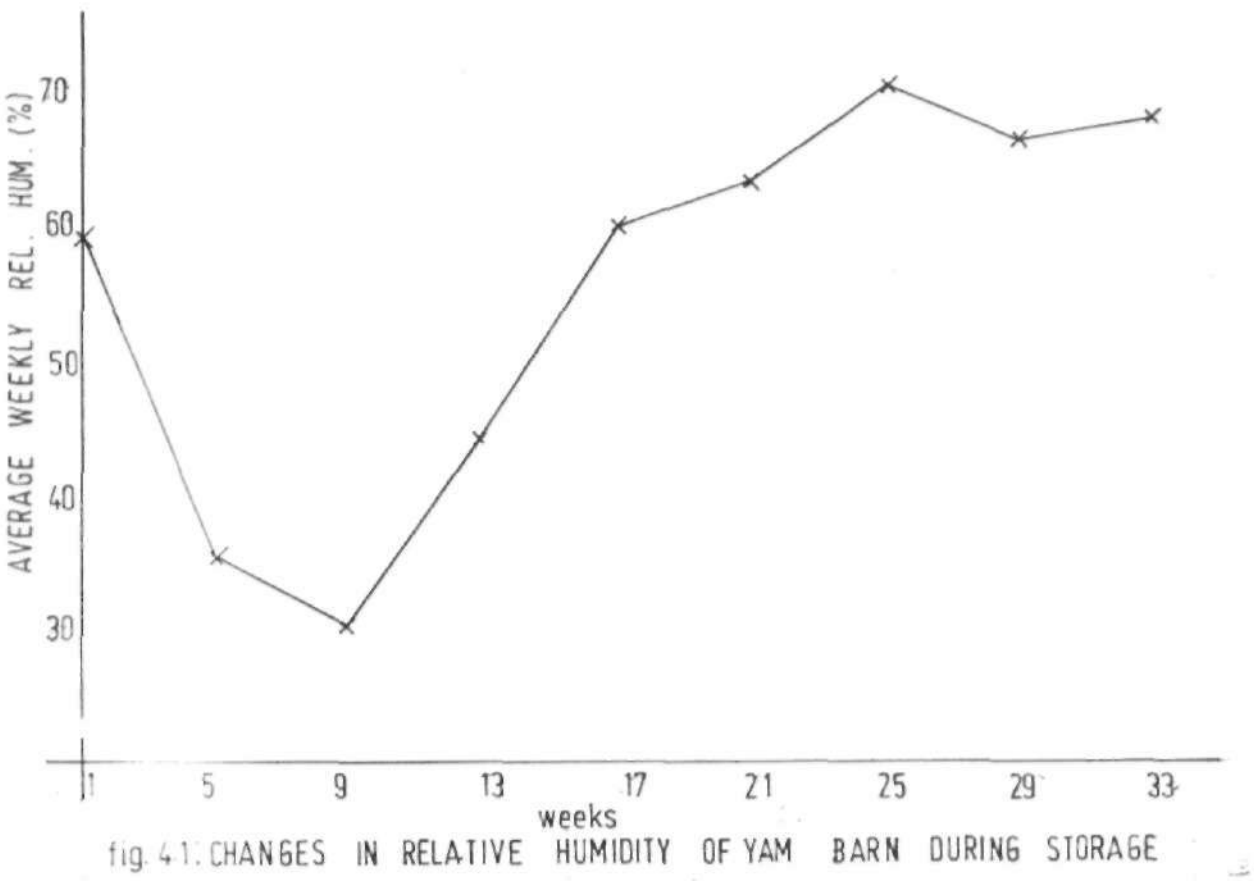


fig. 4.1. CHANGES IN RELATIVE HUMIDITY OF YAM BARN DURING STORAGE

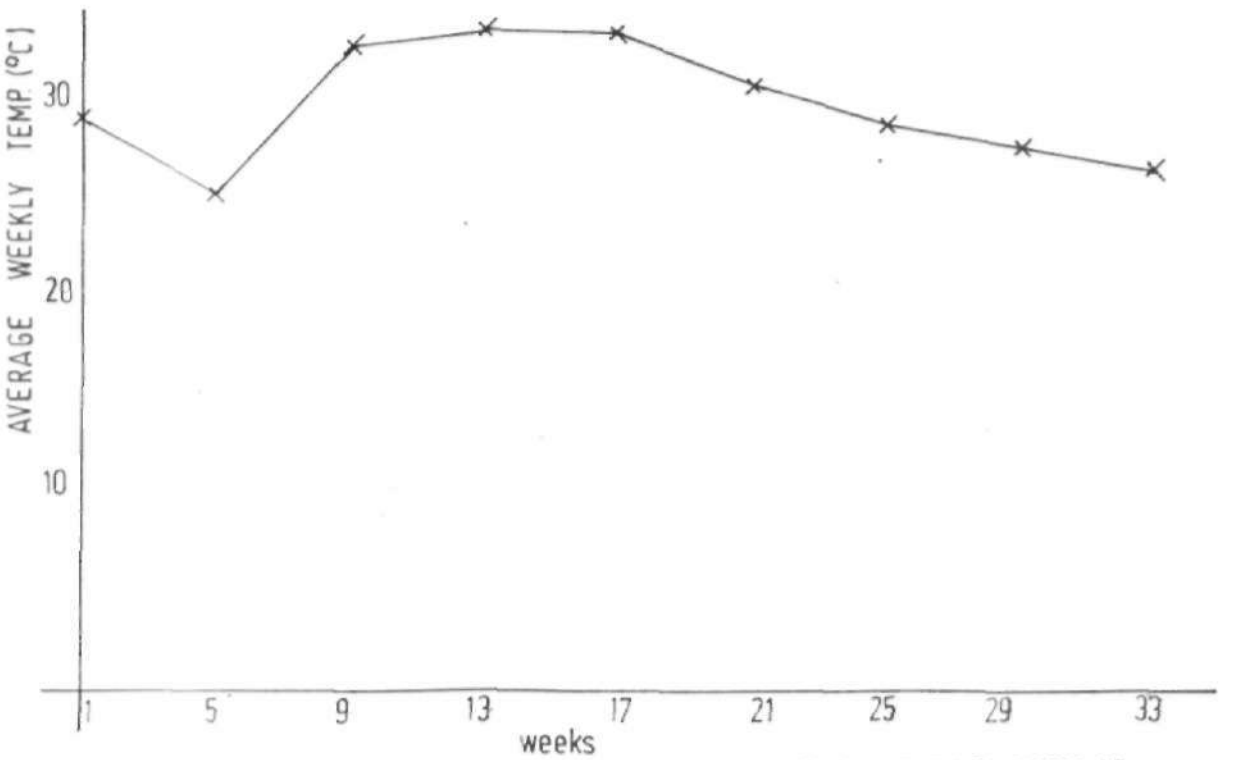


fig 4.' CHANGES IN AIR TEMPERATURE OF YAM BARN DURING STORAGE

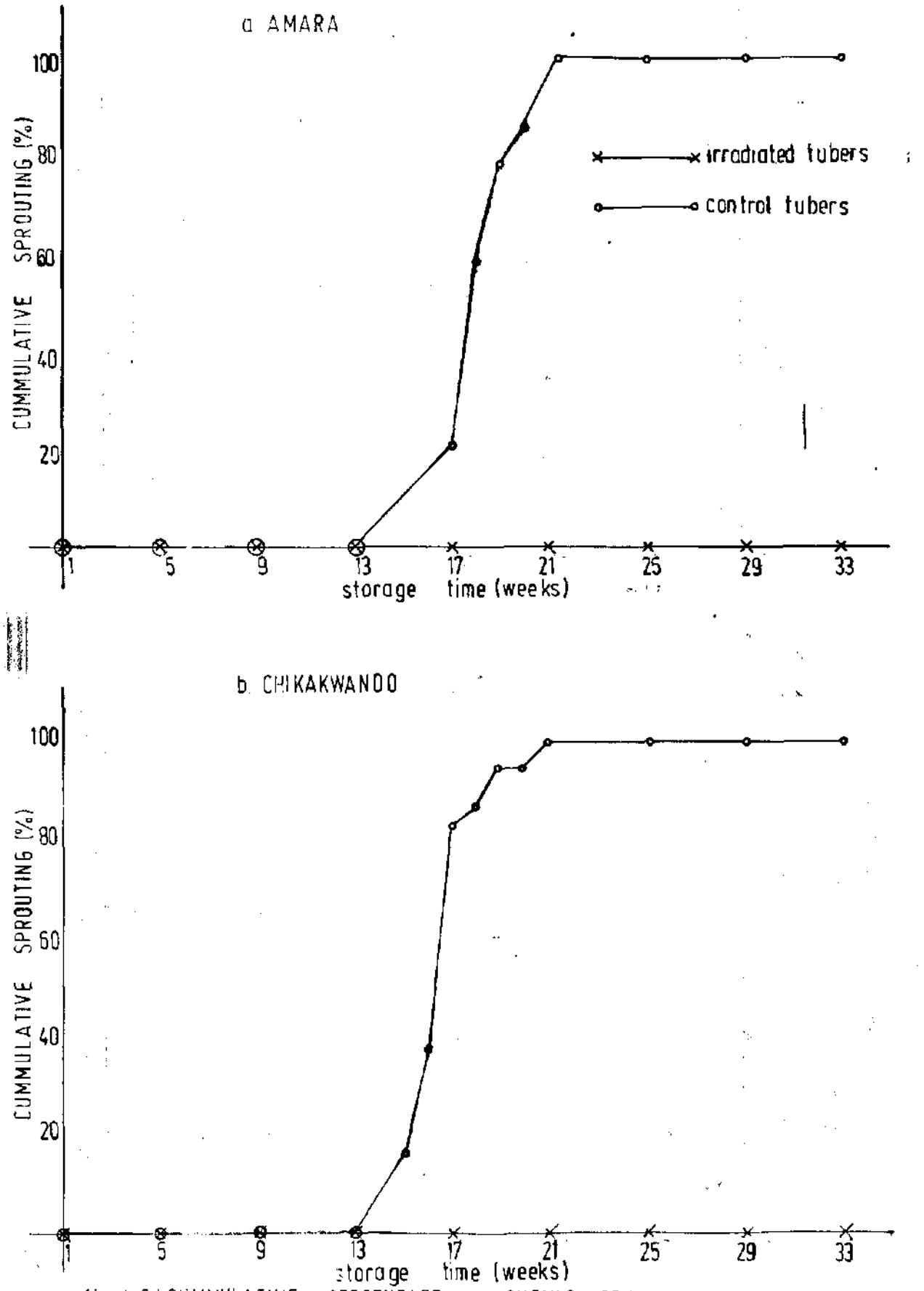


fig + 2 : CUMMULATIVE PERCENTAGE SPROUTING OF IRRADIATED YAM TUBER STORED AT ROOM TEMP (22°-35°C) AND RH 22-78%

irradiated before sprouting in storage required 100 Gy and higher doses to achieve complete inhibition of sprouting for six months. This is at variance with our findings in which dose of 50 Gy were found to inhibit sprouting in the two cultivars for 9 months of storage. This might be due to the different variety of D. rotundata used for this study, or to the fact that in this study, the tubers were irradiated a week after harvest, in contrast to that of Adesuyi and Mackenzie (1973) in which irradiation was done 4 weeks after harvest. 60 and 90 Gy doses were required for inhibition of two Indian varieties of potatoes (Dharkar, 1966). 100 and 140 Gy doses reportedly prevented sprouting in stored potatoes in Israel (Kahan and Temkin-Gorodeiskii, 1966) and potato tubers irradiated with 100 Gy did not sprout even when planted in the soil (Metlitskii, 1968) although Martin et al (1974) reported radiation stimulation of sprouting in yam tuber.

The same range of irradiation doses seems to be required to prevent sprouting in yam and potato tubers during storage. Irradiation is thought to act on the meristematic tissue of the sprouting loci in yam, potato tubers and onion bulbs (Metlitskii, 1968).

CHIKAKWANDO



AMARA



PLATE 4.1: PHOTOGRAPHS SHOWING THE YAM CULTIVARS AFTER 10 MONTHS IN STORAGE.
(Chikakwando on top, Amara below. From left to right shows the control, the one with 50 Gy, 100 Gy and 180 Gy,respectively).

A



B



PLATE 4.2: PHOTOGRAPH SHOWING THE YAM CULTIVARS DURING STORAGE
(The shelve on top showed the control sprouting - Amara to the left and Chikakwondo to the right and the down shelve showed the non-sprouting irradiated tubers).

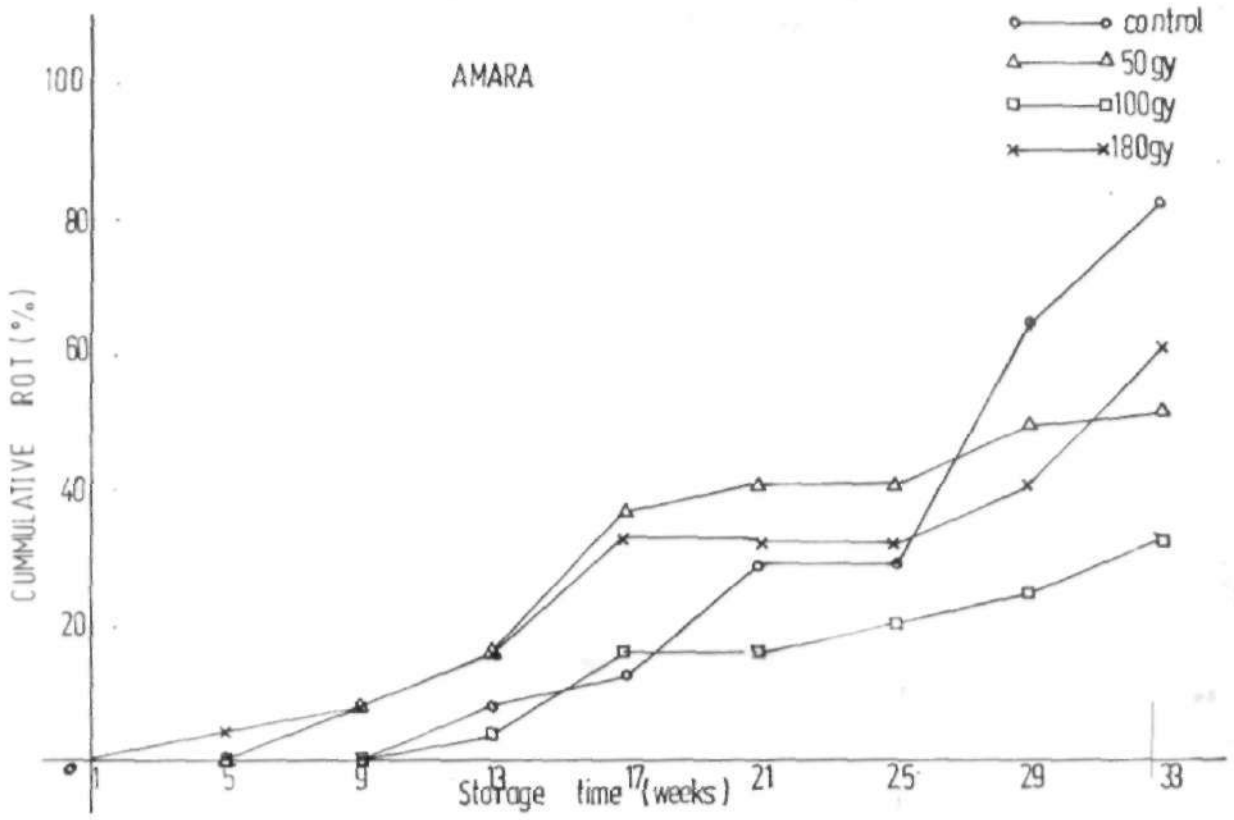
4.3 Incidence of Rot:

The percentage rot of irradiated tuber of the two cultivars during storage are shown in Figs. 4.3a and 4.3b respectively.

The percentage rot in the control Amara at the 37th week of storage is about 83 % while that of irradiated tubers were 54 %, 33 % and 71 % for 50, 100 and 180 Gy doses of irradiation respectively. Here irraddiation did not significantly ($P > 0.05$) reduce percentage rot. In chikakwando control, percentage rot is 75 % at the 37th week of storage whereas the irradiated tubers were 42 %, 42 % and 54 % for 50, 100, and 180 Gy doses of irradiation respectively. here irradiation significantly ($P < 0.05$) reduced percentage rot from the 21st week of storage.

This result suggests that high radiation doses prevent sprouting, they also significantly reduced ($P < 0.05$) percentage rot in chikakwando but not in Amara. This observation supports previous reports (Kahan and Temkin-Gorodeiski, 1966; Metlitskii, 1968; Adesuyi and Mackenzie, 1973; Ogbadu, 1981b).

Irradiation is known to decrease the natural resistance of potatoes to phytopathogenic organism (Metlitskii, 1968). In yam it is likely that it affects the internal tissue of the tuber latter in storage. It might also be possible that irradiation might lower the resistance of the tuber.



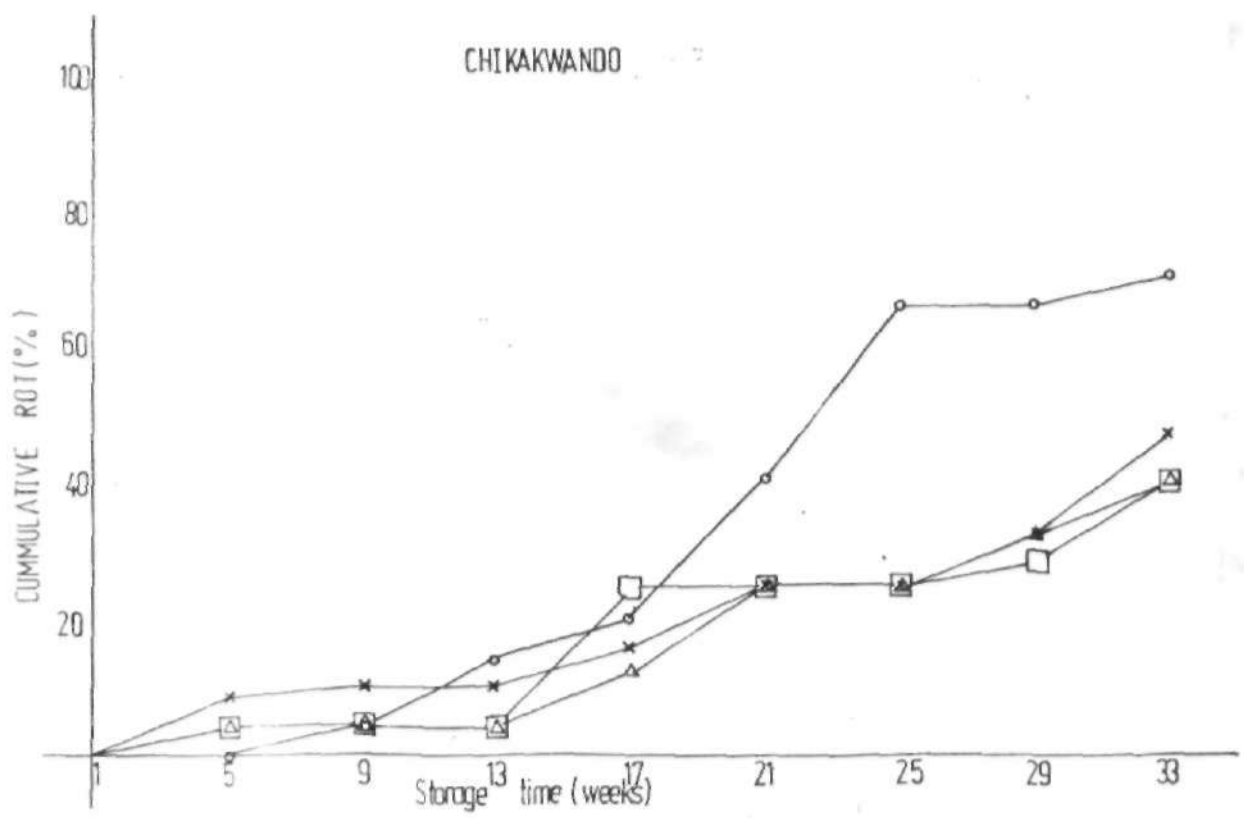


fig 4-3: CUMMULATIVE PERCENTAGE ROT OF IRRADIATED YAM TUBER STORED AT ROOM TEMPERATURE (22°C – 35°C) AND RELATIVE HUMIDITY (22–78%)

The higher incidence of rot in tuber irradiated with 50 Gy compared with those irradiated with 100 Gy in "Amara" (Fig. 4.3a) might be due to the fact that 100 Gy is a threshhold dose for Amara, hence doses below and above it may promote rotting.

Periodic examination of the irradiated yam tuber during storage revealed signs of discolouration of the growth centres in several irradiated tubers. This increased during storage. In several cases, the discolouration was accompanied by rotting of the growth centre. Similar discolouration of irradiated yam tuber has been reported by Adesuyi and Mackenzie (1973). It was suggested by Nair et al (1973) that the discolouration of the growth centre may be due to the death of the meristematic tissue which become more susceptible to microbial attack. Similar observation was made by many workers on onion bulbs (Nuttall et al, 1961; Kahan and Temkin-Gorodeiski, 1966; Nair et al, 1973).

Discolouration however, does not cause a serious problem during domestic cooking as this part can easily be removed, but when processing into flour or flakes, it may give a poor product.

4.4 Tuber weight losses:

The trend in loss of tuber weight of the yam cultivars during storage are shown in Figs. 4.4a and 4.4b respectively.

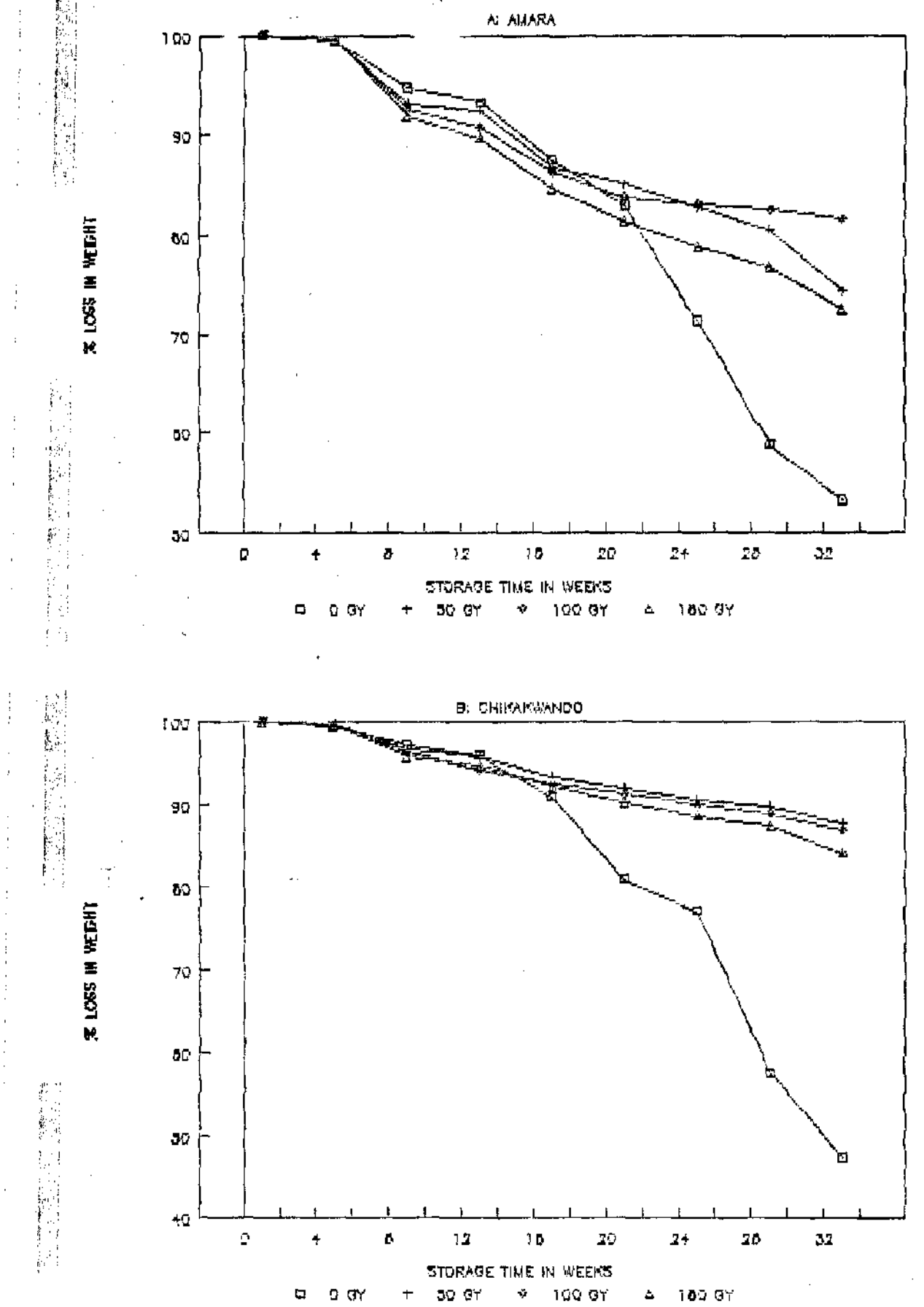


FIG. 4.4: WEIGHT LOSSES ON IRRADIATED YAM TUBERS DURING STORAGE

It can be seen that there was a significant ($P < 0.05$) loss in weight in control tuber compared with irradiated tuber for both cultivars. The loss in weight of "Amara" control is approximately twice that of its irradiated counterpart (48 %:25 %), while the loss in weight is approximately four times in Chikakwondo (53 %:14 %). These results compare favourably with that of Adesuyi and Mackenzie (1973).

There was a marked loss in weight of the control tubers because of profuse sprouting in storage. Irradiation treatments that inhibited sprouting (50-180 Gy) significantly ($P < 0.05$) reduced the loss in weight of the stored tubers.

The losses in the weight of tubers can be directly translated into thermodynamic energy change (Osuji and Umezurike, 1985). Work is done when a system experiences physical and/or chemical changes. This element of work is calculated as the product of extensive and intensive factors (Moore, 1974). For the yam tuber under storage, the extensive factor is the decrease in weight and the intensive factor is the free energy change (DG) resulting largely from the oxidation of the stored starch, that is, respiration. Starch is the major storage food item, its rate of degradation determines the half-life of the yam tuber.

A mole of glucose causes a free energy change (DG) of 686 kcal on complete oxidation to water and carbon dioxide.

Since D. rotundata contains 78 % amylopectin and 22 % amylose (Rasper and Coursey, 1967) and DG for the oxidation of a mole of starch is about 205,800 kcal (Osuji and Umezurike, 1985), so that 3.81 kcal is released per gram of starch oxidised, or per gram loss in weight of tuber. The energy liberated by loss in weight of 1g is referred to as E_{resp}. This is equivalent to half the energy released when a mole of ATP is hydrolysed to ADP.

Our data on weight losses of heathy yam tuber stored for 8 months showed that sound "Amara" tubers lost 47 % of their weight while about 24 % weight on the average were lost by the irradiated counterpart, compared to about 53 % and 14 % for non-irradiated and irradiated "Chikakwando", respectively. The weight losses is a result of deletorious endogenous biochemical reactions. The energy released by the weight-decreasing biochemical reaction in a period of 8 months can be calculated from E_{resp}. x Dwt. the energy released lost by "Amara" were 1800 kcal per kg tuber and 926 kcal per kg for the control and irradiated tubers respectively. The corresponding value for "Chikakwando", were 2000 kcal per kg and 529 kcal per kg tuber respectively. All this energy is redistributed among the molecular components of the tuber for increasing their molecular randomness, leading to the increase of the entropy of the molecular structures (e.g. starch, proteins, chromosomes, membranes e.t.c.) of the tuber

with increasing duration of tuber storage. The increase in entropy will be very negligible when the decrease in weight is caused by dessication alone, and will be very high when the weight decrease is large as in sprouting tubers. The rate of entropy increase is thus a direct index for determining the half-life of yam tubers.

4.5 Proximate Composition

4.5.1 Moisture:

The graphs showing the variation of the moisture content of yam tuber during storage are shown in Figs. 4.5a and 4.5b for "Amara" and "Chikakwando", respectively.

Moisture was steadily lost from stored yam tubers irrespective of whether the tuber was allowed to sprout or not; the older the tuber, the lower the moisture content. The mean percentage loss in moisture of non-irradiated "Amara" for the period of study is 21 % while that of irradiated counterpart was about 5.8 %. The corresponding values for "Chikawondo" were 31 % and 12.2 %, respectively. Moisture is obligatorily lost through the tuber surface and in sprouted tubers, moisture is equally obiligatorily loss through the sprout surface also.

Irradiation had significant effect on the moisture loss ($P<0.05$) especially from the seventeenth week of storage. This is possible because irradiation suppressed sprouting, hence obligatory water loss from sprout surfaces are eliminated.

Irradiation at various dose levels appeared not to have

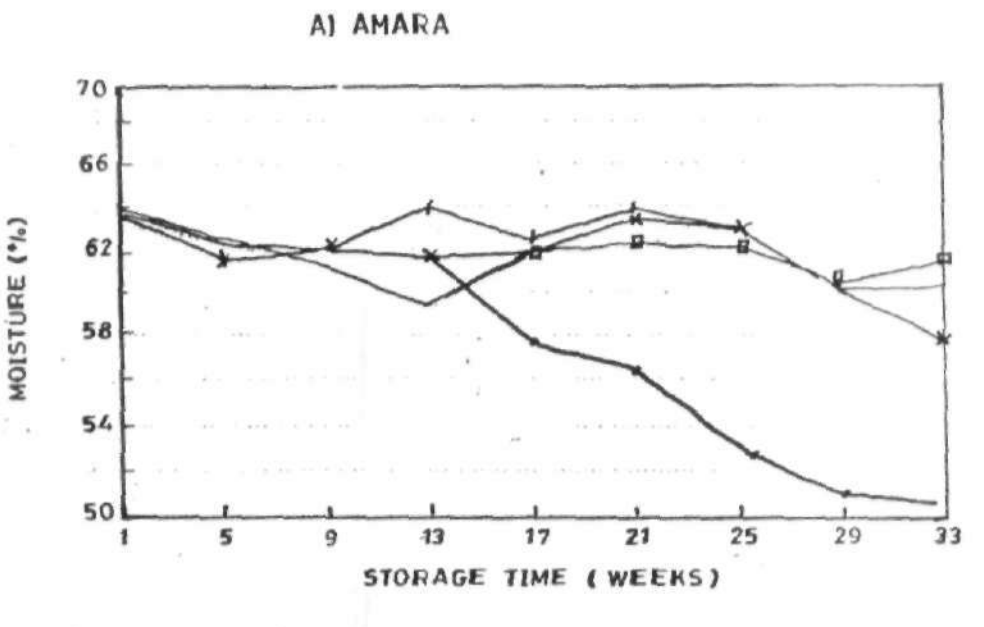


Fig. 4.5. Variation of the moisture content of irradiated yam tuber during storage.

significant effect (P>0.05) on the moisture content of both cultivars. The dose of 180 Gy significantly (P<0.05) affect the moisture content of "Amara" from the 29th week of storage (Fig. 4.5a).

4.5.2 Ash:

The trends in the variation of ash content of yam tuber during storage are shown in Figs. 4.6a and 4.6b for "Amara" and "Chikakwando" respectively.

The ash gives a rough idea of the amount of mineral element in a given sample (Joslyn, 1970). The ash content of "Amara" is fairly constant upto about the 13th week of storage. After the break in dormancy, the ash content then gradually increased, peaking at the 21st week. Thereafter there is a progressing decrease. In all cases old yam had higher ash content than the new yam. For "Chikakwando", a different trend was observed. The ash content of the control and irradiated samples were more or less the same up to the 17th week. Thereafter, the ash content of the control sample falls and then gradually pick up again from the 21st week. This might be due to variety differences. Joslyn (1970) showed that ash content vary between individual food component and within species or even cultivars. The variation in ash content may also be due to changes in weight caused by progressive decomposition of carbonates, or losses of relatively volatile constituents such as chlorides.

There were significant differences (P<0.05) in the ash

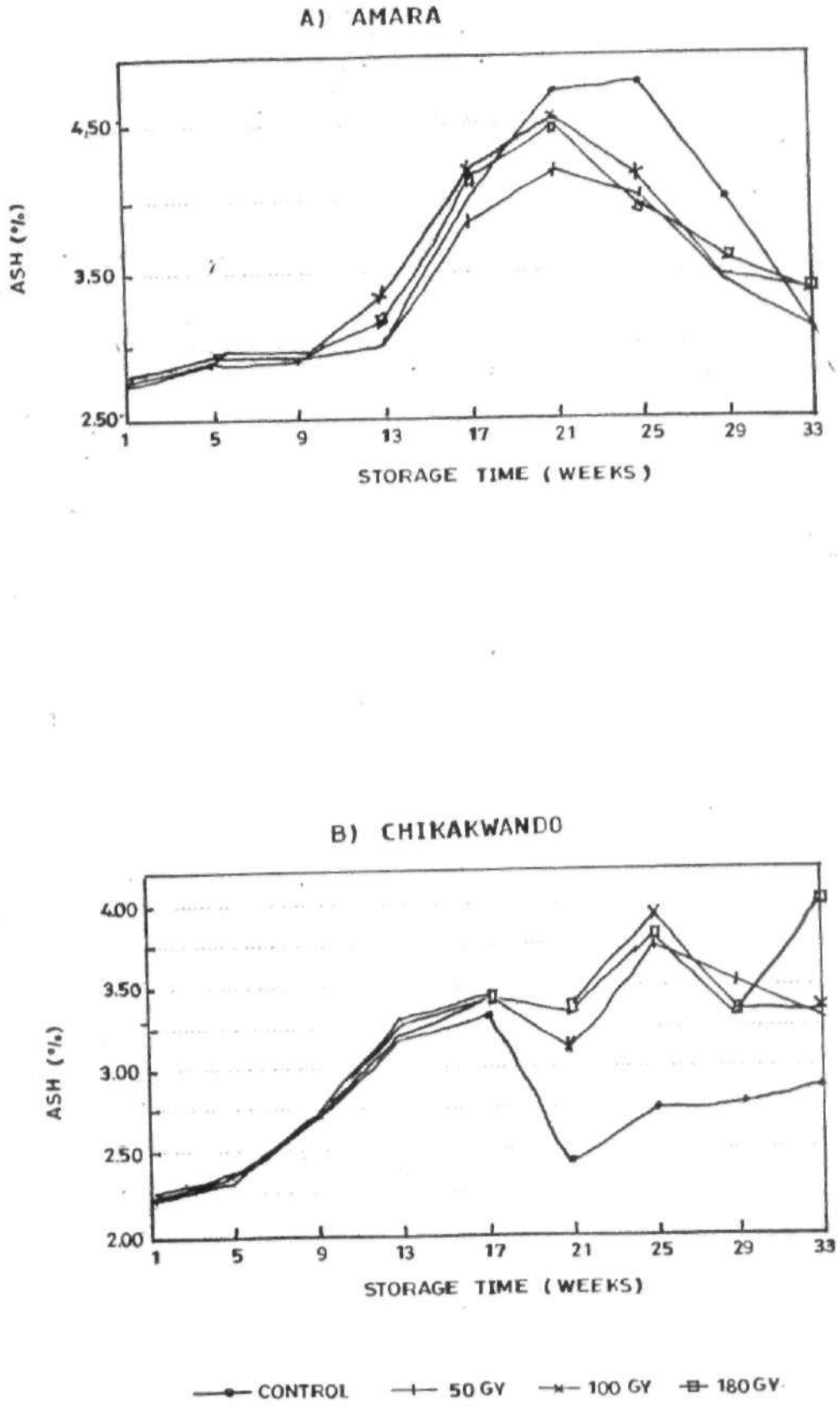


Fig. 4.6. Variation of the ash content of irradiated yam tuber during storage .

content of irradiated and control samples of both cultivars from the 21st week of storage. Irradiation at various dose levels did not significantly affect the ash content of the tuber ($P>0.05$) of both cultivars except for doses of 100 Gy and 180 Gy at 33 weeks of storage (Figs. 4.6a and 4.6b).

4.5.3 Protein and Amino Acids:

Figs. 4.7a and 4.7b shows the variation of the protein content of yam tuber ("Amara" and "Chikakwando") during storage. The result for the amino acid content are shown in Figs. 4.8a and 4.8b, respectively.

Crude protein level of the yam tuber increased steadily from the 1st to the 13th week of storage while that of total free amino acid decreased steadily within this period. The maximum level of protein in the yam tuber was obtained at the initiation of sprouting which was a stage of enhanced metabolic activity. Zaleski (1988) found that there was very active synthesis of protein during storage of onion bulbs and he associated it with enhanced metabolic activity. Hulmes (1954) showed that a striking increase in protein accompanied a climateric rise in fruits and Ulrich (1958) suggested that the new proteins might include enzymes catalysing respiratory reaction; perhaps the amino acids were used both for protein synthesis and as respiratory substrates within this period of dormancy when there was a low level of free sugars serving as respiratory substrate (Oti, 1981).

During senescence there was a decrease in protein level

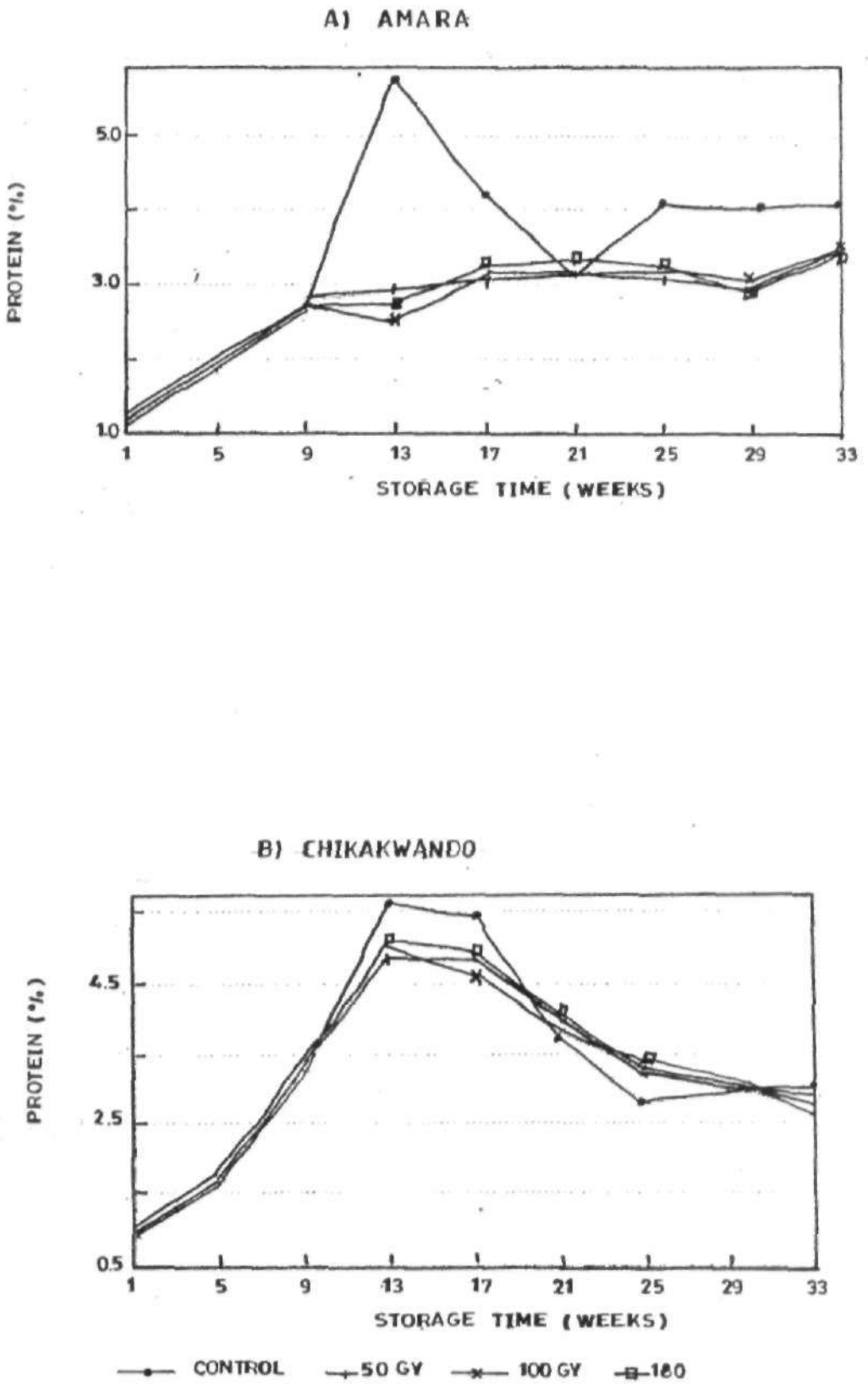


Fig. 4.7. Variation of the protein content of irradiated yam tuber during storage.

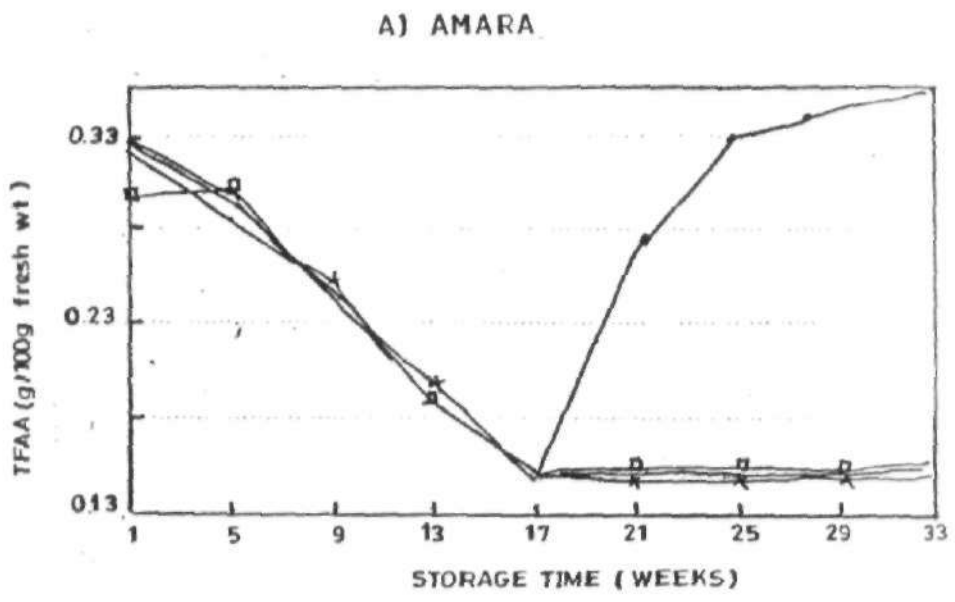


Fig. 4.8. Variation of the total free amino acid content of irradiated yam tuber during storage

and also an accummulation of amino acids probably as a result of decreased protein synthesis or increased protein degradation (Beevers, 1976). The decrease in crude protein level and the increase in the level of total free amino acid observed after the onset of sprouting suggest that yam tuber enters a phase of senescence soon after sprouting commences. It appears that during senescence of yam tuber, proteins are degraded leading to an accummulation of amino acids. The purpose of this process may be to furnish amino acid to be translocated to the sprouts as a respiratory substrate. The increase in the level of crude protein in the 25th week after a steady fall from the 13th to 21st week of storage are in agreement with the findings of Vickery et al (1940) that proteins in plants are in dynamic states and the suggestion by Street (1958) that in plants amino acids may be utilized in protein synthesis by being linked together through the synthesis of peptide bonds.

Irradiation significantly affects ($P<0.05$) the protein content of "Amara" from the 13th week, that is after sprouting. This might be because irradiation suppresses sprouting in the treated sample and hence enzyme activities. This may explain the marginal increase in the protein content of the irradiated "Amara". But in Chikakwando, there was no significant difference ($P>0.05$) between the irradiated and control sample until in the 17th and 25th week of storage (Fig. 4.7b). In the two cultivars, the total free amino acid

content was not significantly affected by irradiation before sprouting ($P>0.05$), but after sprouting, between 13th and 17th week, irradiation significantly affected ($P<0.05$) the total free amino acid content of the tubers.

Irradiation at various dose levels did not significantly affect the protein content of both cultivars ($P>0.05$) whereas, there was a significant difference ($P<0.05$) in the amino acid content of the tuber following application of different irradiation doses.

4.5.4 Lipids:

Figs. 4.9a and 4.9b shows the lipid content of irradiated "Amara" and "Chikakwando" yam tubers during storage.

Lipid content is significantly higher ($P<0.05$) in "Amara" than in "Chikakwando" throughout the period of the experiment. The level of lipid in the tuber used for the experiment decreased steadily with time during the dormancy period. This may be due to degradation in biochemical reaction involving lipase and lipooxidase activities. Ikediobi and Synder (1977) had earlier shown that soyabean lipoxygenase cooxidised Beta-carotene while catalysing the oxidation of linoleic acid. Probably the fatty acids were being oxidised into acetyl CoA to support respiratory activities of the tuber during this period when the level of sugar was low. At this stage, there was

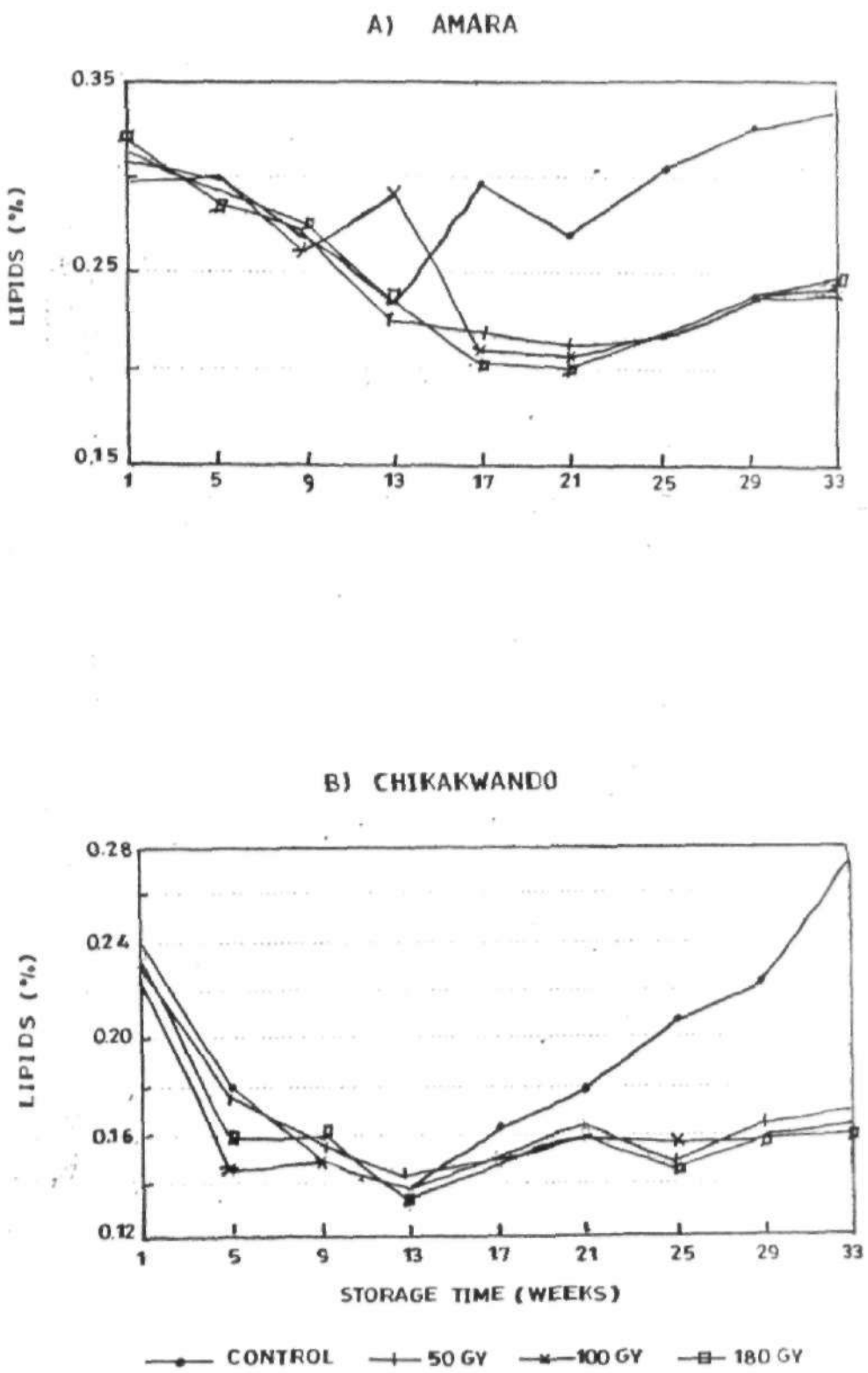


Fig. 4.9. Variation of the lipid content of irradiated yam tuber during storage.

no significant difference (P>0.05) in the lipid content of irradiated sample of both cultivar as compared to the control. When dormancy was broken, the level of lipid rose gradually and steadily to the end of storage in all cases, during dormancy, there was a significant difference (P<0.05) between the lipid content of the control and that of the irradiated sample of both cultivars after breakage of dormancy. Apparently, the activities of phosphorylase, amylase and invertase now provided enough sugars to sustain the respiratory activities of the tuber; the lipid degradation machinery had to slow down and the equilibrum tilted in favour of lipid synthesis. The difference between in the lipid content of control and that of irradiated sample can be explained by the fact that irradiation supressed sprouting in irradiated sample, hence decrease enzyme activities, resulting in a decrease in lipid synthesis. Mondy et al (1963) obtained slightly lower level of total lipids in potatoes after sixteen weeks of storage. Boggess et al (1967) obtained higher levels of total lipids after storage of some varieties of sweet potatoes.Thier data, however, showed that both synthesis and oxidation of fatty acids were occurring during storage.

Irradiation at various dose levels did not significantly affect (P>0.05) the lipid content of the yam tuber. This is in agreement with the work of Loaharanu (1971) on Banana.

4.5.5 Nitrogen free extractive/total carbohydrate:

Figs. 4.10a and 4.10b show the variation of NFE of the yam tubers during storage.

Nitrogen free extractive is high in yam tuber making it a very good source of carbohydrate (Eka, 1985). The NFE content of "Amara" is significantly ($P<0.05$) higher than that of "Chikakwando" in all cases.

The NFE content decreased during dormancy. There was no significant difference ($P>0.05$) between the control and irradiated sample before dormancy breakage. After breakage of dormancy, the NFE gradually increased from the 13th week for both cultivars. The NFE content was significantly higher in controls ($P<0.05$) than in the irradiated sample. This may be attributed to the phenomenon of resumption of enzyme activities generally associated with dormancy breakage in yams.

Irradiation at various dose levels had no significant effect ($P>0.05$) on the NFE content of both cultivars (Figs. 4.10a and 4.10b).

4.5.6 Starch:

Starch content of the tuber decreased steadily from the 1st to 33rd week of storage (Figs. 4.11a and 4.11b). In the first 9 weeks, the rate of decrease was quite small. This was the phase of dormancy, when the activity of the starch degrading enzymes were at the lowest ebb. At sprouting, the ra

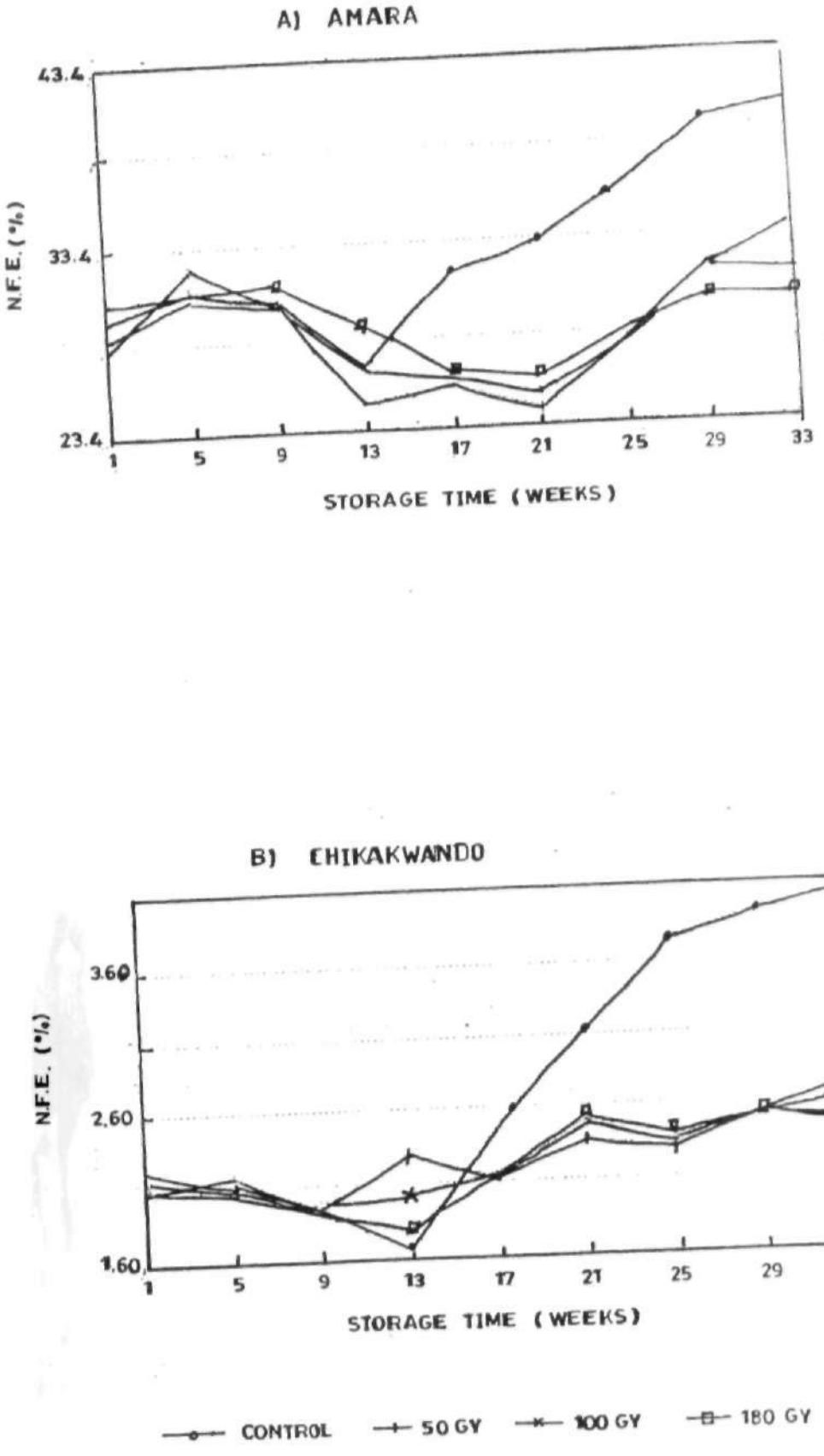
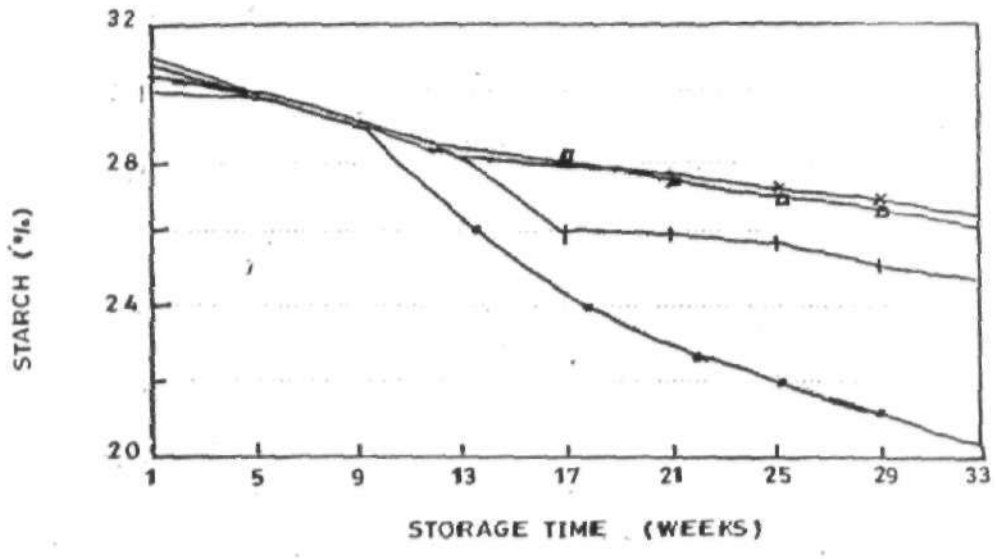


Fig. 4.10. Variation of the nitrogen free extractive content of irradiated yam tuber during storage.



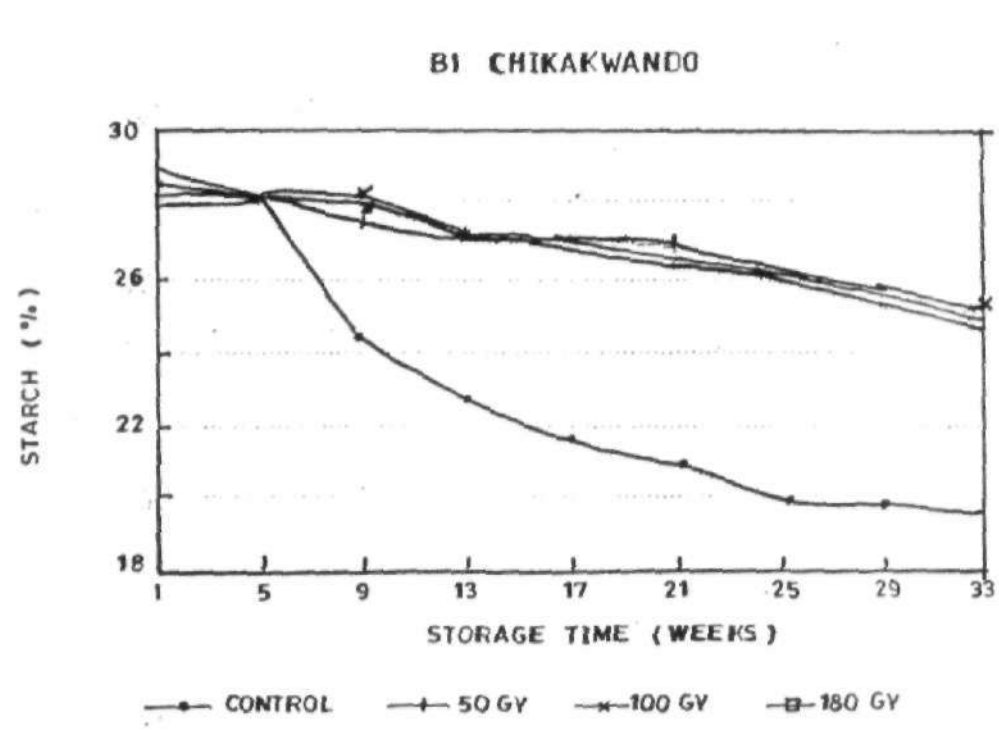


Fig. 4.11. Variation of the starch content of irradiated yam tuber during storage.

of degradation was significantly increased ($P<0.05$). From the 21st to 23rd week, the rate of degradation of starch decreased again; but in irradiated sample, the percentage decrease was significantly lower ($P < 0.05$) (15-18 % in irradiated "Amara" and 11-13 % in irradiated "Chikakwando") than that of "Amara" control (33 %) and "Chikakwando" control (32 %) respectively. The percentage decrease in the starch content of "Amara" irradiated with 50 Gy was higher (18 %) than those irradiated with 100 and 180 Gy (15 %). These might be due to the fact that irradiation dose of 50 Gy is insufficient to completely inactivate the starch degrading enzymes in "Amara" to appreciable extent like doses of 100 and 180 Gy.

Result from the present study showed that, there was a substantial loss in starch during storage. However sprouting increased the rate of loss of starch. Sprouting significantly affected ($P<0.05$) the starch content of both cultivars of yam tuber. This is in agreement with the work of Adesuyi (1975b) on D. rotundata. Increased degradation of starch is necessary in sprouting tubers to furnish the sprout with sugars utilised for growth and development (Hayward and Onyearu, 1962).

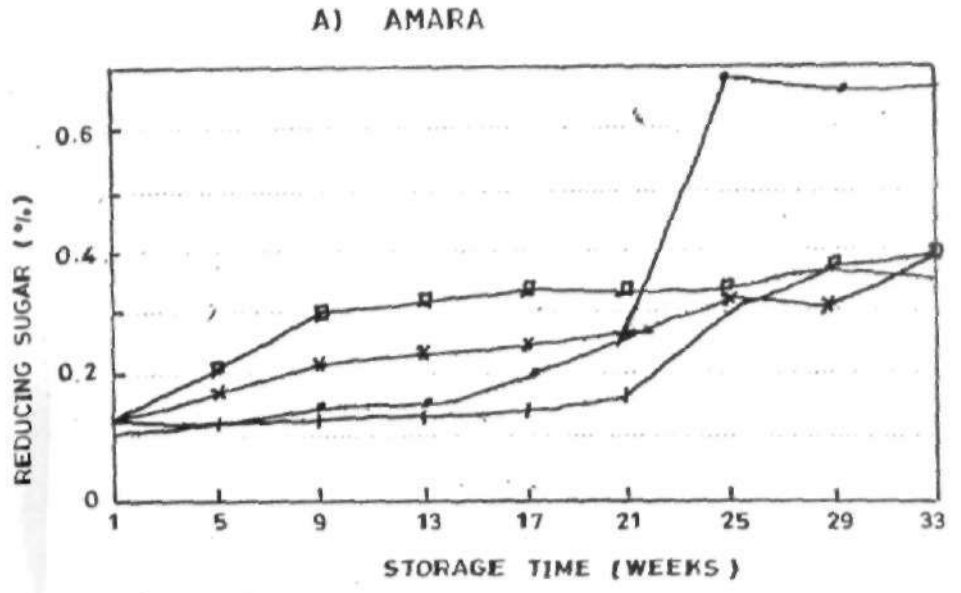
Irradiation at various dose levels had no significant effect ($P>0.05$) on the starch content of both cultivar expect for the dose of 50 Gy in "Amara".

4.5.7 Reducing Sugars:

The changes in the reducing sugar content of yam tubers during storage are given in Figs. 4.12a and 4.12b. At harvest, the reducing sugar level of "Chikakwando" was significantly higher ($P<0.05$) than that of "Amara". In both cultivars, reducing sugar levels increased during storage until the end of dormancy, which explains why old yam has more sugar level than new yam, this is consistent with the findings of Asemota and Osagie (1988).

The initial increase in the reducing sugar was similar to that previously reported for onion during storage (Salem, 1974; Mahmoud et al, 1978). The increase in reducing sugars may be due to enzymatic breakdown of the cell wall to oligo and monosaccharides (Godwin and Mercer, 1972). The stored starch may become converted into sugar, mainly sucrose, glucose and fructose due to activities of amylase (Whelan, 1961; Nordin and Kirkwood, 1965).

Irradiation at various levels significantly affected ($P<0.05$) the reducing sugar content in "Amara", probably by weakening the alpha (1-4) glycosidic linkage in the starch, making it easier for enzymatic attack (Metlitskii, 1968). The sugar content was highest at the dose of 180 Gy followed by those at 100 Gy in stored "Amara". This is contrary to what was observed for "Chikakwando" where irradiation doses had no significant effect ($P>0.05$) on the sugar content of the tuber. The findings of Adesuyi (1973) suggested that



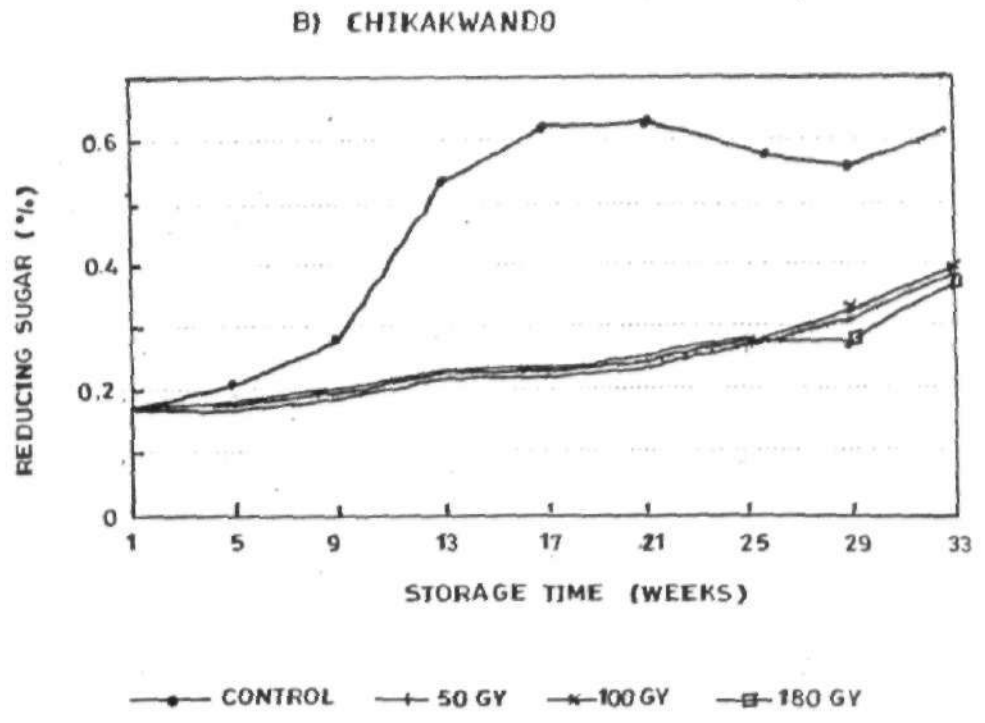


Fig. 4.12. Variation of the reducing sugar content of irradiated yam tuber during storage

indicated that the difference between the reducing sugar content of the two yams cultivar might be due to genetic variation. It is possible that the starch in "Chikakwando" might be more resistant to irradiation than those in "Amara".

4.5.8 Dietary fibre and carbohydrate profiles:

The results showing the variations in crude fibre, soluble carbohydrate, hemicellulose, cellulose and lignin of yam tuber during storage are presented in Figs. 4.13a and 4.13b, 4.14a and 4.14b, 4.15a and 4.15b, 4.16a and 4.16b and 4.17a and 4.17b, respectively.

Analyses of dietary fibers was done every eight weeks contrary to every four weeks sampling done for other parameters evaluated. Hemicellulose, cellulose and lignin content of the yam was however not determined at 17th week, due to loss of sample. The crude fibre did not differ significantly from the control at the levels of radiation tested. There was no significant difference ($P>0.05$) between the control and irradiated sample except for "Amara" after 25th week of storage. The fiber content tended to increase with the storage time of the tuber with pronounced increase being observed during sprouting.

The soluble carbohydrates also did not differ significantly for the control at the level of radiation tested, expect for "Chikakwando" irradiated with 180 Gy where the difference was observed only after 25 weeks of

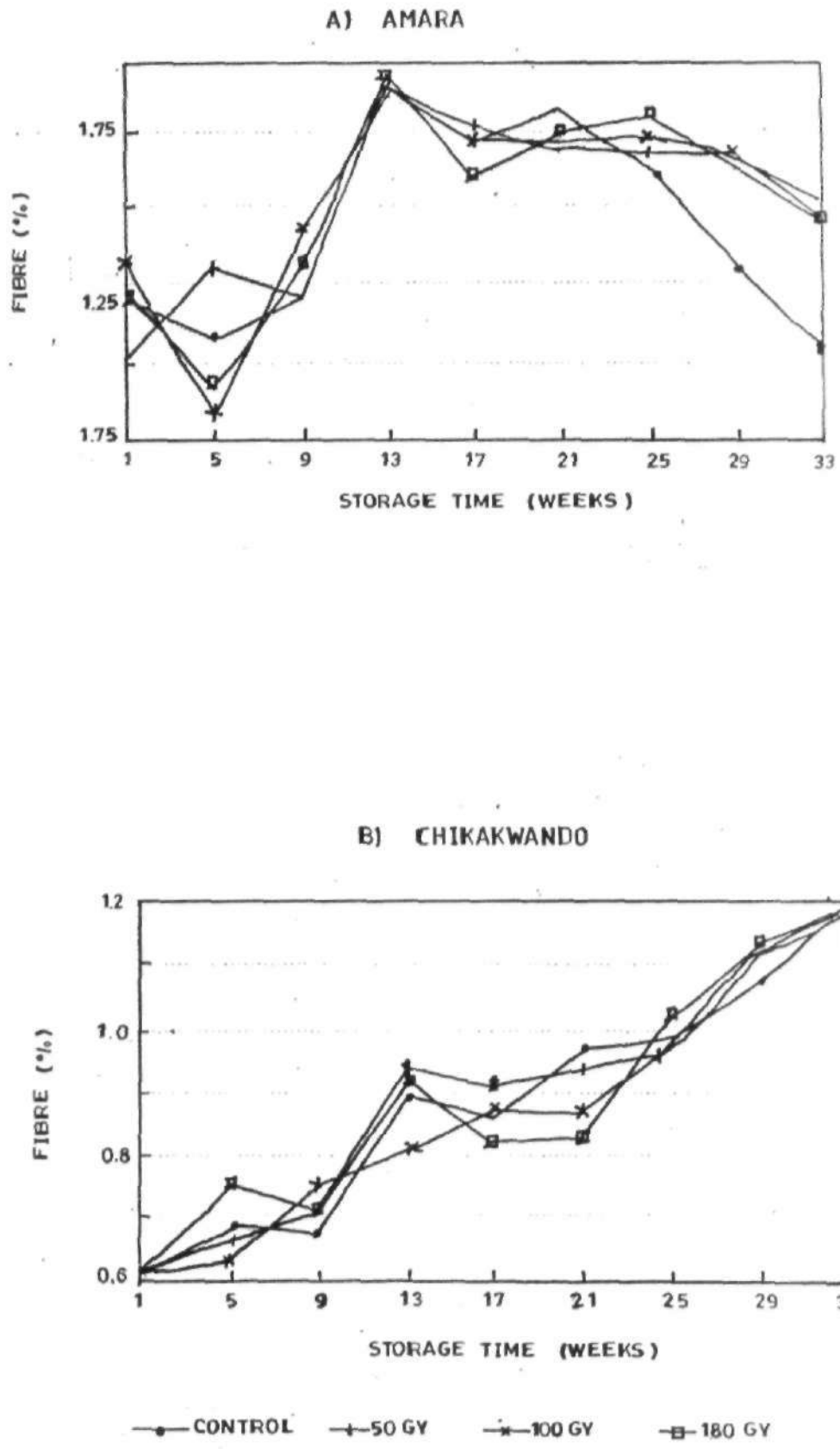


Fig. 4.13. Variation of the fibre confent of irradiated yam tuber during storage .

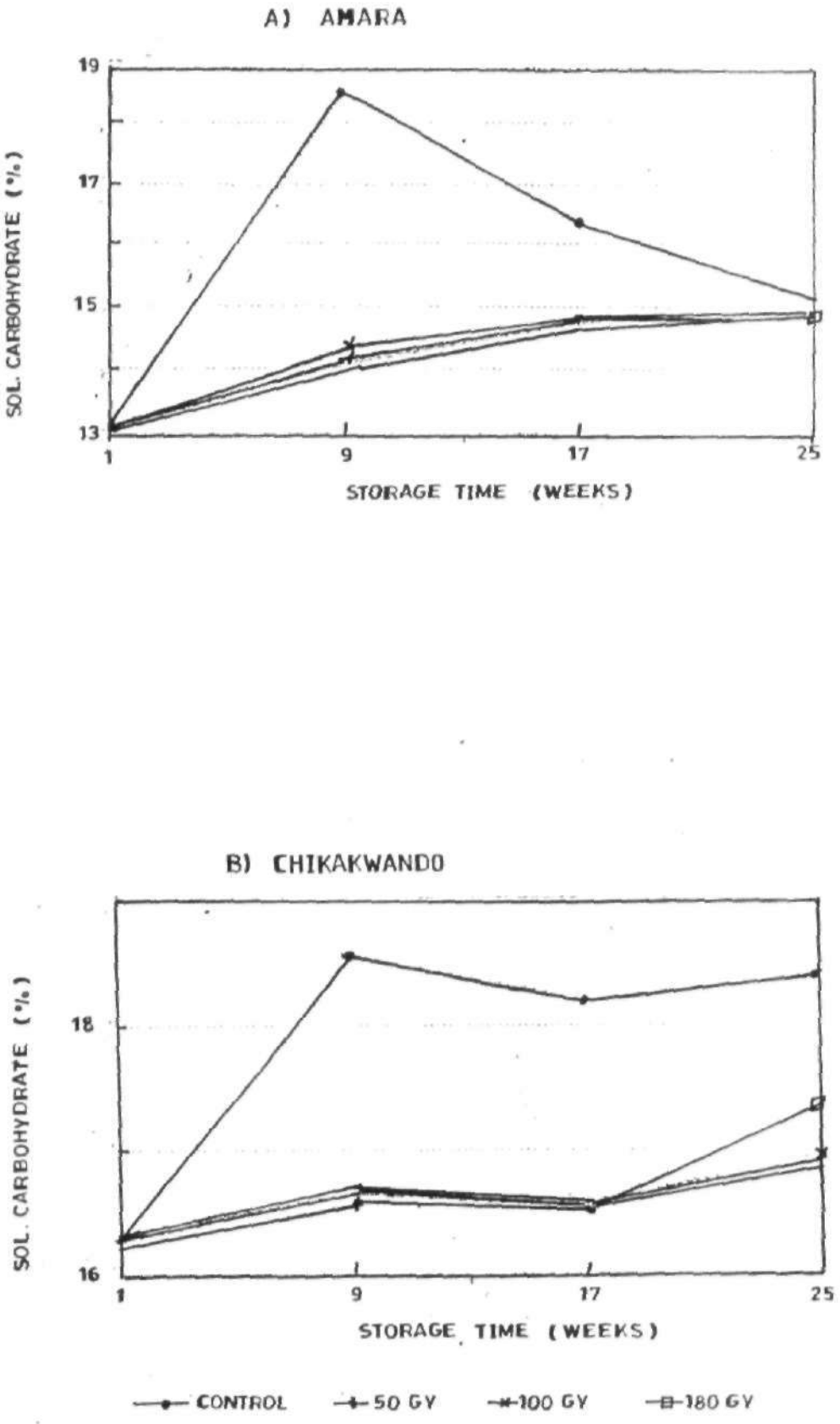
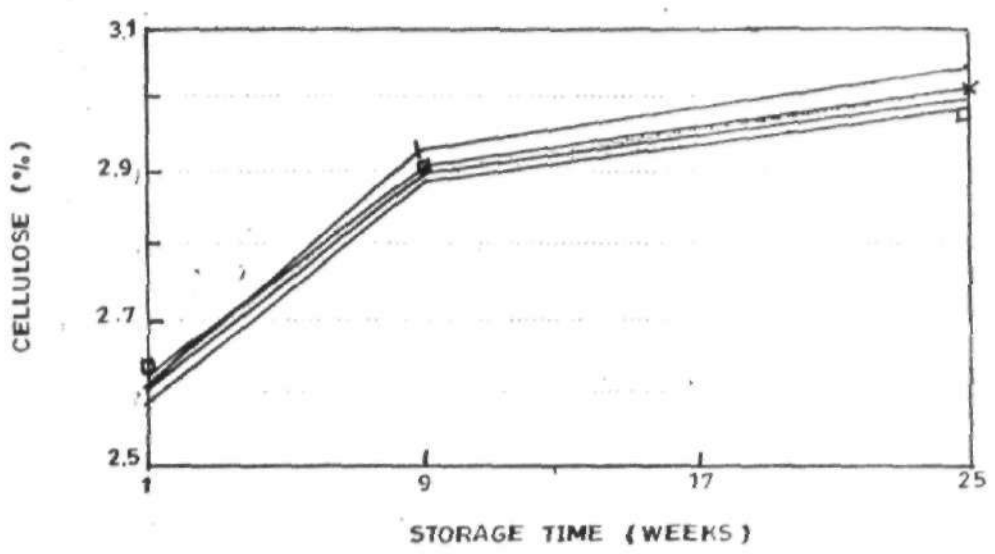


Fig. 4.14. Variation of the soluble carbohydrate content of irradiated yam tuber during storage.



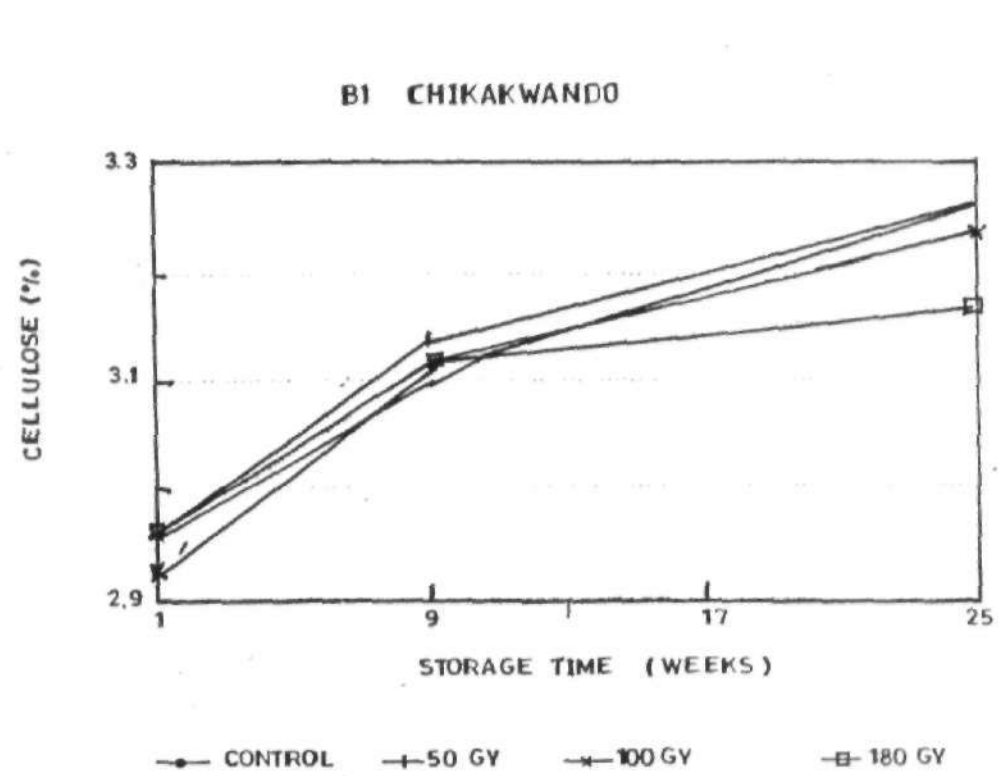


Fig. 4.15. Variation of the cellulose content of irradiated yam tuber during storage.

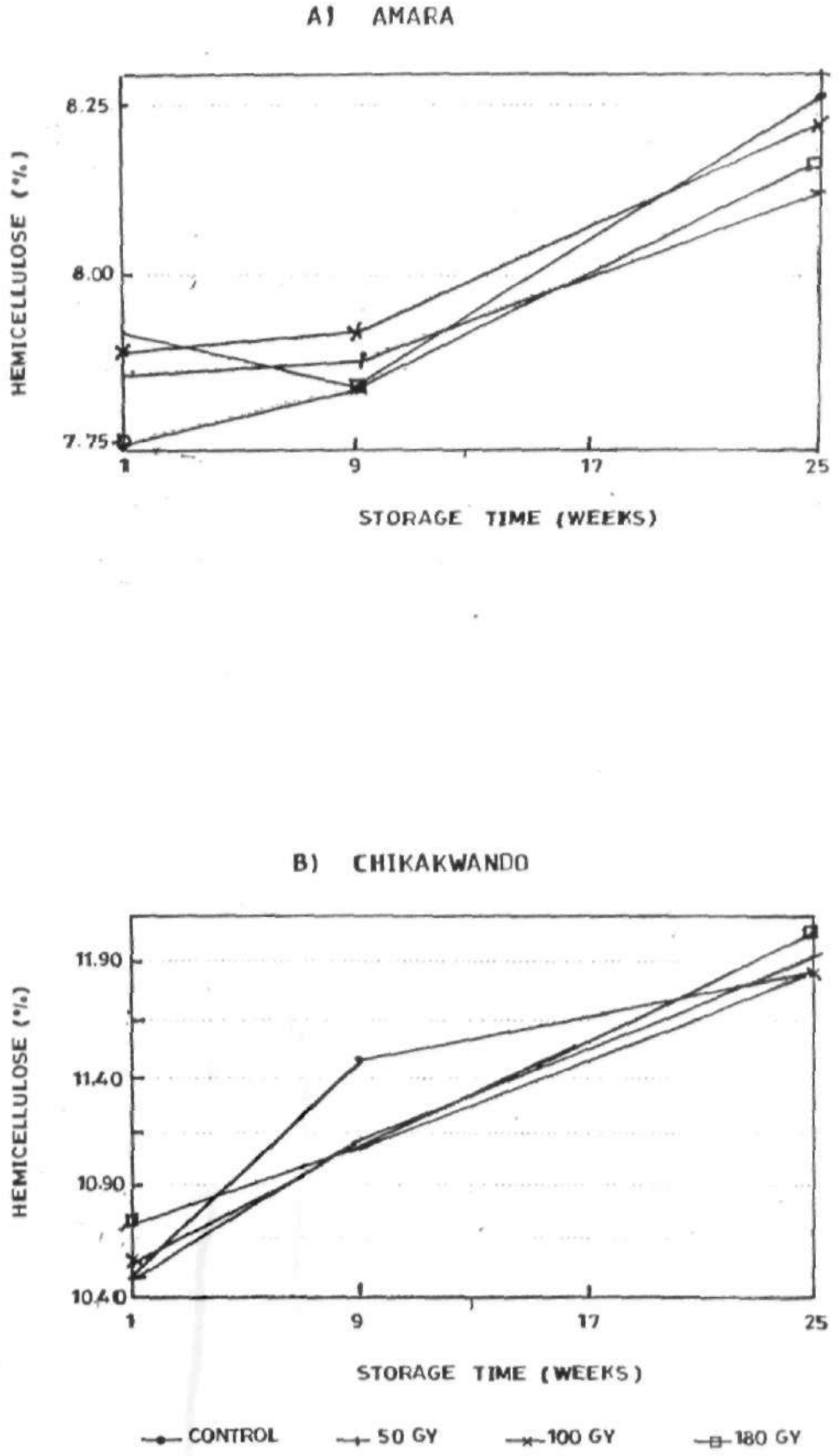


Fig. 4.16. Variation of the hemicellulose content of irradiated yam tuber during storage.

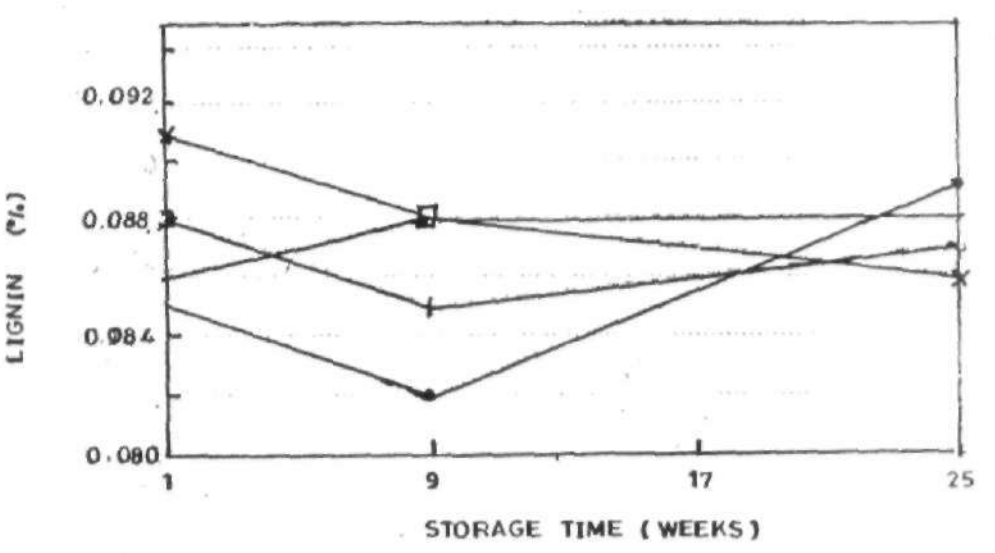


Fig. 4.17. Variation of the lignin content of irradiated yam tuber during storage.

storage. There was a significant variation ($P<0.05$) between the control and irradiated sample of both cultivars. The control soluble carbohydrate profile showed a distinct peak at the 9th week. In contrast, irradiated tubers showed a more or less curvilinear profile with no sharp peak.

Similarly, there was no significant change ($P>0.05$) in the cellulose and hemicellulose contents of irradiated sample as compared to the control, though there were slight variations. Also concentration of lignin in the tuber was not altered significantly by the different gamma irradiation doses.

These results are in agreement with the work of Ogbadu (1979a) on the carbohydrate content of soya-gari diet, and that of Cloutier et al. (1959) on the carbohydrate content of irradiated potatoes. These workers found that irradiation did not significantly affect ($P > 0.05$) the carbohydrate content.

Interpretation of results from dietary fibre analysis are usually an uphill task (Adamson, 1985). The lack of understanding of the complex nature of dietary fibre has been the complicating factor (Cumming, 1976). Dietary fibre are those plant constituents which are partially resistant to digestion by secretions of the human gastro-intestinal tract, it includes a heterogenous group of carbohydrate compounds (cellulose, hemicellulose, mucillage, pectin, and gum) and non-carbohydrate compounds, lignin, which is a polymer of phenylpropane units (Adamson, 1985). Functional group present

in the constituent polymers aggregate to confer on dietary fibre its physiological roles (Adamson, 1985). Cellulose which is an unbranched 1,4-ß-D glucose polymer has the ability to take up water, a property that is related to its ability to increase fecal weight. The presence of Uronic acids which behaves as carboxylic acids present in hemicelluloses contributes to the property of dietary fibre in binding ions and metals. Lignin which is the insoluble polymer of substituted phenylpropane unit has the property of adsorting organic material such as bile acids and therefore may enhance the rate at which this materials are excreted in faeces (Adamson, 1985).

CHAPTER FIVE

5.0 CONCLUSION AND SUGGESTIONS

5.1 Conclusion:

Gamma irradiation at doses of 50-180 Gy completely inhibited sprouting of yam tuber throughout the storage period of 40 weeks.

The resistance of yam tuber to rot disease seemed to be lowered by gamma irradiation. The optimum dose could not be effectively determined as the percentage rot recorded for all the treated sample were not significantly different ($P>0.05$) from each other. However, since the cost of irradiation depends on the dose required, a dose of 50 Gy (for inhibition of sprouting) is suggested for large scale application.

After 40 weeks of storage, irradiated yam tubers were found to have better morphological appearances with minimal weight loss. The chemical and nutritive qualities of the yam regarding the proximate composition, starch, reducing sugars, total free amino acid, carbohydrate profiles and dietary fibre were not adversely affected by irradiation at dose up to 180 Gy.

The use of gamma irradiation in yam preservation is still at the experimental stage. Investigation into the harmful effects due to the ingestion of irradiated yam tubers are beyond the scope of the present study. Provisional acceptance has not yet been given to irradiated yam tuber unlike what we have for similar but botanically

unrelated crops, potato, sweet potatoes and onions (FAO/IAEA/WHO, 1976). These could be attributed to the relatively low level of research on the effect of gamma irradiation on yam compared to works on temperate crops. However, the Joint FAO/IAEA/WHO Expert Committee on wholesomeness of Irradiated Food have concluded that irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard, hence toxicological testing of food so treated is no longer required (FAO/IAEA/WHO, 1980).

Inspite of the considerable research already carried out on the gamma irradiation of food and the encouraging results which have emerged, much remains to be accomplished before irradiation can take its place along with the conventional food preservation processes.

5.2 Suggestion for Further Studies:

1. The effect of pre-treatment of tubers with fungicides on rotting by gamma irradiation. Since losses in irradiated yam tubers were mainly due to rotting during storage, a prior treatment of the tubers with fungicides before irradiation may reduce the percentage loss due to rotting in irradiated tubers. Either the yam tuber field is sprayed before harvest or tubers are sprayed immediately after harvest. In this way, the loss due to sprouting and rotting in yam tubers may be reduced to insignificant level.

2. Foods, generally are irradiated in the raw state and then stored for a period of time before they are cooked and consumed. Cooking is known to result in loss of nutrients, depending on the method of cooking. The extent to which irradiation may contribute to these losses needs looking into. Thus nutritional evaluation of irradiated yam tuber should be carried out on the tubers as they are actually consumed (cooked, fried, pounded yam, etc.).
3. Toxicity studies should be carried out on irradiated yam. This should involve standard assay of toxicity risks, preferably using animals.
4. There is need to educate the public on the subject of radiation, in order to reassure them as to the safety of irradiation as a food preservation process.

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APPENDIX 1: CALCULATION OF IRRADIATION DOSE USED

SOURCE: CO^{60}-"GAMMA CELL" 220

LOCATION: BICOT (Biological Control Unit)
Veterinary Research Institute,
Vom, Jos.

DATE: Tuesday, 4 December, 1990

DATA

MONTH	DOSERATE	TIME (SEC)FOR 120GY (Center of Chamber)	TIME(MIN)FOR 0.5kgy (Top and bottom of Chamber)	TIME(MIN)FOR 1KGY(Top and bottom of Chamber)
Nov.	4.237	102.0	8.9	18
Dec.	4.191	103.1	8.9	18

DOSAGE REQUIRED

1. control = 120 GY 103.15

2. 50GY = 1 GY 103.1
120
50 GY 42.95 seconds.

3. 100 GY = 85.9 seconds

4. 180 GY = 154.62 seconds.

APPENDIX 2: AVERAGE WEEKLY RELATIVE HUMIDITY AND AIR TEMPERATURE OF THE YAM BARN DURING STORAGE

	STORAGE (WEEKS)/TIME	DATE	TEMPERATURE (^{O}C)	RELATIVE HUMIDITY (%)
*	1	11/12/90	32	53
	2	18/12/90	27	66
	3	25/12/90	-	-
	4	1/1/91	26	58
*	5	8/1/91	23	40
	6	15/1/91	23	40
	7	22/1/91	25	33
	8	29/1/91	30	25
*	9	5/2/91	32	30
	10	12/2/91	35	22
	11	19/2/91	32	28
	12	26/2/91	30	40
*	13	5/3/91	32	43
	14	12/3/91	33	54
	15	19/3/91	31	52
	16	26/3/91	34	30
*	17	2/4/91	30	70
	18	9/4/91	35	45
	19	16/4/91	30	66
	20	23/4/91	34	58
*	21	30/4/91	34	59
	22	7/5/91	32	65
	23	14/5/91	27	78
	24	21/5/91	27	72
*	25	28/5/9	25	78
	26	4/6/91	32	62
	27	10/6/91	28	70
	28	18/6/91	28	73
*	29	25/6/91	30	68
	30	2/7/91	25	68
	31	9/7/91	25	63
	32	16/7/91	29	73
*	33	23/7/91	25	63
	34	30/7/91	28	70
	35	6/8/91	29	63
	36	18/8/91	23	78
*	37	28/8/91	26	66
	38	27/8/91	28	62
	39	3/9/91	29	55
	40	10/9/91	32	55

*AGE (WEEKS)/DATE SAMPLES WERE COLLECTED FOR ANALYSES.
TEMPERATURE RANGE DURING STORAGE 22-35 ^{O}C
RELATIVE HUMIDITY (%) RANGE DURING STORAGE 22 %-78 %.

APPENDIX 3a: CUMMULATIVE PERCENTAGE SPROUTING OF IRRADIATED YAM TUBER (AMARA) STORED AT ROOM TEMPERATURE (22-35 ^{O}C) AND RH 22-78 %

STORAGE TIME	DOSE (GRAYS)			
IN WEEKS	CONTROL	50	100	180
1	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
17	20.83	0.00	0.00	0.00
18	54.17	0.00	0.00	0.00
19	79.17	0.00	0.00	0.00
20	83.33	0.00	0.00	0.00
21	100.00	0.00	0.00	0.00
25	100.00	0.00	0.00	0.00
29	100.00	0.00	0.00	0.00
33	100.00	0.00	0.00	0.00
37	100.00	0.00	0.00	0.00

APPENDIX 3b: CUMMULATIVE PERCENTAGE SPROUTING OF IRRADIATED YAM TUBER (CHIKAKWANDO) STORED AT ROOM TEMPERATURE (22-35 ^{O}C) AND RH 22-78 %

STORAGE TIME	DOSE (GRAYS)			
IN WEEKS	CONTROL	50	100	180
1	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
15	16.67	0.00	0.00	0.00
16	37.50	0.00	0.00	0.00
17	83.33	0.00	0.00	0.00
18	87.50	0.00	0.00	0.00
19	95.83	0.00	0.00	0.00
20	95.83	0.00	0.00	0.00
21	100.00	0.00	0.00	0.00
25	100.00	0.00	0.00	0.00
29	100.00	0.00	0.00	0.00
33	100.00	0.00	0.00	0.00
37	100.00	0.00	0.00	0.00

APPENDIX 4a: CUMMULATIVE PERCENTAGE ROT OF IRRADIATED YAM TUBER (AMARA) STORED AT ROOM TEMPERATURE (22-35 ^{O}C) AND RH 22-78 %

STORAGE TIME	DOSE (GRAYS)			
IN WEEKS	CONTROL	50	100	180
1	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	4.17
9	0.00b	8.33a	0.00b	8.33a
13	8.33a	16.67b	4.17c	16.67b
17	12.50a	37.50b	16.67a	33.30b
21	29.16a	41.67b	16.67c	33.30a
25	29.16a	41.67b	20.83c	33.30a
29	66.67a	50.00b	25.00c	41.67d
33	83.33a	50.00b	33.30c	54.17b
37	83.33a	54.17b	33.30c	70.83d

APPENDIX 4b: CUMMULATIVE PERCENTAGE ROT OF IRRADIATED YAM TUBER (CHIKAKWANDO) STORED AT ROOM TEMPERATURE (22-35 ^{O}C) AND RH 22-78 %

STORAGE TIME	DOSE (GRAYS)			
IN WEEKS	CONTROL	50	100	180
1	0.00	0.00	0.00	0.00
5	0.00a	4.17b	4.17b	8.33c
9	4.17a	4.17a	4.17a	8.33b
13	12.50a	4.17b	4.17b	8.33c
17	12.50a	12.50a	25.00b	16.67d
21	20.83a	25.00b	25.00b	25.00b
25	41.67a	25.00b	25.00b	25.00b
29	66.67a	33.30b	29.17b	33.30b
33	66.67a	41.60b	41.67b	41.67b
37	75.00a	41.60b	41.67b	54.17c

Values with the same alphabet did not differ significantly (P>0.05) from one another.

APPENDIX 5: TUBER WEIGHT LOST ("AMARA" CONTROL)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/A	287.48	286.05	277.82	275.13	260.77	245.40	200.35	154.47	122.89	164.59	57.25
A/0/02/A	259.80	259.28	253.54	251.45	242.97	224.22	194.45	163.67	146.63	113.17	43.56
A/0/03/A	228.95	228.31	223.08	221.60	212.91	194.80	169.75	142.70	131.70	97.23	42.47
A/0/04/A	175.11	173.92	168.39	167.00	159.45	143.83	117.27	91.91	69.74	105.37	6.17
A/0/05/A	222.70	221.80	215.32	215.30	204.11	191.36	165.22	135.52	115.68	107.02	48.06
A/0/07/A	249.84	248.90	242.10	239.40	232.51	223.72	202.72	179.76	164.47	85.37	34.70
A/0/08/A	155.88	154.38	148.41	147.22	142.11	132.71	105.50	91.90	83.95	71.93	46.14
A/0/09/A	188.80	188.23	183.29	181.03	168.88	160.46	139.27				
A/0/10/A	156.95	156.13	152.00	151.01	146.07						
A/0/11/A	232.35	230.83	220.47	217.89							
A/0/12/A	181.16	180.46	175.64	174.44	168.55	158.66	129.72	109.91	102.71	78.45	43.30
MEAN	212.18	211.22	204.84	202.89	192.63	183.45	155.35	129.82	113.91	104.80	48.11
±SD	±41.88	±41.85	±40.95	±40.47	±40.52	±38.27	±35.95	±32.96	±31.03	±27.60	±8.95

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/B	136.84	136.32	116.01								
A/0/02/B	108.40	107.24	103.72	102.53	96.60	91.31	75.23	51.50			
A/0/03/B	89.84	89.27	86.25	85.56	82.94	78.83	–	55.41	51.95	37.89	42.17
A/0/04/B	156.23	155.62	151.16	149.74	145.12	133.87	122.10	99.13	89.04	67.19	43.01
A/0/05/B	139.66	137.72	95.26	75.32	49.80	42.94	42.01	44.78			
A/0/06/B	121.74	121.34	117.58	116.20	110.68	103.57	89.27	74.81	67.63	54.11	44.45
A/0/07/B	120.82	119.58	111.13	110.19	104.93	97.86	73.70	–	68.06	52.76	43.65
A/0/08/B	148.44	147.40	141.52	140.07	113.94	118.94	99.97	73.04	66.07	82.37	55.49
A/0/09/B	150.13	148.98	140.24	137.57	127.11	110.59	92.50	64.88	57.66	92.47	61.59
A/0/10/B	132.92	132.36	128.34	126.87	121.87	112.37	99.99	77.08	68.48	64.44	48.48
A/0/11/B	85.22	84.63	81.13	80.17	76.43	72.71	62.20	55.47	50.18	35.04	41.11
A/0/12/B	137.68	136.73	129.66	128.38	125.06	120.20	110.01	102.03	85.99	51.69	37.54
MEAN	127.33	126.47	116.83	113.87	104.86	98.56	86.70	69.82	67.23	59.77	46.39%
±SD	±22.95	±22.80	±22.39	±25.47	±26.90	±26.0	±23.78	±19.39	±13.44	±19.02	±7.62

APPENDIX 6: TUBER WEIGHT LOSSES ("AMARA" IRRADIATED WITH 50 GY)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/A	113.77	113.50	108.72	107.32	103.69	101.17	99.08	97.61	93.70	20.07	17.64
A/0/02/A	152.11	151.28	143.19	141.26	124.94	120.83	117.46	114.19	109.84	42.27	27.79
A/0/03/A	91.26	90.88	86.25	84.92	81.92	79.86	78.15	76.73	74.17	17.09	18.73
A/0/04/A	143.61	142.83	132.61	129.74	123.46	119.58	116.35	113.43	108.87	34.74	24.19
A/0/05/A	160.07	159.26	147.12	143.72	136.10	130.86	126.08	121.77	113.94	46.13	28.82
A/0/06/A	146.11	145.71	139.95	138.36	134.79	132.32	129.43				
A/0/07/A	122.94	122.52	117.39	116.05	113.15	110.85	109.07	107.76	104.63	18.31	14.89
A/0/08/A	84.01	83.69	79.49	78.21	75.16	72.78	70.83	69.24	66.07	17.94	21.35
A/0/09/A	143.79	143.29	137.37	135.72	131.46	128.43	125.70	123.64	118.87	24.92	17.33
A/0/10/A	232.43	231.13	212.08	205.99	189.70	180.61	173.54	168.63	160.93	71.5	30.76
A/0/11/A	187.79	186.45	163.95	157.67	145.46	138.14	132.32	128.08	119.44	68.35	36.40
A/0/12/A	105.44	104.55	99.11	97.54	92.17						
MEAN	140.28	139.59	130.60	128.04	121.00	119.58	116.18	112.11	107.05	36.13	22.39
±SD	±41.70	±41.40	±36.36	±34.89	±31.17	±29.36	±27.86	±27.89	±26.25	±20.61	±5.73

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/B	128.02	127.14	118.24	-	110.61	107.08	104.09	101.73	98.46	29.56	23.09
A/0/02/B	171.74	170.57	160.61	158.21	152.65	148.53	144.90	141.72	136.81	35.23	20.51
A/0/03/B	176.32	175.66	167.93	166.14	161.08	158.16	155.72	153.05	148.81	27.51	15.60
A/0/04/B	107.93	107.68	104.17	103.12	100.68	98.85	97.32	95.63	85.67	22.26	20.62
A/0/05/B	172.46	171.03									
A/0/06/B	221.46	220.74	212.18	209.79	203.54	199.23	195.03	191.63			
A/0/07/B	166.42	165.85	156.50	154.33							
A/0/08/B	157.73	156.93	146.48	143.24	133.15	128.25	124.34	121.74	115.81	41.92	26.58
A/0/09/B	211.02	210.35	201.47	199.17	194.17	190.75	187.87	185.85	182.03	28.99	13.74
A/0/10/B	132.99	131.88	120.71	117.49	110.60	107.23	102.80	99.99	93.71	39.28	29.54
A/0/11/B	130.35	128.28	114.05	110.15	101.22	95.09	89.86	86.17	79.06	51.29	39.35
A/0/12/B	167.58	166.96	157.79	154.74	148.25	143.85	140.08	135.89			
MEAN	162.00	161.09	150.92	151.64	141.60	137.60	134.20	131.36	117.51	34.51	23.63
±SD	±33.49	±33.57	±35.09	±35.31	±37.18	±37.29	±37.28	±37.21	±35.71	±9.36	±8.21

APPENDIX 7: TUBER WEIGHT LOSSES ("AMARA" IRRADIATED WITH 100 GY)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/A	209.80	208.77	194.96	191.46	183.44	176.26	173.79	168.56	158.07	51.73	24.66
A/0/02/A	198.49	196.63	169.31	160.24	140.50	128.25					
A/0/03/A	243.47	242.29	222.51	216.53	203.81	195.74	189.18	184.37	174.18	69.29	28.46
A/0/04/A	117.42	117.01	105.80	102.76	97.06	93.46	90.45	80.02			
A/0/05/A	143.28	142.96	137.48	135.81	131.88						
A/0/06/A	230.77	229.58	213.22	209.09	200.38	194.74	190.16	187.05	181.59	49.18	21.31
A/0/07/A	166.89	166.47	160.00	157.78	152.49	148.87	145.71	143.18	137.32	29.57	17.72
A/0/08/A	177.71	176.46	160.01	155.69	146.27	140.07	134.92	131.42	125.05	52.66	29.63
A/0/09/A	170.47	169.80	160.91	158.24	149.64	144.98	141.03	138.11	130.20	40.27	23.62
A/0/10/A	181.10	180.25	166.86	163.00	152.81	147.09	142.59	139.61	133.94	47.16	26.04
A/0/11/A	174.27	173.36	151.27	143.03	125.22	114.83					
A/0/12/A	132.96	132.44	123.97	120.74	114.11	107.84	106.21				
MEAN	178.89	178.00	163.79	159.53	149.80	144.92	146.00	146.54	148.62	48.55	24.49
±SD	±37.66	±37.34	±34.04	±33.46	±32.62	±33.40	±34.31	±34.52	±22.61	±12.17	±3.24

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/B	213.78	211.77	156.79	142.42							
A/0/02/B	159.65	159.26	153.14	151.39	147.52	144.92	142.78	141.25	137.22	22.43	14.05
A/0/03/B	251.98	250.95	238.52	235.23	227.64	22.536	218.29	215.55	210.50	41.48	16.40
A/0/04/B	217.90	216.77	201.87	197.98	188.96	177.40	164.22				
A/0/05/B	242.40	241.87	232.69	230.19	224.40	220.53	217.33	215.07	210.85	31.55	13.02
A/0/06/B	231.85	230.78	215.40	210.73	200.02						
A/0/07/B	173.47	172.73	161.50	158.48	151.46	146.85	143.01	139.65	132.73	40.74	23.49
A/0/08/B	242.35	241.59	226.57	221.84	211.22	204.22	198.32	193.84	184.17	58.18	24.01
A/0/09/B	184.41	183.61	171.24	167.69	159.85	154.83	150.58	147.80	142.72	41.69	22.61
A/0/10/B	239.70	238.15	222.85	218.88	207.78	201.99	197.19	193.90	187.72	51.98	21.69
A/0/11/B	157.83	156.77	147.37	144.81	138.87	134.74	131.74	128.97	124.86	32.97	20.89
A/0/12/B	171.43	170.78	163.70	162.10							
MEAN	207.23	205.62	194.24	191.06	183.59	178.67	174.91	172.00	166.35	40.13	19.52
±SD	±35.59	±41.10	±39.26	±38.77	±37.51	±34.50	±36.31	±36.13	±35.78	±11.40	±4.37

APPENDIX 8: TUBER WEIGHT LOSSES ("AMARA" IRRADIATED WITH 180 GY)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/A	107.04	106.53	99.09	97.16	90.95	87.30	84.33	82.06	77.78	29.22	27.31
A/0/02/A	154.61	153.89	137.71	133.78	124.53	118.48	113.62	109.66	102.93	51.68	33.43
A/0/03/A	131.72	129.95	113.37	110.01	102.62	97.77	93.90	90.73	85.21	46.51	35.31
A/0/04/A	163.23	162.75	153.68	151.19	140.47	134.85	130.32				
A/0/05/A	141.89	140.81	122.94	118.40	107.93						
A/0/06/A	170.90	172.21	153.22	147.99	136.66	129.62	123.86	119.75	112.45	58.45	34.20
A/0/07/A	211.22	210.74	203.19	201.06	195.49	191.98	189.07	186.93	183.27	27.95	13.23
A/0/08/A	170.23	169.88	163.53	161.66	156.64	153.05	149.84	146.53			
A/0/09/A	148.89	148.20	134.52	129.88	118.95	112.49	106.64	101.06			
A/0/10/A	144.58	144.20	134.52	131.56	124.84	120.64	117.40	114.62	108.64	35.94	24.86
A/0/11/A	182.06	181.47	174.65	172.43	166.81	162.82	159.31	156.35	148.17	33.89	18.61
A/0/12/A	158.86	157.85	147.64	145.00	138.00	133.42	129.39	126.29	120.11	38.75	24.39
MEAN	157.35	157.11	145.42	142.37	134.99	130.25	126.36	123.30	117.32	40.30	26.42
±SD	±26.39	±32.01	±32.97	±32.10	±33.56	±33.83	±34.01	±34.20	±34.25	±10.92	±7.85

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
A/0/01/B	191.01	190.06	176.28	172.48	163.06	156.93	152.13	148.56	136.23	54.78	28.68
A/0/02/B	178.45	176.58	153.18	146.95	132.08	122.92	115.45	110.34	101.40	77.05	43.18
A/0/03/B	264.71	262.93	221.87	206.94							
A/0/04/B	195.33	194.84	188.13	186.41							
A/0/05/B	176.36	174.65	153.03	147.30	132.41	122.69	114.36	107.60			
A/0/06/B	151.41	150.67	141.82	139.65	134.23	130.58	127.62	125.12	119.65	31.76	20.98
A/0/07/B	190.24	189.53	176.67	172.72	163.42	157.43	152.27	147.67	137.70	52.54	27.62
A/0/08/B	117.91	117.16	101.38	97.04	87.92	82.37	78.20	74.77	68.57	49.34	41.85
A/0/09/B	174.51	173.67	157.38	152.20	139.35	131.32					
A/0/10/B	154.88	154.03	143.53	140.44	132.83	127.88	123.83	120.41	113.88	41.00	26.47
A/0/11/B	120.65	120.28	114.92	113.24	109.09	106.68	104.81	103.16	100.75	19.9	16.49
A/0/12/B	117.80	117.02	97.99	91.91							
MEAN	157.79	156.90	144.03	140.36	131.80	126.40	122.04	118.58	111.17	46.62	29.32
±SD	±30.56	±38.32	±28.46	±28.09	±27.16	±26.63	±26.19	±25.87	±23.91	±18.26	±9.96

APPENDIX 9: TUBER WEIGHT LOSSES ("CHIKAKWANDO" CONTROL)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/0/01/A	626.68	624.64	613.09	609.56	585.90	571.20					
C/0/02/A	574.10	571.92	560.90	558.25	546.95	532.78	502.17	381.37	350.12	223.98	39.01
C/0/03/A	566.89	569.59	552.60	550.50	535.30	519.33	462.81	338.54			
C/0/04/A	552.40	550.78	541.05	536.60	509.15	496.93	413.17	320.88	225.85	326.55	59.11
C/0/05/A	443.10	442.50	443.72	429.10	409.05	362.03	311.11	252.68	240.14	202.96	45.80
C/0/06/A	547.59	544.78	534.42	531.40	504.20	489.66	439.62	327.65	262.62	284.97	52.04
C/0/07/A	407.69	407.00	397.28	396.40	386.60	370.96	300.19	251.09	211.51	196.18	48.12
C/0/08/A	524.70	524.00	516.70	514.50	503.50		419.62	305.56	256.28	262.48	51.16
C/0/09/A	432.70	431.28	422.10	418.60	398.55	365.63	317.92	242.08	200.24	232.46	53.72
C/0/10/A	515.40	513.75	503.12	497.30	450.25			245.98	223.86	291.54	56.57
C/0/11/A	500.82	496.82	489.20	487.00	480.38						
C/0/12/A	456.25	454.18	445.15	443.18	430.50	408.45	359.36	246.83			
MEAN	499.71	498.25	488.66	480.59	463.53	436.33	486.26	290.91	246.33	252.64	50.69
±SD	±62.83	±62.31	±61.93	±59.33	±60.45	±72.24	±77.29	±50.84	±46.96	±46.29	±6.37

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/0/01/B	569.30	546.10	536.50	533.90	511.95	462.10	412.19	314.59	273.67	295.63	51.93
C/0/02/B	439.08	438.08	429.10	425.20	403.80	372.34		236.17	204.07	235.01	53.52
C/0/03/B	447.65	445.32	433.78	428.64	401.80	372.41		250.65	221.38	226.27	50.55
C/0/04/B	528.89	527.35	516.22	510.80	490.35	442.20		320.97			
C/0/05/B	496.10	494.00	484.15	481.60	468.60	402.79		323.16			
C/0/06/B	496.59	495.65	481.98	474.50	417.62	357.25		225.80	207.46	289.13	58.22
C/0/07/B	545.97	545.00	537.75	535.85	521.85	455.93		342.75			
C/0/08/B	603.90	602.19	589.30	583.15	538.45	322.34		299.89	263.70	340.20	56.33
C/0/09/B	494.32	494.29									
C/0/10/B	547.90	567.15	555.28	552.10	529.45	484.93		317.46			
C/0/11/B	437.10	434.80	424.00	418.97							
C/0/12/B	461.79	460.32	449.75	444.20	414.68	372.66		230.64	195.25	266.54	57.72
MEAN	503.05	497.94	486.28	481.17	447.33	376.17		287.01	227.59	275.46	54.71
±SD	±68.51	±64.75	±64.13	±63.99	±60.69	±46.31		±44.39	±33.08	±42.24	±3.18

APPENDIX 10: TUBER WEIGHT LOSSES ("CHIKAKWANDO" IRRADIATED WITH 50 GY)

GROUP A

SAMPLE STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/I/01/A	400.27	399.95	389.61	386.38	378.37	372.77	368.43	365.69	360.43	39.84	9.95
C/I/02/A	197.10	196.69	190.07	188.15	182.09	178.60	175.71	173.65	169.68	27.42	13.91
C/I/03/A	194.92	194.57	187.98	186.06	181.36						
C/I/04/A	400.76	399.04	381.81	378.80	367.10	359.01	352.01	347.86	321.23	79.53	19.84
C/I/05/A	293.79	292.99	283.10	280.48	269.93	265.18	260.96	258.25	252.93	40.86	13.91
C/I/06/A	266.50	265.64	256.75	254.34	248.09	243.94	240.52	238.48	234.47	32.03	12.02
C/I/07/A	223.97	223.38	217.97	216.40	212.36	209.23	206.79	205.23	201.67	22.3	9.96
C/I/08/A	211.18	210.61	203.29	201.04	195.15	191.21	187.91				
C/I/09/A	389.27	338.04	324.56	321.30	313.11	307.58	302.90	300.01	290.84	48.43	14.27
C/I/10/A	252.43	251.48	242.33	239.59	232.43	227.66	223.70	221.37	216.44	35.99	14.26
C/I/11/A	371.33	370.42	360.58	357.85	351.28	346.97	343.35	340.95	336.40	34.93	9.41
C/I/12/A	217.92	217.12	204.80	201.32	192.87	187.33	182.79	180.24	175.23	42.69	19.59
MEAN	295.8	295.0	284.6	282.0	274.4	269.3	265.1	262.7	255.4	40.40	13.71
±SD	±75.11	±76.75	±74.60	±74.21	±73.34	±72.37	±71.89	±71.12	±68.19	±15.69	±3.69

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/I/01/B	337.54	337.16	328.51	325.87	319.00	314.05	310.07	307.83	303.33	34.21	10.14
C/I/02/B	226.28	225.90	219.89	218.38							
C/I/03/B	256.12	255.59	248.01	245.71	239.35	234.96	231.28	229.26	225.12	31.08	12.13
C/I/04/B	284.04	283.82	278.78	277.26	273.42	270.19	267.36	265.55	262.06	21.98	7.73
C/I/05/B	236.61	236.43	231.74	230.20	226.23	223.24	220.87	219.52	261.89	19.72	8.33
C/I/06/B	259.18	258.79	253.67	252.10	247.99	244.94	242.45	240.95	237.85	21.33	8.23
C/I/07/B	241.68	240.66	231.41	228.19	221.82	217.14	212.54	207.79			
C/I/08/B	278.71	278.04	271.40	269.44	262.96	260.14	256.86	254.88	250.57	28.14	10.10
C/I/09/B	373.00	372.02	359.33	355.64	346.47	340.06	334.56	331.30	324.48	48.52	13.01
C/I/10/B	381.82	381.29	372.24	369.41	362.25	356.97	352.71	350.21	344.89	36.93	9.67
C/I/11/B	260.61	259.75	248.16	244.69	235.60	228.73	223.23	220.13	213.36	47.25	18.13
C/I/12/B	282.71	282.17	275.90	273.94	268.64	265.05	262.04	259.57	255.05	27.66	9.78
MEAN	295.03	294.1	286.3	283.9	277.7	273.50	269.7	267.56	262.9	31.68	10.73
±SD	±40.91	±51.02	±49.33	±48.76	±48.05	±47.28	±46.79	±41.61	±45.88	±10.18	±3.09

APPENDIX 11: TUBER WEIGHT LOSSES ("CHIKAKWANDO" IRRADIATED WITH 100 GY)

GROUP A

SAMPLE STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/II/01/A	314.03	313.64	306.93	314.72	299.07	294.86	291.64	289.59	285.41	29.38	9.23
C/II/02/A	427.55	427.17	416.83	413.41	404.66	398.78	393.96	390.66	384.69	42.31	9.91
C/II/03/A	328.24	326.75	309.74	305.41	294.60	287.51	281.65	278.58	256.22	72.02	21.94
C/II/04/A	265.04	264.69	258.00	255.90	250.50	245.97	242.33	240.24	236.16	28.88	10.90
C/II/05/A	352.41	351.85	343.29	340.62	333.58	328.51	324.32	321.88	320.44	31.97	9.07
C/II/06/A	191.96	191.55	186.00	184.34	179.99						
C/II/07/A	271.03	270.81	266.21	264.88	259.63	256.48	253.79	251.51	247.85	23.18	8.55
C/II/08/A	172.09	171.48	162.00	159.15	151.76	146.88	143.10	140.05	132.29	39.8	23.13
C/II/09/A	263.79	262.28	248.74	245.60	236.62	231.12	226.55				
C/II/10/A	310.64	308.39									
C/II/11/A	155.33	154.71	149.37	146.72	142.31	139.32	136.80	134.20	130.04	25.29	16.28
C/II/12/A	241.55	240.41	229.70	226.90	219.26	214.18	209.87	205.44	198.29	43.26	17.91
MEAN	280.55	279.55	270.89	260.00	258.70	256.33	252.52	249.78	243.23	37.34	14.10
±SD	±86.14	±86.29	±84.85	±79.99	±79.50	±83.24	±76.75	±82.63	±83.03	±14.91	±5.81

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/II/01/B	375.16	374.60	361.18	358.03	348.92	343.14	338.27	335.28	329.21	45.95	12.25
C/II/02/B	285.46	284.97	277.98	275.73	269.95	266.01	262.64	260.57	256.06	29.4	10.30
C/II/03/B	369.74	369.34	361.67	359.15	352.77	347.18	342.68	339.85	334.62	35.12	9.50
C/II/04/B	334.90	334.53	327.32	325.48	319.48	314.79	311.40	308.84	304.33	30.57	9.13
C/II/05/B	433.00	432.65	421.01	417.31	408.48	902.35	397.59	395.08	390.03	42.97	9.92
C/II/06/B	275.18	274.20	263.86	260.92	252.95	247.66	243.21	240.85	235.07	40.11	14.58
C/II/07/B	324.69	323.10	293.21	286.21	268.86	257.71	248.44	243.06	233.36	91.33	28.13
C/II/08/B	325.80	325.21	316.25	313.37	305.96	301.10	297.04	294.70	289.48	36.32	11.15
C/II/09/B	255.92	255.30	248.60	246.71	241.75	238.34	235.34	233.43			
C/II/10/B	234.42	233.79	226.73	224.92							
C/II/11/B	375.68	374.61	359.30	354.83	343.81	336.68	330.84	327.42	320.55	55.13	14.67
C/II/12/B	336.60	335.68	325.52	322.87	314.96	310.27	306.21	303.74	298.79	37.81	11.23
MEAN	343.10	340.30	330.30	326.90	317.80	312.31	307.40	304.40	298.80	44.47	13.09
±SD	±46.70	±44.51	±47.07	±47.04	±47.40	±47.57	±47.76	±48.15	±48.62	±18.11	±5.63

APPENDIX 12: TUBER WEIGHT LOSSES ("CHIKAKWANDO" IRRADIATED WITH 180 GY)

GROUP A

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/III/01/A	149.33	148.99	135.73	132.56	124.93						
C/III/02/A	401.86	400.72	381.89	377.26	366.21	358.89	352.88	346.88	339.89	61.97	15.42
C/III/03/A	299.22	298.33	284.99	281.69							
C/III/04/A	255.05	253.91	232.06	227.09	215.10	207.52	201.74	198.03			
C/III/05/A	427.11	425.80	407.29	402.67	391.07	373.04	376.58	358.20	336.13	90.98	21.30
C/III/06/A	364.20	363.48	352.20	348.07	337.65	330.97	325.55	322.26	314.68	49.52	13.60
C/III/07/A	214.63	214.37	209.55	208.03	204.10	201.14	198.62				
C/III/08/A	354.20	353.76	341.77	338.00	328.46	321.84	316.49	313.31	306.86	47.34	13.37
C/III/09/A	284.02	283.02	266.13	262.32	253.28	247.32	242.56	239.62	233.86	50.16	17.66
C/III/10/A	397.20	396.29	380.77	376.20	364.30	355.91	349.22	345.14	336.84	60.36	15.20
C/III/11/A	433.06	432.11	417.35	413.27	402.78	395.70	389.44	386.26	336.84	96.22	22.22
C/III/12/A	268.56	267.37	252.63	248.37	237.63	230.58	224.68	221.36	214.73	53.83	20.04
MEAN	366.00	364.88	349.5	345.5	334.75	327.38	321.63	316.25	301.75	63.80	17.35
±SD	±61.95	±61.82	±61.34	±61.19	±60.72	±60.19	±59.86	±57.82	±50.00	±19.14	±3.48

GROUP B

SAMPLE/ STORAGE TIME IN WKS	WEIGHT OF TUBERS IN GRAMMES 1	5	9	13	17	21	25	29	33	LOSS IN WEIGHT	% LOSS IN WT.
C/III/01/B	368.32	367.75	351.49	347.18	336.33	328.82	322.72	318.68	309.98	58.34	15.84
C/III/02/B	179.57	178.94	170.43	167.95	161.66	157.24	153.54	151.20	145.21	34.36	19.13
C/III/03/B	256.40	256.13	250.08	248.07	242.93	239.39	236.40	234.48	230.45	25.95	10.12
A/III/04/B	289.83	289.56	284.34	282.54	277.95	274.20	271.32	269.03	257.27	32.56	11.23
C/III/05/B	216.51	215.31	200.10	196.55	187.58	181.47	176.52	172.94	165.75	50.76	23.44
C/III/06/B	258.40	257.99	247.33	244.41	237.11	232.10	228.13	225.33	212.14	46.21	17.83
C/III/07/B	310.51	309.84	300.25	297.47	290.11	284.61	280.20	277.48	271.83	38.68	12.46
C/III/08/B	237.05	236.63	228.88	226.59	221.25	217.40	214.25	212.43	208.66	28.39	11.98
C/III/09/B	320.56	319.92	306.93	303.50	295.20	289.26	284.41	281.35	275.42	45.14	14.08
C/III/10/B	452.70	452.30	436.90	431.80	420.81	413.03	406.69	402.47	394.30	58.40	12.90
C/III/11/B	289.13	288.40	279.39	276.72	269.78	264.76	260.97	258.47	253.37	35.76	12.37
C/III/12/B	363.26	362.98	354.56	351.92	345.25	340.13	335.83	333.24	328.09	35.17	9.68
MEAN	298.75	294.00	283.75	280.67	273.33	267.17	263.81	261.00	253.92	40.81	14.26
±SD	±74.76	±74.90	±73.22	±72.75	±71.65	±70.83	±70.08	±69.73	±69.48	±10.91	±4.09

APPENDIX 13: TUBER WEIGHT LOSSES (AVERAGE)

A: AMARA

SAMPLE/STORAGE TIME OF TUBERS IN WEEKS	WEIGHT OF TUBERS IN GRAMMES									LOSS IN WEIGHT	% LOSS IN WT.
	1	5	9	13	17	21	25	29	33		
(CONTROL) 0GY	169.76 ±60.00	168.85 ±59.93	160.84 ±62.23	158.38 ±62.95	148.75 ±62.06	141.01 ±60.03	121.03 ±48.54	99.82 ±42.43	90.57 ±33.01	82.29 ±31.84	47.25 ±1.22
50GY	151.14 ±15.36	150.34 ±15.20	140.76 ±14.37	139.84 ±16.69	131.3 ±14.57	128.59 ±12.74	125.19 ±13.64	121.74 ±11.06	112.28 ±7.40	35.32 ±1.15	23.01 ±0.88
100GY	193.06 ±20.04	191.81 ±19.53	179.02 ±21.53	175.30 ±22.30	166.70 ±23.89	161.80 ±23.86	160.46 ±20.44	159.27 ±18.00	157.49 ±12.54	44.34 ±5.95	22.01 ±3.51
180GY	157.57 ±0.31	157.01 ±0.15	144.73 ±0.98	141.37 ±1.42	133.40 ±2.26	128.33 ±2.72	124.2 ±3.05	120.94 ±3.34	114.25 ±4.35	43.46 ±4.47	27.87 ±2.05

Results are expressed as mean ± SD of 12 tubers each.

B: CHIKAKWANDO

SAMPLE/STORAGE TIME OF TUBERS IN WEEKS	WEIGHT OF TUBERS IN GRAMMES									LOSS IN WEIGHT	% LOSS IN WT
	1	5	9	13	17	21	25	29	33		
(CONTROL) 0GY	501.38 ±2.36	498.10 ±0.21	487.47 ±1.68	480.88 ±0.41	455.43 ±11.46	406.25 ±42.54	386.26 ±27.29	288.96 ±2.76	236.96 ±13.25	264.05 ±16.14	52.70 ±2.84
50GY	295.55 ±0.92	294.55 ±0.64	285.45 ±1.20	282.95 ±1.34	276.05 ±2.33	271.4 ±2.97	267.4 ±3.25	265.13 ±3.44	259.15 ±5.30	36.04 ±6.17	12.22 ±2.11
100GY	311.83 ±44.23	309.93 ±42.96	300.60 ±42.01	293.45 ±47.31	288.25 ±41.79	284.32 ±39.58	279.96 ±38.81	277.09 ±38.62	271.02 ±39.29	40.91 ±5.04	13.60 ±0.71
180GY	330.38 ±50.38	329.44 ±50.12	316.63 ±46.49	313.09 ±45.84	304.04 ±43.43	297.78 ±41.87	292.72 ±40.88	208.63 ±39.07	277.84 ±33.82	52.31 ±16.26	15.81 ±2.18

Results are expressed as mean ± SD of 12 tubers each.

APPENDIX 14: MOISTURE (%)

DOSE (GRAYS)/ STORAGE TIME IN WEEKS	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	63.74 ±0.27	62.18 ±0.08	62.03 ±0.06	61.72 ±0.28	57.68* ±0.28	56.51* ±0.66	53.09* ±0.17	51.00* ±0.06	50.55* ±0.01
50	63.76 ±0.08	62.34 ±0.86	62.06 ±0.20	63.95* ±2.38	62.48 ±0.37	63.89 ±0.21	63.04** ±0.04	60.11 ±0.04	60.37 ±0.44
100	63.63 ±0.28	61.37 ±0.53	62.05 ±0.04	61.69 ±0.42	61.90 ±0.19	63.37 ±0.87	62.56 ±0.11	59.99 ±0.09	57.73** ±0.01
150	63.19 ±0.30	62.27 ±0.04	61.31 ±0.86	59.42 ±1.12	61.90 ±0.15	62.37 ±0.81	62.23 ±0.47	60.41** ±0.05	61.47** ±0.13

Results are expressed as mean ± SD

DOSE (GRAYS)/ STORAGE TIME IN WEEKS	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	75.65 ±0.40	74.28 ±0.26	73.90 ±0.20	73.24 ±0.43	67.28* ±0.11	62.25* ±0.11	56.01* ±0.11	53.81* ±0.24	52.16* ±0.24
50	75.24 ±1.39	73.60 ±0.91	73.89 ±0.04	68.09 ±2.38	69.50 ±0.34	68.11** ±1.22	69.02 ±0.13	66.85 ±0.01	65.55 ±0.13
100	75.31 ±0.03	74.15 ±0.25	74.11 ±0.12	70.82 ±0.60	69.06 ±0.09	67.16 ±3.01	68.61 ±0.40	67.31 ±0.52	66.21 ±0.32
150	74.73 ±2.07	74.53 ±0.13	74.06 ±0.10	72.58 ±0.72	69.13 ±0.10	67.19 ±1.35	67.98 ±0.19	67.10 ±0.16	66.19 ±0.11

Results are expressed as mean ± SD

No superscript = No significant difference ($P>0.05$)

* = Differs significantly ($P<0.05$)

** = Differs significantly ($P<0.05$).

APPENDIX 15: ASH CONTENT (g/100g dry weight)

DOSE (GRAYS)/ STORAGE TIME IN WEEKS	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	2.75 ±0.00	2.88 ±0.03	2.91 ±0.01	3.01 ±0.00	4.00 ±0.01	4.70* ±0.01	4.78** ±0.22	3.99** ±0.16	3.10 ±0.02
50	2.76 ±0.01	2.88 ±0.01	2.91 ±0.04	3.00 ±0.00	3.84 ±0.23	4.18 ±0.25	4.01 ±0.01	3.42 ±0.06	3.08 ±0.04
100	2.79 ±0.03	2.90 ±0.01	2.89 ±0.01	3.33 ±0.47	4.17 ±0.23	4.52 ±0.03	4.12 ±0.07	3.44 ±0.25	3.35** ±0.04
180	2.77 ±0.01	2.95 ±0.08	2.92 ±0.04	3.17 ±0.23	4.10 ±0.13	4.48 ±0.03	3.95 ±0.38	3.58 ±0.22	3.34** ±0.06

Results are expressed as mean ± SD

DOSE (GRAYS)/ STORAGE TIME IN WEEKS	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	2.22 ±0.01	2.34 ±0.02	2.70 ±0.04	3.17 ±0.23	3.33 ±0.00	2.41* ±0.13	2.74* ±0.21	2.76* ±0.08	2.88* ±0.09
50	2.20 ±0.00	2.31 ±0.04	2.71 ±0.01	3.20 ±0.01	3.45 ±0.07	3.11* ±0.15	3.74 ±0.06	3.74 ±0.15	3.52 ±0.08
100	2.22 ±0.04	2.35 ±0.03	2.70 ±0.01	3.20 ±0.09	3.43 ±0.06	3.35 ±0.49	3.92 ±0.08	3.36 ±0.16	3.35 ±0.04
180	2.18 ±0.02	2.35 ±0.04	2.72 ±0.01	3.72 ±0.01	3.43 ±0.03	3.35 ±0.21	3.80 ±0.04	3.33 ±0.26	4.0* ±0.11

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 16: PROTEIN CONTENT (g/100g dry weight)

DOSE (GRAYS)/ STORAGE TIME IN WEEKS	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	1.14 ±0.01	1.92 ±0.06	2.68 ±0.04	5.79** ±0.05	4.20** ±0.11	3.10 ±0.04	4.07** ±0.01	4.02** ±0.02	4.08** ±0.17
50	1.09 ±0.05	1.85 ±0.035	2.76 ±0.09	2.92 ±0.08	3.06 ±0.1	3.19 ±0.05	3.05 ±0.08	2.95 ±0.01	3.42 ±0.08
100	1.15 ±0.10	1.87 ±0.01	2.68 ±0.13	2.50* ±0.06	3.14 ±0.06	3.15 ±0.04	3.19 ±0.11	3.075 ±0.12	3.47 ±0.36
180	1.13 ±0.01	1.86 ±0.09	2.69 ±0.04	2.74 ±0.11	3.24 ±0.18	3.34 ±0.17	3.25 ±0.23	2.91 ±0.31	3.41 ±0.01

Results are expressed as mean ± SD

DOSE (GRAYS)/ STORAGE TIME (WEEKS)	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	0.91 ±0.05	1.67 ±0.04	3.26 ±0.01	5.02 ±0.03	5.45** ±0.33	3.72 ±0.20	2.78* ±0.09	2.98 ±0.02	3.00** ±0.05
50	0.88 ±0.02	1.65 ±0.13	3.41 ±0.06	4.89 ±0.05	4.83 ±0.04	4.08 ±0.18	3.22 ±0.06	3.09 ±0.11	2.62 ±0.06
100	0.88 ±0.03	1.68 ±0.03	3.32 ±0.13	5.00 ±0.14	4.63 ±0.18	3.83 ±0.04	3.27 ±0.08	3.00 ±0.09	2.79 ±0.10
150	0.91 ±0.02	1.72 ±0.04	3.26 ±0.13	5.09 ±0.19	4.95 ±0.21	3.99 ±0.05	3.30 ±0.17	3.01 ±0.18	2.92* ±0.06

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 17: TOTAL FREE AMINO ACID CONTENT (g/100g fresh weight)

STORAGE TIME	AMARA								
(DOSE/GRAYS)	1	5	9	13	17	21	25	29	33
0 (Control)	0.3261** ±0.0020	0.2983* ±0.0006	0.2421 ±0.0001	0.1996** ±0.0001	0.1476 ±0.0050	0.2648** ±0.0021	0.3293** ±0.0006	0.3457** 0.0007	0.3545** ±0.0050
50	0.3198* ±0.0003	0.2869 ±0.0001	0.2511** ±0.0020	0.1893 ±0.0006	0.1506* ±0.0006	0.1529 ±0.0004	0.1489 ±0.0004	0.1534* ±0.0003	0.1564 ±0.0080
100	0.3271** ±0.0009	0.2987* ±0.0007	0.2457* ±0.0010	0.1982** ±0.0006	0.1497* ±0.0010	0.1494 ±0.0008	0.1509 ±0.0008	0.1524* ±0.0005	0.1522 ±0.0025
180	0.2971 ±0.0020	0.3015** ±0.0004	0.2431 ±0.0001	0.1894 ±0.0007	0.1524** ±0.0004	0.1542* ±0.0006	0.1546 ±0.0070	0.1503 ±0.0007	0.1527 ±0.0048

Results are expressed as mean ± SD

DOSE (GRAYS)/ STORAGE TIME (WEEKS)	CHIKAKWANDO								
	1	5	9	13	17	21	25	29	33
0 (Control)	0.2636* ±.0003	0.2471* ±.0003	0.1540** ±.0006	0.0993 ±.0005	0.3147** ±.0002	0.3933** ±.0038	0.3836** ±.0008	0.4156** ±.0006	0.4212* ±0.0020
50	0.1519* ±.0004	0.1471 ±.0007	0.1469 ±.0004	0.0997 ±.0033	0.1358* ±.0020	0.1687* ±0.0023	0.1566* ±0.0009	0.2212 ±.0006	0.2245 ±0.0064
100	0.1490 ±.0004	0.1500* ±.0003	0.1469* ±.0004	0.1220 ±.0060	0.1419* ±0.0030	0.1526* ±.0005	0.1423* ±.0005	0.2185 ±.0017	0.2235 ±0.0110
180	0.1494 ±.0001	0.1486 ±.0006	0.1489 ±0.0001	0.1191 ±.0040	0.1260 ±.0014	0.1423 ±.0002	0.1670 ±.0010	0.2207 ±.0008	0.2184 ±0.0095

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 18: LIPIDS CONTENT (g/100g dry weight)

STORAGE TIME (WEEKS) (DOSE/GRAYS)	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	0.312 ±0.020	0.292 ±0.010	0.275 ±0.010	0.233 ±0.020	0.295 ±0.007	0.264** ±0.006	0.304** ±0.011	0.324 ±0.006	0.332** ±0.008
50	0.296 ±0.010	0.301 ±0.030	0.267 ±0.010	0.226 ±0.010	0.218 ±0.011	0.212 ±0.012	0.219 ±0.030	0.237 ±0.014	0.241 ±0.002
100	0.311 ±0.050	0.299 ±0.03	0.261 ±0.002	0.291 ±0.003	0.209 ±0.013	0.206 ±0.008	0.219 ±0.002	0.238 ±0.002	0.239 ±0.005
180	0.318 ±0.070	0.286 ±0.020	0.271 ±0.010	0.235 ±0.006	0.203 ±0.001	0.201 ±0.002	0.217 ±0.016	0.238 ±0.006	0.245 ±0.024

Results are expressed as mean ± SD

DOSE (GRAYS) STORAGE TIME (WEEKS)	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	0.242 ±0.014	0.180 ±0.014	0.150 ±0.001	0.138 ±0.003	0.162** ±0.002	0.175** ±0.004	0.206** ±0.006	0.223** ±0.006	0.272** ±0.006
50	0.131 ±0.015	0.176 ±0.006	0.156 ±0.005	0.144 ±0.004	0.151 ±0.003	0.164 ±0.002	0.149 ±0.004	0.164 ±0.006	0.170 ±0.004
100	0.225 ±0.021	0.145 ±0.021	0.150 ±0.001	0.138 ±0.008	0.150 ±0.004	0.158 ±0.002	0.157 ±0.005	0.158 ±0.008	0.161 ±0.002
180	0.235 ±0.021	0.158 ±0.015	0.159 ±0.005	0.135 ±.004	0.148 ±0.006	0.160 ±0.001	0.147 ±0.001	0.158 ±0.004	0.161 ±0.004

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 19: NITROGEN FREE EXTRACTIVE CONTENT (g/100g dry weight)

STORAGE TIME (WEEKS) (DOSE/GRAYS)	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	30.49 ±0.04	31.07 ±0.12	30.48 ±0.25	26.99 ±0.55	31.71** ±0.61	33.17** ±0.47	36.13** ±0.31	39.37** ±0.21	40.90** ±0.21
50	28.75 ±0.08	30.76 ±0.98	30.32 ±0.22	24.90 ±2.16	25.72 ±0.66	24.23 ±0.37	27.98 ±0.04	31.63 ±0.09	31.39 ±0.59
100	28.16 ±1.99	32.10 ±0.47	30.16 ±0.20	26.68 ±0.37	26.12 ±0.47	25.04 ±1.00	27.89 ±0.23	31.59 ±0.15	33.77* ±0.24
180	29.68 ±2.49	31.09 ±0.15	31.23 ±0.88	29.18* ±1.05	26.50 ±0.03	26.13 ±1.14	28.56* ±0.19	30.09 ±0.98	30.09 ±0.22

Results are expressed as mean ± SD

DOSE (GRAYS) STORAGE TIME (WEEKS)	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	20.39 ±0.45	20.86 ±0.20	19.33 ±0.11	16.55 ±2.07	24.54* ±0.27	31.32* ±0.05	37.29** ±0.18	39.16** ±0.26	40.22** ±0.40
50	20.85 ±1.36	21.61 ±0.73	19.13 ±0.06	22.75* ±2.36	21.17 ±0.29	23.62 ±1.22	22.92 ±0.02	25.27 ±0.05	27.15 ±0.31
100	20.78 ±0.06	21.05 ±0.40	19.49 ±0.73	20.05 ±0.69	21.56 ±0.57	24.64 ±3.51	23.18 ±0.30	25.07 ±0.77	26.16 ±0.47
180	21.35 ±2.03	20.51 ±0.04	19.10 ±0.01	17.72 ±1.15	21.53 ±0.22	24.99 ±1.15	23.77* ±0.29	25.27 ±0.18	24.63 ±1.73

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 20: STARCH CONTENT (g/100g fresh weight)

STORAGE TIME (WEEKS) (DOSE/GRAYS)	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	30.44 ±0.60	29.92 ±0.04	29.20 ±0.13	26.30* ±0.18	24.31* ±0.08	22.96* ±0.08	22.11* ±0.06	21.23* ±0.13	20.29* ±0.45
50	30.01 ±0.37	29.82 ±0.44	29.29 ±0.31	28.17 ±0.21	26.03 ±0.06	25.91 ±0.13	25.74 ±0.17	25.01 ±0.11	24.67 ±0.21
100	30.86 ±0.47	29.95 ±0.08	29.11 ±0.02	28.42 ±0.32	28.00** ±0.97	27.69** ±0.37	27.16** ±1.22	26.93** ±1.32	26.31** ±0.95
180	30.59 ±0.16	30.01 ±0.18	29.24 ±0.06	28.21 ±0.14	27.92** ±0.55	27.51** ±1.02	27.06** ±0.45	26.71** ±0.28	26.12** ±0.24

Results are expressed as mean ± SD

DOSE (GRAYS) STORAGE TIME (WEEKS)	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	28.86 ±0.71	28.13 ±0.62	24.41* ±0.18	22.76* ±0.58	21.55* ±0.85	20.95* ±0.42	19.90* ±0.28	19.86* ±0.23	19.53* ±0.31
50	28.21 ±0.51	28.23 ±0.62	27.46 ±0.44	27.01 ±0.30	27.11 ±0.08	26.84 ±0.18	26.25 ±0.20	25.72 ±0.16	25.01 ±0.23
100	28.47 ±0.16	28.11 ±0.17	28.02 ±0.28	27.26 ±0.08	27.04 ±0.14	26.52 ±0.44	26.18 ±0.25	25.67 ±0.72	25.07 ±0.03
180	28.46 ±0.41	28.06 ±0.24	27.93 ±0.25	27.13 ±0.11	26.80 ±0.20	26.37 ±0.79	25.96 ±0.38	25.33 ±0.38	24.78 ±0.17

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 21: REDUCING SUGAR CONTENT (%)

STORAGE TIME (WEEKS) (DOSE/GRAYS)	AMARA 1	5	9	13	17	21	25	29	33
0 (Control)	0.099 ±0.006	0.118 ±0.004	0.144 ±0.006	0.146* ±0.005	0.191* ±0.004	0.259* ±0.002	0.677** ±0.006	0.657** ±0.018	0.661** ±0.003
50	0.120 ±0.005	0.119 ±0.005	0.128 ±0.002	0.130 ±0.003	0.138 ±0.006	0.165 ±0.009	0.300 ±0.011	0.368* ±0.034	0.348 ±0.010
100	0.125 ±0.009	0.167* ±0.001	0.213* ±0.009	0.232** ±0.004	0.245** ±0.006	0.264* ±0.013	0.320 ±0.009	0.309 ±0.009	0.383 ±0.011
180	0.130 ±0.003	0.209** ±0.025	0.297** ±0.016	0.319** ±0.004	0.338** ±0.006	0.332** ±0.028	0.336* ±0.011	0.369* ±0.004	0.389* ±0.004

Results are expressed as mean ± SD

DOSE (GRAYS) STORAGE TIME (WEEKS)	CHIKAKWANDO 1	5	9	13	17	21	25	29	33
0 (Control)	0.169 ±0.009	0.208** ±0.010	0.275** ±0.016	0.534** ±0.009	0.617** ±0.009	0.628** ±0.016	0.584** ±0.017	0.555** ±0.009	0.611** ±0.009
50	0.170 ±0.003	8.180 ±0.002	0.190 ±0.004	0.223 ±0.006	0.229 ±0.002	0.240 ±0.002	0.265 ±0.006	0.308 ±0.006	0.382 ±0.013
100	0.168 ±0.003	0.177 ±0.004	0.194 ±0.004	0.218 ±0.001	0.228 ±0.009	0.242 ±0.004	0.271 ±0.016	0.316 ±0.001	0.390 ±0.006
180	0.169 ±0.007	0.151 ±0.007	0.191 ±.004	0.221 ±.014	0.227 ±.003	0.242 ±.001	0.276 ±.019	0.274 ±.055	0.373 ±.006

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 22: FIBRE CONTENT (g/100g dry weight)

STORAGE TIME (WEEKS) (DOSE/GRAYS)	AMARA 1	5	9	13	17	21	25	29
0 (Control)	1.19 ±0.02	1.07* ±0.12	1.21 ±0.06	1.92 ±0.11	1.71 ±0.04	1.82 ±0.05	1.63 ±0.06	1. ±0.
50	0.02 ±0.05	1.30** ±0.03	1.21 ±0.06	1.90 ±0.03	1.77 ±0.01	1.69 ±0.02	1.68 ±0.06	1. ±0.
100	1.31 ±0.23	0.83 ±0.05	1.41** ±0.06	1.87 ±0.01	1.72 ±0.01	1.72 ±0.04	1.73 ±0.05	1 ±0
150	1.21 ±0.02	0.92 ±0.05	1.30 ±0.02	1.94 ±0.03	1.59** ±0.06	1.74 ±0.11	1.80 ±0.11	1 ±0

Results are expressed as mean ± SD

----------0	83.95	71.93	46.14					
A/0/09/A	188.80	188.23	183.29	181.03	168.88	160.46	139.27	
A/0/10/A	156.95	156.13	152.00	151.01	146.07			
A/0/11/A	232.35	230.83	220.47	217.89				
A/0/12/A	181.16	180.46	175.64	174.44	168.55	158.66	129.72	109.91
MEAN	212.18	211.22	204.84	202.89	192.63	183.45	155.35	129.82
±SD	±41.88	±41.85	±40.95	±40.47	±40.52	±38.27	±35.95	±32.96

week

Results are expressed as mean ± SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 23: SOLUBLE CARBOHYDRATE CONTENT (%)

STORAGE TIME (WEEKS)	AMARA			
DOSE (GRAYS)	1	9	17	25
0 (control)	13.12 ±0.20	18.52** ±0.62	16.37** ±0.12	15.22** ±0.36
50	13.11 ±0.02	14.08 ±0.18	14.75 ±0.09	14.90 ±0.03
100	13.14 ±0.11	14.10 ±0.03	14.75 ±0.06	14.91 ±0.01
180	13.07 ±0.04	14.11 ±0.01	14.77 ±0.06	14.90 ±0.06

Results are expressed as mean ±SD

STORAGE TIME (WEEKS)	CHIKAKWANDO			
DOSE (GRAYS)	1	9	17	25
0 (control)	16.29 ±0.04	18.53** ±0.13	18.89** ±0.04	18.40** ±0.15
50	16.26 ±0.08	16.65 ±0.04	16.56 ±0.05	16.97 ±0.08
100	16.32 ±0.13	16.63 ±0.17	16.57 ±0.16	16.92 ±0.08
180	16.30 ±0.01	16.64 ±0.62	16.52 ±0.14	17.35 ±0.83

Results are expressed as mean ±SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 24: CELLULOSE CONTENT (%)

STORAGE TIME (WEEKS)	AMARA			
DOSE (GRAYS)	1	9	17	25
0 (control)	2.62 ±0.44	2.91 ±0.16	-	3.01 ±0.11
50	2.58 ±0.44	2.93 ±0.16	-	3.04 ±0.20
100	2.59 ±0.93	2.89 ±0.48	-	2.99 ±0.18
180	2.68 ±0.48	2.90 ±0.07	-	3.01 ±0.06

Results are expressed as mean ±SD

STORAGE TIME (WEEKS)	CHIKAKWANDO			
DOSE (GRAYS)	1	9	17	25
0 (control)	2.96 ±0.36	3.11 ±0.21	-	3.26 ±0.44
50	2.96 ±0.12	3.14 ±0.09	-	3.26 ±0.32
100	2.95 ±0.08	3.12 ±0.19	-	3.24 ±0.26
180	3.02 ±0.17	3.12 ±0.09	-	3.17 ±0.04

Results are expressed as mean ±SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 25: HEMICELLULOSE CONTENT (%)

STORAGE TIME (WEEKS)	AMARA			
DOSE (GRAYS)	1	9	17	25
0 (control)	7.92 ±0.32	7.84 ±0.30	-	8.26 ±0.41
50	7.86 ±0.46	7.88 ±0.55	-	8.12 ±0.14
100	7.89 ±0.82	7.92 ±0.11	-	8.22 ±0.26
150	7.76 ±0.15	7.84 ±0.19	-	8.17 ±0.09

Results are expressed as mean ±SD

STORAGE TIME (WEEKS)	CHIKAKWANDO			
DOSE (GRAYS)	1	9	17	25
0 (control)	10.50 ±0.17	11.48 ±0.13	-	11.86 ±0.33
50	10.42 ±0.56	11.12 ±0.04	-	11.92 ±0.21
100	10.55 ±0.21	11.08 ±0.22	-	11.86 ±0.11
150	10.72 ±0.19	11.09 ±0.09	-	12.02 ±0.11

Results are expressed as mean ±SD

No superscript = No significant difference (P>0.05)

* = Differs significantly (P<0.05)

** = Differs significantly (P<0.05).

APPENDIX 26: LIGNIN CONTENT (%)

STORAGE TIME (WEEKS)	AMARA			
DOSE (GRAYS)	1	9	17	25
0 (control)	0.085 ±0.086	0.082 ±0.018	-	0.089 ±0.032
50	0.088 ±0.045	0.085 ±0.014	-	0.087 ±0.047
100	0.091 ±0.045	0.088 ±0.014	-	0.086 ±0.047
180	0.086 ±0.099	0.088 ±0.066	-	0.088 ±0.012

Results are expressed as mean ±SD

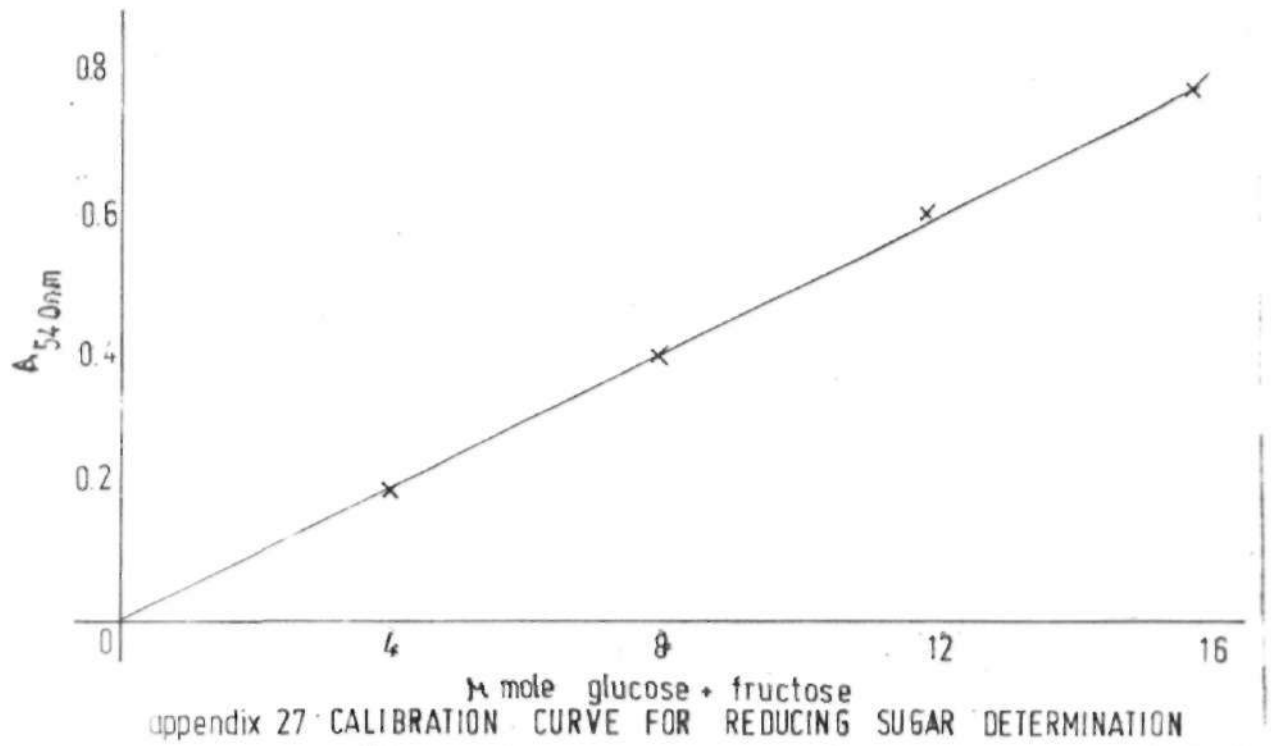
STORAGE TIME (WEEKS)	CHIKAKWANDO			
DOSE (GRAYS)	1	9	17	25
0 (control)	0.110 ±0.021	0.120 ±0.044	-	0.140 ±0.062
50	0.120 ±0.036	0.120 ±0.042	-	0.140 ±0.001
100	0.110 ±0.012	0.110 ±0.028	-	0.130 ±0.011
180	0.110 ±0.016	0.120 ±0.071	-	0.130 ±0.018

Results are expressed as mean ±SD

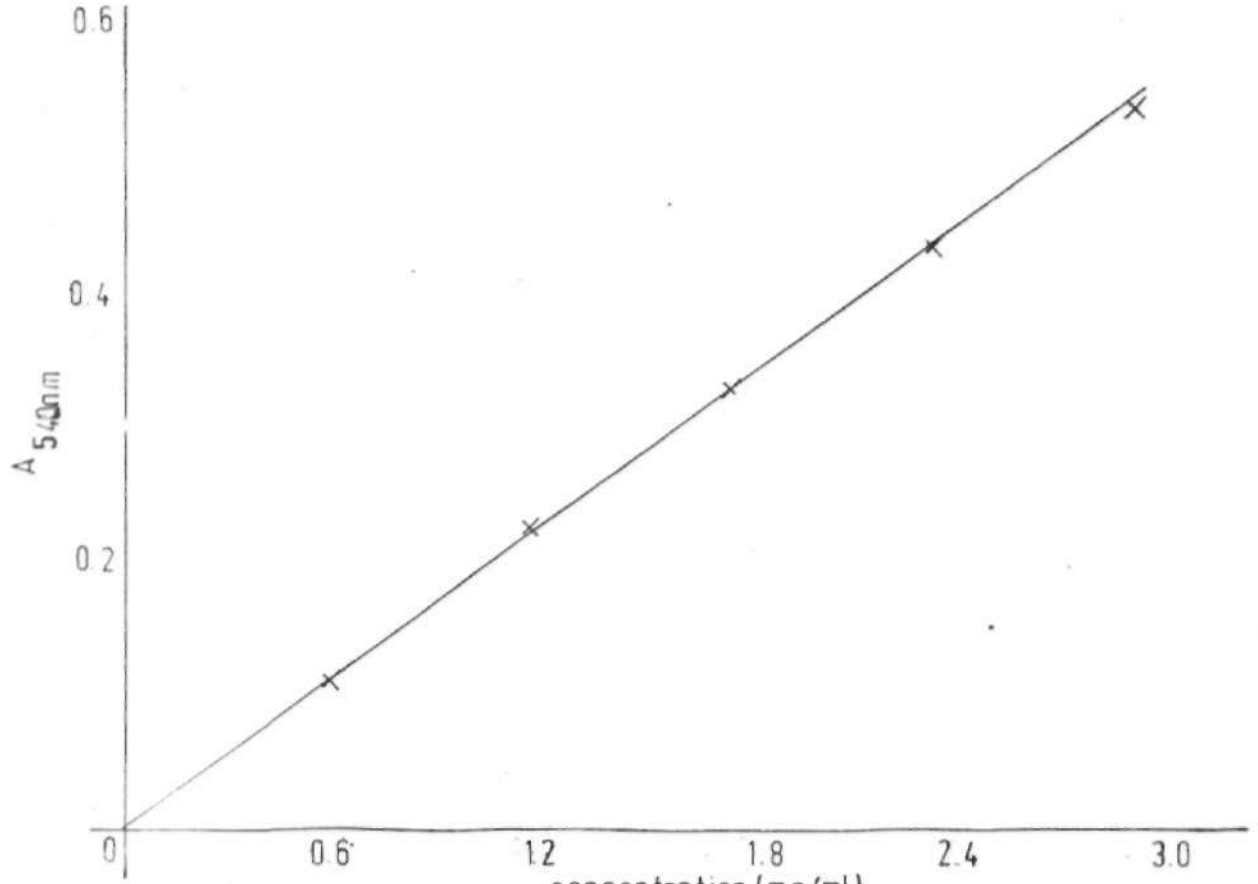
No superscript = No significant difference (P>0.05)

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** = Differs significantly (P<0.05).



appendix 27 CALIBRATION CURVE FOR REDUCING SUGAR DETERMINATION



appendix 28: CALIBRATION CURVE FOR TOTAL FREE AMINO ACID DETERMINATION USING DL GLUTAMINE