

CASHEW PROCESSING AND QUALITY INDICES

BY

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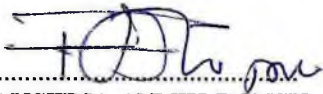
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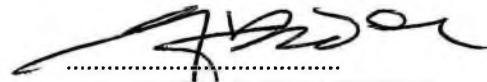
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DECLARATION

This research was conducted by me under the supervision of Prof. Samuel Sefa-Dedeh of the Nutrition and Food Science Department, University of Ghana, Legon.


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.....
PROF. S. SEFA-DEDEH



DEDICATION

To my dear Dee, Sedi and Selorm

*"Many are the afflictions of the righteous but the
Lord delivers him from them all".*



ABSTRACT

Cashew is made up of the nut attached to the apple (false fruit) both of which have nutritional significance and economic value. Evaluating the changes that occur during growth and maturation as well as processing will help to optimize quality. This is what the study involved.

Compositional and physical changes were monitored in six cultivars of cashew (apple and nut). Local cashew trees were selected randomly after flowering. Collection of samples commenced after fruit set and at weekly intervals till 8 weeks (maturity). Physical analysis included weight (whole cashew, nut, apple, cashew nut, nut kernel and shell) and size (length of apple and nut, thickness and width of nut and top and bottom diameter of apple).

All the physical indices of apples showed a single phase of continuous increase after fruit set reaching maximum values at 8 weeks. Weight and length of apples increased from 0.31 ± 0.01 - 68.56 ± 0.32 g and 0.69 ± 0.03 - 5.82 ± 0.12 cm respectively. Unlike the apples, the growth pattern of nuts occurred in two stages. There was initial rapid increase with the attainment of maximum values at 4 and 5 weeks after which a decrease occurred. At 8 weeks the nuts attained a proportion of their maximum values i.e. weight (4.89 ± 0.09 - 6.33 ± 0.15 g) and length (2.41 ± 0.01 - 2.90 ± 0.02 cm). Growth time was more strongly correlated with the physical indices of apples.

Similar trends of total sugar accumulation occurred in both the apples and cashew nut kernels. Increases were observed with maturation and optimal values of 10.01-10.85% for apple and 5.04-6.14% for the kernels was observed at 8 weeks. Increase in the ash (0.48-2.70g/100g), total solids (27.57-80.28%), fat (1.81-39.42g/100g) protein (0.95-20.93g/100g) and mineral (e.g K:20.81-491.35mg/100g) contents occurred in the kernel from fruit set to 8 weeks. These increases were rapid after 4 weeks of growth. The apples increased in moisture (69.42-86.95%), vitamin C (72.51-225.9-49mg/100g) and titratable acidity during growth and maturation (Fruit set-8 weeks). All the above constituents in the cashew kernel and apple were at maximal values by the eighth week of growth. The nut kernel generally decreased in moisture (73.46-19.46%) with growth. pH (4.11-3.65) of apples generally decreased whilst total solids (30.58-13.05%) ash (0.84-0.45g/100g) and mineral (e.g. P:243.04-128.21mg/100g)

contents decreased continuously from fruit set to 8 weeks. Pectin and tannin contents of the apples increased to maximum values generally between 3-5 weeks, after which depletion occurred. At 8 weeks, minimum values of pectin (0.59-0.76%) and tannin (0.19-0.40 g/100g) was attained.

Changes in chlorophyll (total chlorophyll, chlorophyll a & b) and absorption spectra of two apple cultivars were monitored during growth. Chlorophyll contents of the apples (e.g. total chlorophyll:15.05-1.04mg/100g) decreased with maturation (fruit set to 8 weeks). The same occurred for the number of peaks (5-1) in the absorption spectra.

Processing methods, peeling, steaming and peeling before steaming were applied to the apples. Quality indices of the resultant juice was analyzed by objective and sensory methods and during one week of storage. pH, acidity, vitamin C and tannin contents of apples were significantly affected by the methods of processing ($P < 0.05$). Peeling before steaming was most effective in reducing tannin contents. Apart from tannin, vitamin C (266.42-155.42mg/100g) and pH (4.41-4.08) decreased whilst titratable acidity increased during storage. Sensory analysis included sweetness, colour, flavour, astringency intensities, and overall acceptability. Panelists generally preferred and most accepted the quality indices of juices obtained from steamed (SAJ and PSAJ) apples as compared to unsteamed ones (WAJ and PAJ).

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God Almighty, to you I owe my very existence, you have lifted up me up from the miry clay and set my feet on the rock to stay, thank you that I was not put to shame. Like one of the ten lepers my soul says thanks.

God repay you all in thousandfold, Thank you.

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1.0 INTRODUCTION

1.1 BACKGROUND OF CASHEW

Cashew nut tree (*Anacardium occidentale* L.) is a fruit tree which originated from Brazil. It was introduced into Africa in the second half of the 16th century and its more wide spread in Africa than any other continent (Anon, 1997a). It tolerates wide ranges of rainfall regimes and is also adopted to many types of soil including marginal degraded land (Nyamekye- Boamah, 1996). It is mainly cultivated in the tropics with commercial production concentrated in India, Brazil and East Africa with a high potential for development in West Africa (FAO, 1982).

1.1.1 Prospects and Production of Cashew in Ghana

About 65% arable land (arid savanna zones) in Ghana has the ability to support cashew cultivation (Nyamekye-Boamah, 1996). These are Upper East and West, Northern, Brong Ahafo, parts of Greater Accra, Central and Volta Regions (Anon, 1997b). Ghana depends mainly on cash crops like cocoa, timber, coffee etc. for foreign exchange earnings. The unstable and sometimes plummeting commodity prices combined with high cost of production and soaring interest rates has led to the need for developing other non traditional crops into cash crops for export in order to earn more foreign exchange. It has been established that revenue obtained from cashew in Brazil surpasses that obtained for gold in Ghana (Anon, 1997a). Due to creation of new trade flows for cashew, there has been recent increase in world demand for it particularly in the United States and Europe. The world demand for cashew is about 450,000 metric tonnes and Ghana currently produces only 540 metric tonnes per annum (Anon, 1997b). For these reasons, there is the need for Ghana to take advantage of the world demand for a product it has comparative advantage of producing as well as

processing. Developing cashew as a cash crop with an export market orientation, under the savanna ecosystems, would revive the rural economies and contribute to poverty alleviation just as cocoa has done for rural folks in the forest belts.

1.1.2 **Growth, Development and Maturation of Cashew**

Although cashew nut is directly attached to the apple they appear to grow independently of each other (Pratt and Mendoza Jr., 1980). After fruit set cashew nut grows at a very fast rate and reaches maximum size within 30-36 days. The apple, which was then growing at a slow rate, starts growing rapidly and reaches maximum size within 48-52 days (Filgueiras *et al.*, 1995). During this period the nut which had reached its maximum size loses moisture resulting in shrinkage due to drying. Cashew matures within 7-8 weeks after fruit set or within 44-72 days (Wunnacht and Sedgly, 1992). Wide range of changes (physical and biochemical) take place during growth and development of cashew. These include size, colour, acidity and pH, astringency, total solids, ascorbic acid, sugars etc. (Pratt and Mendoza Jr, 1980).

1.2 **CHARACTERISTICS AND UTILIZATION OF CASHEW**

Cashew comprises of a highly priced nut (true fruit), attached to the apple, which is a juicy swollen pedicel usually called false fruit (Francisco *et al.*, 1996).

1.2.1 **Nut**

The cashew nut is a kidney shaped achene with a pinkish-grey leathery epicarp commonly called the shell (Nomisma, 1994). The kernel, which is the edible portion of the nut, is made up of two ivory coloured cotyledons and can be consumed only in the processed form

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(Rosengarten, 1984). Like many other seeds, the kernel constitutes mainly of fat (34.5-46.8%) and protein (13.3-25.3%) fractions besides carbohydrates (18%) and mineral salts (Menninger, 1977 ; Nomisma, 1994). It is also high in minerals, e.g. calcium, iron and phosphorous (Francisco *et al.*, 1996). The kernel is therefore considered to be of high nutritional quality, rich in polyunsaturated fatty acids and is a tasty energy giving food which can be eaten by all groups of people (Nomisma, 1994). The quality of cashew protein makes it a complete food, better than many of vegetable origin. Cashew kernels have of recent times been of great interest to processing industries due to their wide range of uses. The roasted kernels are consumed as snacks and used in the production of ice creams, nougat, biscuits etc. (Anon, 1997a).

1.2.2 Apple

Botanically cashew apple is not a true fruit. It is soft, juicy, somewhat fibrous, astringent in taste and has a thin waxy skin that easily bruises (Anthony *et al.*, 1993; Maciel *et al.*, 1986). It is mostly heart shaped, several times larger than the nut (3-6 or more times), and when fully ripe it is either bright red, yellow or a mixture of the two colours (Alberto *et al.*, 1982 ; Ohler, 1988). It has high moisture content (84.5-90.4%) and moderate amounts of minerals e.g. phosphorous (12.3-16.7mg/100g). It has high riboflavin (99-124mg/100g) and vitamin C contents (147-548mg/100g) (Alves, 1992 ; Filgueiras *et al.*, 1995). The vitamin C content is several times higher than most common tropical fruits (Alves, 1992) i.e nine times higher than that of orange (Anon, 1997a).

Cashew apple can be eaten fresh or processed into wide range of products including sweets, fruit pies, jam, jelly, flour cashew bread, ketchup, etc.

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The juice is commercialised for direct consumption as fresh products or used in the production of alcoholic beverages i.e. wine, gin, champagne etc. (Francisco *et al.*, 1996 ; Ohler, 1988). The apple is a valuable fruit, and it's a pity consumption and processing in tropical countries, especially Ghana is almost insignificant.

1.3 PROBLEMS RELATED TO CASHEW PRODUCTION, PROCESSING AND EXPORT

1.3.1 Nut

Cashew nut produced in Ghana are exported in their raw unprocessed state. Nuts destined for export do not undergo any quality criteria and routine quality checkups apart from moisture determinations. As a result the quality of nut for export is generally low to medium across the production districts (Nyamekye-Boamah, 1996). This results in low returns on revenue and the fact that processed nuts fetch far more than raw nuts. These problems can be attributed to little or lack of knowledge about quality characteristics of nuts, poor general post harvest handling, little or no information related to growth, development and maturation, lack of knowledge about harvest indices, no laid down quality criteria for cashew nuts etc.

1.3.2 Apple

Cashew apples constitute about 90% of total harvest of cashew at the farm gate (Owusu, 1996). It's weight is about 5-10 times that of the nut produced, however the use of this fruit is of minor economic importance, the greater portion of it being wasted (Ohler, 1988). Despite high nutritive value, pleasant flavour and suitability for a variety of products, losses can be as high as 90% (Lindgraf, 1989). It is estimated that only 5% of the total harvest is taken advantage of while the remaining is wasted or lost (Francisco *et al.*, 1996).

In Ghana, the main aim of growing cashew is for the highly priced nut, most of the apples go waste and it presents the least industrialisation percentage (Nyamekye-Boamah, 1996). Efficient use of apples can provide considerable extra income to the cashew farmer with its value becoming potentially higher than that of nuts (Ohler, 1988). Limitations of apples to attain marketable quality has been attributed to a variety of factors. These include restrictive climatic conditions, poor and inefficient production techniques, lack of knowledge on harvest, transportation, handling and nutritive value, short harvesting period and non-climacteric nature (Filgueiras *et al.*, 1995). In Ghana, natural use of the apple is limited due to little or no knowledge and information about its quality and processing characteristics, harvest indices, compositional as well as physical changes occurring during development and maturation, lack of simple and economical methods of preservation etc.

1.4 OBJECTIVES

The main objective of this research is therefore to study quality changes associated with growth and maturation as well as processing of cashew in order to optimize quality.

1.4.1 Specific Objectives

1. To study the effect of growth, development and maturation on physical characteristics of cashew.
2. To determine compositional changes in cashew during growth, and maturation.
3. To study changes in pigment of cashew apple during growth, development and maturation.
4. Processing of cashew apples and evaluation of quality by objective and sensory methods and during storage.



2.1 FRUITS

Fruits are considered botanically as ripened ovary and adjacent tissues which contain them i.e. it is the seed bearing organ (Haard, 1985). More than any food group, they are attractive because of their colour, flavour and texture (Batissie *et al.*, 1994). The term soft fruit includes botanically unrelated fruits which have become associated rather through their culinary qualities than for any morphological similarity (Green, 1970). Examples of these include berries, currants and cashew apples.

2.1.1 Compositional changes during growth and ripening

Fruits like all living things consists of wide range of different chemical compounds and also vary in their structure and composition. During growth and development, fruits pass through series of changes colour, texture and flavour reflecting possible compositional changes (Simpson *et al.*, 1976). Some of these changes may be due to either degradative or synthetic processes or both.

2.1.1.1 Water

Fruits generally have very high moisture content which ranges from 70-90% of the fresh weight (Haard, 1985). Structural, chemical as well as extrinsic factors can influence the maximum amount of moisture that can be found in a tissue. High moisture makes fruits more susceptible to microbial and mechanical damage. Cashew apples for example are very juicy and highly perishable due to high moisture content (84.4 - 90.4%) (Filgueiras *et al.*, 1995).

Sugar content of fruits vary widely from negligible (in avocado) to over 20% (in ripe banana) on fresh weight basis. Principal sugars in fruits include sucrose, fructose and glucose and they play important roles in various properties of fruits some of which are flavour, balance between acid and sugar, texture etc. (Haard, 1985; Whiting, 1970). Starch is the principal carbohydrate of plant tissues which is not associated with the cell walls. It occurs in high quantities in very young fruits (Pratt and Reid, 1974). During ripening, starch which is a reserve food is hydrolysed by specific enzymes (amylases) into sugars (Matsumoto *et al.*, 1983). Terra *et al.*, (1983) reported that, during ripening of bananas, decreases in starch with increases in sugars occurred, causing the characteristic sweetness of most ripe fruits. Filgueiras *et al.*, (1995) also reported increases in total sugars of cashew apples during ripening.

2.1.1.3

Pectic Substances

Pectic substances are the major components of the cell wall and middle lamella and they act as cementing materials (Voragen *et al.*, 1983). It increases in amount during the development of fruits. During ripening, structural changes occur in the middle lamella and the polysaccharide cell wall, leading to cell separation and softening of tissues (Bartley and Knee, 1989). There is hydrolysis of pectic substances by pectolytic enzymes (polygalacturonase, pectin methyl esterase and beta-galactosidase) and this involves depolymerisation and deesterification (Barrett and Gonzalez, 1994; Huber, 1983). The process continues until pectin reaches a stage where the fruit loses its firmness and pectin has less gelation power. The cell wall gradually loosens and is torn apart more readily hence the soft nature of most ripe fruits.

2.1.1.4 Organic acids

Organic acids are important sources of respiration in plant cells and their synthesis during normal metabolic processes, contribute to the acidity and pH of fruits (Johnson and Peterson, 1974; Ulrich, 1970). Acidity is important to the flavour of fruits and pectin gelation. The most common and abundant organic acids in fruits are citric and malic acids (Haard, 1985). Cashew apples have malic acid as the most abundant acid (Lopez, 1972). During ripening changes in acidity vary for different fruits. In apples and grapes, peak titratable acidity occurred as they mature while in bananas a steady fall occurred from development to ripening. Mangoes decrease in acidity, with a shift of pH from 2.0 - 5.5 during ripening (Ulrich, 1970). Total acidity of many fruits decline during ripening although specific acids may actually increase (Haard, 1985).

2.1.1.5 Minerals

The ash content gives an indication of the total mineral matter of plant tissues and this varies from 0.1-5% fresh weight (Haard, 1985). The most abundant mineral elements in plants (macro-nutrients) are calcium, potassium, magnesium, iron, phosphorous, sulphur and nitrogen. Micro-nutrients include copper, manganese, zinc, molybdenum and chlorine. Their distribution within the plant is not uniform and varies with plant part and even in different parts of the same cell (Duckworth, 1966). The most abundant individual mineral in fruits is potassium and its content ranges between 60-600 mg/100g fresh material.

Fruits are known to vary widely in their vitamin contents and are also the major source of several vitamins for all primates (Mapson, 1970). Some of these are vitamin A, thiamin, riboflavin, pantothenic acid, vitamin C etc. The main contribution of fruits and their processed products to the nutrition of man is their supply of vitamin C which occurs naturally as L-ascorbic acid. Vitamin C concentration depends on the variety of fruit, environmental conditions of growth, stage of ripeness, acidity and storage conditions. Different tissues of the same fruit can also vary widely in their vitamin C contents (Mapson, 1970). Cashew apple for example is valuable due to its high vitamin content, i.e. vitamin C (147 - 486mg/100g) and riboflavin (99-124 mg/100g) (Alves, 1992; Francisco *et al.*, 1996).

Vegetable tannins are water soluble phenolic compounds which can cause precipitation of alkaloids, gelatin and other protein compounds in addition to phenolic reactions (King-Thom and Cheng-I, 1997). They are widely distributed in higher plants and their presence is associated with astringency in foods (Sistrunk, 1985), discolouration, inhibition of enzymes and antioxidant properties (Senter *et al.*, 1989). The level of tannins vary widely according to specie, variety, season and location of the fruit etc. In fruits, accumulation of phenols may vary from one part of the plant to another i.e. it is known to occur in the peels of fruits e.g. cashew apples (Alberto *et al.*, 1982). During ripening, monomeric tannins which had been synthesized at the earlier stages of development are polymerised to form highly condensed tannins (Eskin, 1979; Porter and Woodruffe, 1984)). Highly condensed tannins are less soluble, tightly bound to the cell components and thus an apparent decrease in their contents

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(Senter and Callaham, 1990). Due to size exclusion, highly polymerised tannins are prohibited from interacting with molecules of salivary rich protein leading to reduced astringency of ripened fruits (Menhansho *et al.*, 1987).

2.1.1.8 Pigments

Fruits are attractive and appealing to the eye mostly because of the bright colours of pigments they contain. The distinctive colour of fruits is normally not due to a single pigment but more often due to a combination of pigments (Newsome, 1986). Carotenoids, chlorophylls and flavonoids are major pigments which occur in plant tissues (Haard, 1985). Cashew apples vary in colour, some of which are bright red, yellow or a mixture of the two colours (Maciel *et al.*, 1986). Chlorophylls are green pigments which occur in leaves and stem whiles carotenoids are a group of yellow, orange and red fat soluble pigment and both are associated in all photosynthetic plants (Gross, 1987).

Changes in the growth phase of fruits i.e. from the developmental to ripening phase is also associated with colour changes (Bauerfiend *et al.*, 1971). The type and quantity of pigments in plant tissues depends on species, variety, degree of ripeness and development, growing conditions etc. (Minguez-Mosquera and Gallardo-Guerrero, 1995). The first sign of ripening is the disappearance of green colour (chlorophyll), colour changes may be due to degradative or synthetic processes or both (Strasburger, 1979). As ripening progresses photosynthetic activities decreases and the chlorophylls disappear. Carotenoids associated with the chlorophylls may disappear at the same time, their concentrations may be maintained or increased due to synthesis of new ones. These changes are associated with colour change in

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fruits at the same time ((Minquez-Mosquera and Gallardo-Guerrero, 1995). Haard (1985) and Looney and Patterson (1967) reported that chlorophyllase is a hydrolytic enzyme that converts chlorophylls a and b into their respective chlorophyllides.

2.2 EDIBLE NUTS

Botanically the term nut refers to an indehiscent fruit that is usually shed as a one seeded unit with its pericarp mostly lignified and indigestible by humans. They however consists of an oleaginous kernel which is usually edible (Wickens, 1995 ; Menninger, 1977). Nuts are among the most nutritionally concentrated human foods and are important sources of food. Major edible nuts which are marketed commercially include cashew nuts, pistachio, sunflower seeds, filberts, chestnuts, pecans, Persian walnuts, Brazil nuts, ground nuts etc. (Rosengarten, 1984).

2.2.1 Composition

2.2.1.1 Water

In their immature state, nuts contain high moisture content of about 50%. At the matured stage, most of the moisture is lost hence it is low (Woodroof, 1979). Due to drying after harvesting their moisture content may fall as low as 3% as with pine and walnuts. In the case of cashew nuts, acceptable moisture content for long shelf life during storage must be below 9% (Okwelogu and Mackay, 1969). The low moisture content is important in preservation, storage and processing of nuts. It is also important in stabilising fat, carbohydrate and protein contents.

2.2.1.2 Fat and Protein

Nuts usually have high fat content reaching more than 70% in macadamia and pecan nuts. The high fat content is important in curing, storing and processing (Wickens, 1995). Nuts are moderately high in protein (5-30%) and it increases during maturation (Menninger, 1979 ; Woodroof, 1979). Nut proteins are of good quality, but due to high fat content, they have the disadvantage of not being used as substitute for meat or other sources of animal protein.

2.2.1.3 Ash and Minerals

Nuts are very good sources of minerals, they are however considered low in calcium. Ash content is usually not more than 3% except in pine, Brazil beech and almonds nuts (ITC, 1993). They contain large quantities of phosphorous and potassium, moderate amounts of magnesium and limited amounts of iron and sodium and are low in vitamins (Kuzio, 1977).

2.2.1.4 Carbohvdrates

Nuts have very low sugar content, however in some (cashew, chest, pine and pistachio nuts), it is high enough to make then quite sweet. Starch content of all nuts except chestnut are very low (Woodroof, 1979).

2.3. **CASHEW PRODUCTION**

2.3.1 **Cultivation**

Cashew tree belongs to the genus *Anacardium*, a member of the family of the *Anacardiaceae* (Ohler, 1988). It is an ever green shrub which can be as tall as 10-15m (Anon, 1997a ; Purseglove, 1987). Cashew is widely cultivated in many tropical and subtropical countries

(Maciel *et al.*, 1986), with commercial production concentrated in India, Brazil and East Africa. Cashew has a high potential for development in West Africa, where plantations have been quickly developing recently (FAO, 1982; ITC, 1993). The cashew nut is its most important product with a world production of about 500,000 tons per year (FAO, 1983). Cashew apple is also obtained from the cashew tree.

Initial attempt of commercial cashew estate development in Ghana was in the 1960's which was later abolished. Cashew plantation was again restarted by UNDP sponsored project in the Wenchi and Jaman districts in the Brong Ahafo region (Nyamekye-Boamah, 1996). All the soil types in Ghana have the ability to support cashew cultivation. The crop however does better in the arid savanna type zones of the country which includes Upper East and West, Northern, Brong Ahafo, parts of the Greater Accra, Central and Volta regions which account for about 65% arable land in Ghana (Anon, 1997b). World demand for cashew is around 450,000 metric tonnes but Ghana currently produces a mere 540 metric tonnes per annum. It however has the potential to produce 20,000 metric tonnes by the year 2005 (Anon, 1997b).

2.3.2 Growth, Development and Maturation

2.3.2.1 Flowering

The age at which a cashew tree starts flowering is influenced by growing conditions and by genetic factors (Ohler, 1988). Under favourable conditions trees may produce their first crop at the age of the 3 years, but few flowers and fruits are usually produced in the second year of growth. There may be differences in the age of the first flowering even for trees growing under the same conditions.

The flowering season may differ from year to year and usually extends over a period of several months. The flowering peak during which 50% of the flowering are produced lasts for only 4-6 months even though the whole period may be extended over four months. The time from the first appearance of the inflorescence to the opening of the first flowers is about 5-6 weeks. The scented flowers are small and white when just opened, in a few days the colour turns pink (Rosengarten, 1984).

2.3.2.2 Fruit Set

Damoradan (1966) reported that, only 6-12% fruit set during studies on the east coast of India. The number of fruits that attain maturity was often very low compared to the number of perfect flowers produced. It was also known that the number of nuts that matured was only 17% of the flowers that had set fruit. Most of the fruits and nuts drop when they were smaller than 5mm. After pollination, enlargement of the ovary occurs with the young nuts becoming visible to the eye after one week (Ohler, 1988).

2.3.2.3 Physical Changes

The cashew nut and apple appear to grow independently of each other (Pratt and Mendoza, 1980). During the first two weeks after fruit set, the pericarp grows more rapidly than the embryo, but then the embryo also grows rapidly until it completely fills the shell cavity by the time the nut reaches the maximum size i.e. five to seven weeks after fruit set (Ohler, 1988). Filgueiras *et al.*, (1995) reported a fast and uniform growth of the nut after anthesis and it may reach its maximum size by 30-36 days. The nut then shrinks in size after this fast growth phase and the shell dries and hardens losing about 15% in weight.

Damodaren *et al.* (1966), observed decrease in the length of the nut during the final stages of ripening. During this drying period the shell changes from its green colour to grey. Ohler (1988) also stated that nut attains 75% of its maximum size when it becomes mature, mainly due to loss of moisture the kernel remains almost constant in size through an equilibrium established between accumulation of dry matter and loss of moisture.

Roth (1974) observed that the growth of cashew apple was very slow or less than that of the nut during the first two thirds of the developmental stage, but then it fairly suddenly increase to twice the length of the nut at the final stage of growth. Valeriano (1972) found that ten days after fruit set, the apple and nut were of the same size. The length of the apple first increased at about the same rate as that the nut, but from about twenty days after fruit set, the apple developed much faster than the nut, reaching a length of 1.5 to 2 times that of the nut when ripped. Wunnacht and Sedgley (1992) observed that, during the fast growing phase of the nut (the early stages of growth i.e. 1-3 weeks after fruit set), the apple grew slowly. As the nut approached maximum size, the apples also grew at a faster rate reaching their maximum size at or near maturity. During ripening, cashew apple changes colour due to chlorophyll loss and synthesis of other pigments.

FAO (1982) and ITC (1993) reported that cashew fruit matures within 2-3 months after fruit set. Generally it is considered that the ripening of the fruits take two months but there are wide variations between cashew trees of different types (Ohler, 1988). Filgueiras *et al.*, (1995) stated that after about 38-50 days the maximum size of the apple is reached and if not harvested both the peduncle and the nut fall from the plant simultaneously after 7-8 weeks.

2.3.2.4 Compositional Changes

The apple accumulates dry matter at an increasing rate from the time it is first visible till maturity, although the dry matter percentage generally decreased through its development (Ohler, 1988). Decrease in acidity and astringency with increase in soluble solids, reducing sugars and ascorbic acid occurs during ripening of apples (Filgueiras *et al.*, 1995). The skin which is very tender becomes exceedingly waxy as the apple ripens. Thompson (1968) found that during the drying period, dry matter percentage of the pericarp increased by 25%, the dry matter percentage rising from 29% to 50%. Decreases in moisture content and increases in protein, fat, total sugars also occur during this period (Ohler, 1988).

2.3.3 **Harvesting and Post Harvest Handling**

2.3.3.1 Nut

a. **Harvesting**

Fruits are harvested when fully ripened (Wickens, 1995). Harvesting generally consists of reaping nuts that have dropped to the ground after maturing (Rosengarten, 1984). If apples are for processing e.g. jam, jellies etc. cashew must be harvested before it falls naturally (Ohler, 1988). Intervals between harvesting rounds without much loss of nut quality depends on climatic conditions. In very dry climates, with dry topsoil, nuts can remain under trees for several weeks without losing their typical flavour and quality to any extent. However, where humidity is high, e.g. rainy season, nuts should be reaped often i.e. twice a week (Bonney, 1996).

b. Drying

Moisture content of nuts at harvest usually depend on climatic conditions, moisture content of soil on which the nuts falls, amount of weed and time between nut fall and harvest (Ohler, 1988). At harvest, moisture content of nuts can be as high as 25%, kernel deterioration may occur when not dried immediately (Pattinson, 1969). These include enzyme actions, bacteria and mould attacks which leads to lose nut quality (nutty taste and aroma). Okwelogu and Mackay (1969) stated that maximum permissible moisture content of raw nuts is 8.9-9.1% for kernels with fat content of 38 - 47%. To ensure good kernel quality, the level of acceptable moisture should be lower than this. Russell (1969) considered whole nut moisture content of 9% or below to be safe for storage.

Nut after harvest, must be cleanly detached from the apple and dried immediately to preserve their quality and artificial drying is not recommended (Bonney, 1996). Raw nuts should be spread over large drying areas not more than 1 inch thick. Exposure of nuts to the sun's infra red and ultra violet rays are said to further mature the nuts (Anstee, 1995). Drying can be done on specially prepared floors, when this is not available, mats made from palm leaves or bamboo sticks can be used. Drying floors should be slightly sloping to allow rain water to run off. Drying takes about one to five days depending on climatic conditions and well dried nuts make rattling sounds (Russell, 1969).

c. Storage

Nuts should be stored in jute sacks and protected from rain as soon as they are well dried. Build up of moisture from respiring nuts occur when polyethylene bags are used (Bonney,

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1996). Bulk storage of nuts is possible in well ventilated warehouses. In areas where humidity is low, thatch roofed huts can be used but in high humid areas, rapid collection and storage in simple warehouses is necessary.

2.3.3.2 Apple

a. **Harvesting**

Cashew apples have a non-climacteric respiratory pattern with low production of ethylene. This physiological behaviour does not make changes associated with ripening possible when the fruit is detached from the tree. When the apple is detached from the tree before completely ripe, signs of softening and loss of green colour may occur, but then it will never reach good eating quality (Carraro and Cunha, 1994). Many indices have been used to indicate the harvest point of the cashew, some of these are colour, firmness, composition and specific gravity of cashew apples (Pratt and Mendoza Jr., 1980). The easiest way however to harvest cashew, is when the apple is fully developed, still firm, without any sign of green colour and easily detachable from the tree at the hand touch (Filgueiras *et al.*, 1995).

No instruments are required in the harvesting of apples intended for fresh consumption, harvesting by hand is recommended since ripe apples are easily detachable. Harvesting must be done very carefully to prevent too much contact of apples with the palm of the hand, due to their delicate skin of apples and also to prevent increase in pulp temperature which can stimulate senescence (Menez, 1992). Apples intended for processing can be harvested with the hand or iron sticks with collecting bags at the tips in cases where the cashew tree is very tall. Bruising occurs when apples fall to the ground hence harvesting with ordinary sticks or by shaking the branches is not recommended.

Harvested fruits must be arranged in single layers in ventilated boxes lined with soft materials to prevent bruising. Apple must be kept in the shade when on the field and during transportation.

b. Post-harvest Handling

i. Washing

Common pathogenic microorganisms which attack cashew apples are from the genus *Rhizopus*, *Coletotricum* and *Penicillium* (Filgueiras *et al.*, 1995). To control the growth of these microbes the following treatments have been adapted in Brazil; immersion in 0.25% citric acid which contains 400-500mg SO₂/litre, 0.1% sorbic acid or chlorinated water with 100mg free chlorine per litre. Washing of the apples removes dirt, reduces temperature (field heat) and pathogenic organisms on apple, increasing shelf life due to reduction in metabolic rate. Washing is done with cold water (20 °C) through immersion or by spraying (Carraro and Cunha, 1994).

ii. Drying, Selection and Grading

The washed apples are dried either by fans or natural drying. Selection and grading involves the following factors: defects, out of shape, colour, size, green or overripe apples. Apples selected for fresh consumption are well packaged and wrapped with plastic shrinkable films. These packages modifies the atmosphere around the fruit (low oxygen/ high CO₂) and together with refrigeration there is extension of shelf life (Menezes, 1992).

After selecting and grading, the rest can be used for processing. A very important procedure in post harvest handling of cashew apple for fresh consumption is pre-cooling.

It lowers temperature difference between incoming apples and the storage room and this prevents condensation of water in the packages. Pre-cooling of packaged apples is done with cold air being blown over boxes of cashew.

2.4 CASHEW

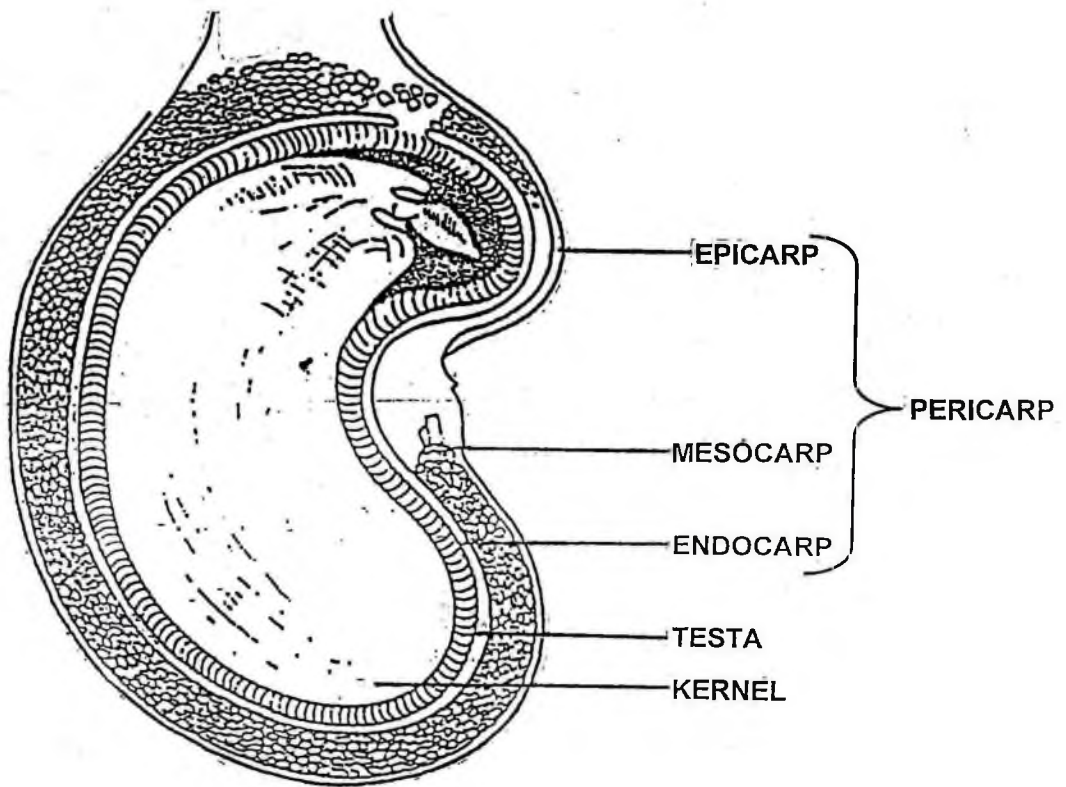
The most important product of cashew tree is considered to be the nut, which is the true fruit and it grows on a fleshy peduncle usually called the apple and also referred to as a false fruit (Maciel, 1986). The apple looks completely different from the nut.

2.4.1 Nut

2.4.1.1 Components

Figure 1 shows the longitudinal section of the cashew nut. The nut is made up of a pericarp, testa and kernel. The pericarp consists of an epicarp, mesocarp and an endocarp which make up the shell (Francisco *et al.*, 1996). The outer layer of the shell is called the epicarp (Figure 1). The mesocarp is an honey comb structure whose cells secrete natural resins commercially called the cashew nut shell liquid (CNSL) (Purseglove, 1987; Russell, 1969). Within the mesocarp is an inner shell (endocarp) which is hard and brittle and protects the kernel from the natural resin. The whole shell complex is called the husk and represents about 65-70% of total weight of the nut (Francisco *et al.*, 1996). The thin membrane covering the kernel is called the testa, it is pinkish in colour and protects the seed which is also the kernel (Nomisma, 1994). The kernel which is the edible portion of the nut, is made up of two ivory coloured kidney shaped cotyledons and an embryo (Kokwaro, 1986).

Figure 1. Longitudinal Section of the Cashew Nut



The cashew nut is obliquely kidney shaped and compressed. It is greenish to pinkish brown in colour depending on the state of maturity as well as dryness (Francisco *et al.*, 1996). The size and shape of the cashew nut as well as the percentage of its components (Table 1) vary considerably mainly according to cultivation conditions and variety (Ohler, 1988). Nomisma (1994), reported average weight of nut to vary from 3-5g and 15-28g according to the variety and cultivation conditions. Giuliano and Agnoloni (1975), investigated cashew nut samples from nine different countries and found average weight varying from 3.6-5.4g. In Ghana, Nyameke-Boamah (1996) reported average nut count per kilogram across the production districts to be 180.

Table 1. Percentage of components of cashew nut

Source	Agnoloni, 1977	Ohler, 1988
Pericarp/shell	63-73	65.8-79.6
Integument	2-5	1.3-3.6
Seed/kernel	20-25	19.1-31.6

The length of most cashew nuts vary between 2.5-4.5cm and the width 2-3cm, there may however be greater variability in solitary trees (Tyman, 1980). Thickness of cashew nuts is also known to vary considerably. Ohler (1988) observed that, not all thick nuts have relatively heavy kernels. Also nuts having the same length and width may vary greatly in their thickness. Kernel percentage is the most important quality indices of nuts, this is because the kernel is the most valuable part of nuts and processing industries pay for nuts by total weight. Any small difference in kernel percentage therefore means a crucial point

between profit and loss (Ohler, 1988). Kernel percentage negatively correlated with nut size, but no concrete conclusion was drawn because, the studies was done on only six randomly selected trees, it may however give an indication that, thick or large nuts do not necessarily have heavy kernels. Rochetti and Moselle (1967) analysed Tanzania cashew nuts and found that the average kernel percentage was approximately 29% and varies between 23 to 43%.

2.4.1.3 Chemical composition

The chemical characteristics of cashew nuts is greatly influenced by the growing conditions, variety, differences in analytical methods etc. (Menninger, 1977). Mohapatra *et al.*, (1972), reported wide variations in the protein content of cashew nuts ranging from 13.13 to 25.03% in different regions in India. The protein content of the nuts were also found to be 12.85% (Francisco *et al.*, 1996). Murthy and Yadana (1972), reported average reducing sugars in the kernel to be 1.3-5.8% and total sugars to range from 2.4-8.7%. Starch content ranged from 4.6-11.2% and fat content varied from 34.5-46.8%. The nut is very rich in minerals especially phosphorous and potassium as indicated in Table 2, and contains vitamins such as thiamine, niacin, tocopherol, riboflavin pyridoxine, vitamins A and D (Finzi, 1966; Wickens, 1995).

Table 2. Mineral constituents of cashew nut kernels (%)

Mineral	Content (%)	Mineral	Content (%)
Calcium	0.04	Magnesium	0.28
Phosphorous	0.88	Iron	0.008
Sodium	0.005	Copper	0.002
Potassium	0.57	Zinc	0.004

Source: Fetuga, (1975)

Cashew nut is a tasty energy giving food, releasing 607 cal/100g edible product (Nomisma, 1994). It is considered to be a source of high quality protein, rich in polyunsaturated fatty acids, fats and carbohydrates. It has high organic calcium, iron and phosphorous contents (Francisco *et al.*, 1996). These are extremely active mineral which promote good health. It has low fibre and moderate protein contents. Its high phosphorous content gives an indication of varying amounts of phospholipids (Menninger, 1977; Rosengarten, 1984). Lipid-free flour of kernels is of high quality for both humans and animals in terms of organic, amino acids and mineral matter. It consists of essential amino acids and the protein value is equal to that of soybean and higher than peanut. Extracted oil contains relatively high percentage of stearic and oleic acids, saturated to unsaturated acid ratio is 4:1 and contains all lipid soluble vitamins (Nomisma, 1994).

2.4.2

Apple

Cashew tree also yields an important product, the "cashew apple" to which the nut is attached. Botanically it is not a true fruit i.e. it is formed due to peduncle hypertrophic development (Maciel *et al.*, 1986). The apple represents the edible portion of cashew *in natura*.

2.4.2.1

Physical characteristics

Size and shape of apples vary widely as that of nuts (Ohler, 1988). Their shape can be almost round or elongated but they are mostly heart shaped hence the name *Anacardium*. In most cases, cashew apple is several times larger than the nut (Alberto *et al.*, 1982), normally with a ratio of 1:8 and 1:10. Some cases have been recorded where sizes of apple and nut was

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comparable. The weight of apple vary from 15-20g to 200g or more (500g) (Nomisma, 1994). Young immature apples are usually green to purple in colour, when fully ripped they are either red, yellow or a mixture of the two colours (Pratt and Mendoza Jr., 1980). The apple is very juicy, somewhat fibrous and has very thin waxy delicate skin which easily bruises (Maciel *et al.*, 1986).

2.4.2.2 Chemical Constituents

Cashew apples vary widely in their composition and variations depend on variety, climatic conditions, stage of maturity etc (Ohler, 1988). The cashew apple is very juicy and contains about 84.5 - 90.4% moisture content (Filgueiras *et al.*, 1995). Its juice is very astringent due to high tannin contents which believed to originate from the waxy layer of the skin and it is a key problem limiting acceptability (Medina *et al.*, 1978). Lopez (1972) reported great variability in tannin contents i.e 0.06 - 0.22g/100g. Tannin content of apples range from 0.27 - 0.72% (Filgueiras *et al.*, 1995). Total sugars was found to be approximately 10% (Nomisma, 1994), 7.7 - 13.2% (Filgueiras *et al.*, 1995) and 6.7 - 10.5% (Lopez, 1972). pH ranged from 3.5 - 4.5 (Filgueiras *et al.*, 1995) and 4.1 - 4.4 (Lopez, 1972). Cashew apples are very rich in vitamins especially vitamin C and riboflavin (Anon, 1997a). Alves (1992) reported vitamin c content to range from 147 - 486mg/100g, it ranged from 234-371mg/100g (Lopez, 1972) and 139-387 (Filgueiras *et al.*, 1995). The apples have a peculiar smell or flavour which sometimes can be very pleasant (Cecchi and Rodriguez-Amaya, 1981).

Cashew apple was relatively neglected until recently, although it is available in far greater tonnage compared to nuts (Muroi *et al.*, 1993). Ohler (1988) stated that, cashew apple is generally of minor economic importance, despite its great potential. Marketing of apples is not wide spread and presently only 5% of the total apple is either sold fresh or processed, the rest are wasted (Alberto *et al.*, 1982). Cashew apples are however valuable fruits and it is unfortunate that their consumption is so minimal in many tropical countries including Ghana (Owusu, 1996).

2.4.3.1 Nutritional qualities

In terms of nutritional contents, cashew apple has higher or comparative values as compared to other commonly known tropical fruits (Table 3). It is interesting to note that, cashew apple has very high vitamin C content compared to most of the commonly eaten tropical fruits like orange (Table 3). Cashew apple has nine times vitamin C than the orange (Anon, 1997a). Ohler (1988) reported cashew apple juice having 2-3 times more vitamin C than citrus fruits. Food shortages are still regularly occurring in developing countries, valuable food material such as the apple must therefore not be wasted. It has been observed that promotion of the use of cashew apple will go a long way to increase the income of the ordinary cashew farmer.

2.4.3.2 Processing capabilities

Cashew apple also has the ability to be prepared into very wide range of products. When compared to nuts, which contribute only 10% of the total harvest, cashew apples make about 90% of the total harvest at the farm gate (Francisco *et al.*, 1996).

Therefore in terms of quantity, apples have a better advantage and when fully utilized, its value is potentially higher than that of nuts (Ohler, 1988). Processing plants in Brazil and Mozambique paid \$115/ton for raw nuts in 1970 and \$45/ton for apples. Even if the total apple weight is only 5 times that of nut, while only half of the apples are processed, their value at that price would still be equal to that of the nuts. The apples could therefore become as important as the nuts when fully utilized (Vandendriessche, 1976).

Table 3. Comparison of Cashew Apple with common Tropical Fruits in terms of Nutritional Constituents

Component (per 100g)	Cashew apple		Other Tropical Fruits		
	Yellow	Red	Pineapple	Orange	Banana
thiamine/ μ g	-	-	80	80	90
riboflavin/ μ g	99	124	20	30	60
Vitamin C (mg)	240	186	24	49	10
Ca (mg)	41	41	16	33	8
P (mg)	11	11	11	23	28
Fe (mg)	0.3	0.3	0.3	0.4	0.6

Source: Ohler (1988)

2.4.4 Market Quality

2.4.4.1 Raw Nuts

Establishment of standards for raw nuts quality is needed to improve trade. Standards set should be such that they can be attainable by small stakeholders. These are preferably the moisture content, incidence of pests and molds and cleanliness of nuts. Maximum moisture content of the nuts allowed is established at 8% (ITC, 1993; Ohler, 1988). In Tanzania, two grades of nuts are distinguished, these are standard and under-grade.

Standard nuts are defined as those containing no more than one-quarter percent by weight of foreign matter and no more than 13% by weight of void, damaged, immature or previous season's nuts and moisture content should not exceed 13%. Under-grade nuts are those not meeting these requirements (Northwood and Kayumbo, 1970). International trade rewards nut size and shape significantly because of their direct bearing on kernel turn out. Big bulging nuts are preferable to small nuts and the preferred nuts per kilo ranges from 120 to 160 (Nyamekye-Boamah, 1996). Nomisma (1994) stated that, the greatest part of nut value lies in its weight and quality of kernels, prices should therefore be preferably based on moisture content, sanitary conditions and characteristics such as size and kernel content.

2.4.4.2 Cashew Nut Kernels

Cashew nut kernels for export must undergo quality tests, rules and quality standards accepted on the world scale. International Standard organization (ISO) 6477 standard states that, selection is in terms of cashew number per weight, according to the weight of kernels. It also makes a distinction for whole, chips, splits, butts and baby bits (Ohler, 1988). In terms of kernel colour, whiter or pale ivory kernels are better, whilst the dark brown ones are indication of poor roasting or drying and the quality is lower. Kernels must be free from insects, moulds rancidness and extraneous materials (ITC, 1993; Ohler, 1988).

2.4.4.3 Apple

The market requirement for cashew apple is very important if it is destined for fresh consumption. These include uniformity of the batches, low astringency and acidity and sweetness (Filgueiras *et al.*, 1995). Size (4-8 apples per tray) and shape (pear shaped) are also

important. For fresh consumption market, cashew must be cosmetically perfect without any sign of physical injury (Carraro and Cunha, 1994). For processing industries, this is not of great concern once there are no signs of diseases or insect attacks.

2.4.5 **Processing of Cashew Nuts**

Processing of nuts before export adds value of more than five-fold (Owusu, 1996). Processing involves the procedure by which the kernels are extracted from the nuts (Wickens, 1995). Economically, the most important features of processing methods are the ratio of kernel to whole nuts obtained. This also includes percentage of kernels which are obtained as whole kernels (Anstee, 1995). Kernel yield usually varies between 22-24% of the total raw material processed and percentage of whole kernels varies between 55 to 85% depending on the processing method and plant management ((Rosengarten, 1984). Kernel extraction include the following processing units:

2.4.5.1 Grading, Cleaning and Conditioning

Extent of time used in conditioning and roasting of nuts depends on their sizes. Sorting according to sizes (width and thickness) is therefore important. Nuts are cleaned to remove dirt and foreign matter using a simple sieve of 3/8 inch wire mesh. Conditioning encourages the bursting of cashew nut shell liquid (CNSL) containing cells during the roasting process. It increases moisture contents of the kernels, making it more rubbery and preventing scorching and breaking during further processing (Anstee, 1995). The easiest way of conditioning is to heap nuts on the floor and sprinkle water on them regularly. Between watering the nuts are covered with gunny bags and floors should be sloppy so that the water

can run off. Steaming for 8-10 minutes is an alternative method for quick and effective conditioning (Nambudini and Lakshminarayana, 1972).

2.4.5.2 Roasting

Roasting is done to render the shells brittle and prevent CNSL from making contact with kernels to discolour them. Two main methods including wet and dry roasting are used. Wet roasting involves dipping the nuts in CNSL at a temperature of 185-190°C for half or one minutes. Dry roasting involves roasting in a hot chamber over a furnace (Russell, 1969). After roasting the nuts are allowed to cool.

2.4.5.3 Shelling, Drying, Peeling and Sorting

Roasted nuts are brittle and break easily along the natural cleavage when struck. Hand or mechanical shelling is usually employed. Shelled nuts are dried to prevent fungal attacks and facilitate peeling due to shriveling of the testa. This is done by oven drying and moisture content should not exceed 3% (Russell, 1969). Peeling is mostly done manually using a wooden or metal scraper. Mechanized forms such as air blasting is also used (Ohler, 1988). Peeled kernels are carefully sorted based on size since they are priced differently. The kernels could be further processed i.e frying and salting etc. and packaged in hermetically sealed tins, other packages include foil pouches and special retailing bags (Matz, 1984). By-products during processing is CNSL and it can be used for a wide variety of things e.g. water proofing agents and preservatives, vanishes, brake-linings, inks etc. (Purseglove, 1987).

2.4.6 Consumption and Utilisation

2.4.6.1 Cashew Nut Kernels

Approximately 60% of cashew kernels are marketed as salted nuts (Rosengarten, 1984; Wickens 1995). Cashew kernel is the edible product obtained from cashew nuts after processing. The kernel is mostly used in confectionery and bakery products. It is used in food industries for the manufacture of nougats, biscuits, ice creams, etc (Anon, 1997). In West Africa they are eaten as roasted nuts or sometimes boiled in soups (Irvin, 1961). The seed of the cashew kernel yields edible oil which is not extracted due to the high value kernels (Francisco *et al.*, 1996).

2.4.6.2 Processing of Cashew Apple as a Value Added Product

The future of the cashew industry is very bright as various by-products are already being obtained from the cashew tree. In case of cashew apple, over 36 different products have been derived from it, some of which are recorded in Table 4. Various products can be derived from the juice and pulp, no portion of the apple is wasted when fully utilized.

Table 4. Stages of Processing Cashew Apples and Products derived

Stages	First stage	second stage	Third stage
Products	Juices	Jelly	Pulp
	Integral, Nectar, Soft drink Wine, Concentrate, Alcohol/Gin, Brandy, vinegar	Ketch up, candy, March jelly, cashew honey, jam	Biscuits, animal feed, Diet fibre, Flour, Cashew cake

Source: Francisco *et al.* (1996).

3.1 MATERIALS

Cashew samples were obtained from Nsuro farms at Adamorobe near Oyibi in the Eastern region.

3.2 EXPERIMENTAL METHODS

3.2.1 Effects of Growth and Maturation on Physical Indices of Cashew

3.2.1.1 Experimental design

A 6 x 9 factorial design based on cultivar (x 6) and growth time (x 9) was used. The principal factors were:

<u>Factor</u>	<u>Level</u>
Cultivar	red, yellow and orange round, red, yellow and orange long
Growth time	0,1,2,3,4,5,6,7,8 weeks (0 - fruit set)

3.2.1.2 Collection and Preparation of samples

Six cultivars of cashew were used for the study. Three trees were randomly selected based on colour and shape of apples for each cultivar. All trees selected were in good physical condition, free from insect damage and diseases. Tagging was done immediately after flowering. The date of flowering and fruit set was also noted. Many flowers as possible were tagged randomly on the trees. Collection of samples commenced at fruit set, and weekly intervals until 8 weeks. Ten fresh fruits were randomly selected from each cultivar, wiped free from dirt and physical indices determined. In the measurement of whole cashew weight twenty determinations were made.

3.2.1.3 Physical Determinationsa. **Weight**

Weight of whole cashew weight (apple attached to nut) was measured. Cashew nut was carefully detached from the apple and each was individually weighed. Components of cashew nut including the shell and kernel (pellicle attached) weights was measured. AG204 (Mettler Toledo, Switzerland) weighing balance was used for the weight measurements.

b. **Size**

Size of apple measured included length, top and bottom diameter. The length, thickness and width of cashew nut was also measured. Size measurements of cashew was done by means of a vernier callipers (Rabone Chesterman No.66) as indicated in Figure 2.

3.2.2 **Compositional Changes During Growth and Maturation of Cashew**3.2.2.1 Experimental design

A 6 x 9 factorial design based on cultivar (x 6) and growth time (x 9) was used. The principal factors were:

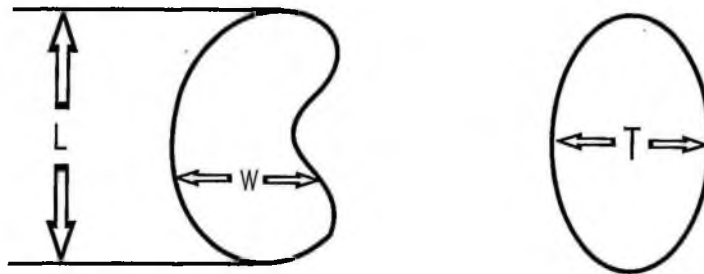
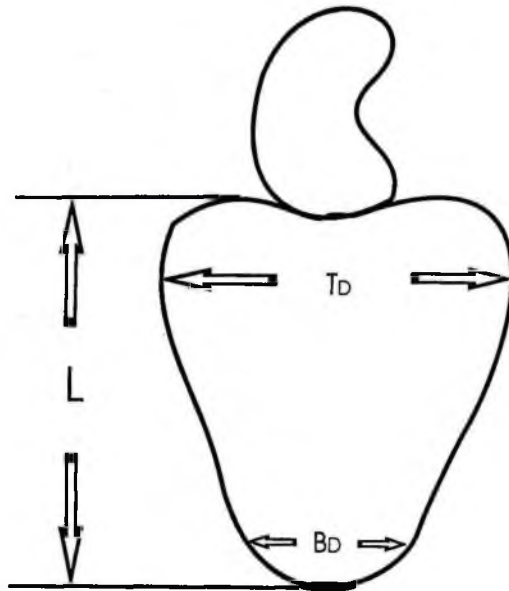
<u>Factor</u>	<u>Level</u>
Cultivar	red, yellow and orange round, red, yellow and orange long
Growth time	0, 1, 2, 3, 4, 5, 6, 7, 8 weeks (0 - Fruit set)

3.2.2.2 Sample Preparation

The nuts were detached from the apples. Cashew apples were then rinsed, wiped dry, cut into small pieces and blended using a Waring blender to form a homogenous mixture (puree).

Figure 2. Size measurements of Cashew

L	-	Length
TD	-	Top diameter
BD		Bottom diameter
W	-	Width
T	-	Thickness



Cashew nut kernel was obtained by cutting through the shell. The pellicle on kernel was removed, the kernel was then cleaned and mashed into a uniform mixture using a laboratory mortar and pestle.

3.2.2.3 Analysis

a. **Moisture content**

Moisture content of samples was determined by drying five grams of sample in a vacuum oven at 70°C at 100mm of mercury using the method of AOAC (1975), Method 22.013. Duplicate determinations was done.

b. **Total solids**

AOAC, (1975) Method: 22.018 was used by drying at 70°C at 100mm of Hg and duplicate determinations was done.

c. **Total sugars**

The modified Lane-Eyon constant volume volumetric method as described by AOAC (1975) Method: 31.078-31.084 was used in the duplicate determination of total sugars of apples and kernels.

d. **Pectin**

Duplicate determinations of pectin content of cashew apples was done using the method of Pearson (1976). Fifteen grams of sample was blended with 100ml of cold water. The mixture was boiled and filtered. About 25 ml of the filtrate was diluted to 150ml, 50ml of 0.1M NaOH was added and allowed to stand overnight.

Twenty-five milliliters of 1M acetic acid was added, followed by 25ml 1M CaCl solution. The solution was allowed to stand for one hour, boiled for few minutes and filtered. The residue was washed with boiling water until free from chlorides. It was boiled with water and filtered on a Gooch crucible, washed with water again, dried (at 40°C overnight) and weighed. Pectin content was calculated on a 100g basis.

e. **Tannin**

Tannin content of apples was determined using the modified calorimetric method of Folin-Denis as described by Joslyn (1970). One gram of sample was boiled for one hour in 20ml of distilled water (water volume being maintained during boiling) cooled and filtered. To each test tube, 0.3ml of filtrate was pipetted and made up to 1ml with distilled water. Folin-Denis reagent (0.5ml) was added along with 1ml of saturated sodium carbonate and the volume made up to 15ml with distilled water. The mixture was well mixed by shaking and the absorbance determined at a wavelength of 595nm, using a spectrophotometer. Determinations were done in triplicates. A standard curve was obtained using varying concentrations of standard tannic acid (0- 1mg/ml). From this a regression equation was obtained and tannin concentration of samples was calculated and expressed in g/100g.

f. **Vitamin C**

The 2,6-dichlorophenolindophenol dye titration method (Pearson 1976) was used for the duplicate determinations of vitamin C content in cashew apple samples.

g. **pH**

Triplicate determinations of pH was done by blending ten grams of apple sample with 40ml of distilled water by means of a pH meter (TOA HM-305).

h. **Titrateable Acidity**

AOAC, (1975) Method 22.060 was used and the sample titrated against 0.1N NaOH to a phenolphthalein end point. The determination was done in triplicates. Acidity of cashew apple was calculated as grams Malic acid per 100 gram sample.

i. **Crude Fat**

Duplicate determinations of fat content of cashew nut kernel was done using the gravimetric method of AOAC (1990) Method: 984.22. Calculations were done on dry matter basis.

j. **Crude Protein**

Nitrogen content of cashew nut kernels was determined using the Kjeldhal distillation method described by AOAC,(1990) Method 950.48. Protein conversion factor of 5.25 for cashew nut (Pearson, 1976) was used to calculate the protein content on dry matter basis and duplicate determinations were made.

k. **Ash**

Duplicate determinations of ash content was done using AOAC Method (AOAC, 1975). Approximately 2g of sample was used. The ash content was calculated as 100g/sample and on dry matter basis.

1. Minerals

Red long and yellow round cashew cultivars were used for the analysis. The minerals determined were zinc, copper, magnesium, iron, calcium, potassium, sodium and phosphorous. Samples were wet digested using approximately one gram of sample.

Zinc, magnesium, calcium, copper and iron contents were determined in triplicates by means of an atomic absorption spectrophotometer (AAS3, CARL ZEISS JENA, Germany). Duplicate determinations of sodium and potassium contents of samples were done using a flame photometer (PFP7, Jenway UK.). Phosphorous was determined spectrophotometrically and the determination was done in duplicate.

3.2.3 Changes in Pigment Content of Cashew Apples during Growth and Development

3.2.3.1 Experimental Design

A 2 x 9 factorial design based on cultivar (x 2) and growth time (x 9) was used for this experiment as indicated below:

<u>Factor</u>	<u>Level</u>
Cultivar	redround, yellowlong
Growth time	0,1,2,3,4,5,6,7,8 weeks (0 - Fruit set)

3.2.3.2 Sample Preparation

The method of Ikan (1991) was used for the extraction of pigment from apple samples. Epidermal layer of apples was obtained by carefully peeling using a sharp Knife. About 2-5g of fresh epidermal tissue was blended with 40ml acetone, 60ml hexane and 0.1g $MgCO_3$ using a Waring blender. The mixture was blended for 5 minutes, filtered with a Buchner funnel and

the residue was washed with 25ml acetone followed by 25ml hexane. The extract (filtrate) was then transferred into a separation funnel and washed with five 100ml portions of water. The upper layer was transferred into a 100ml volumetric flask containing 9ml acetone and made up to the mark with hexane. Alcohol (80ml in conjunction with 60ml hexane may be used instead of acetone for the extraction).

3.2.3.3 Analysis

a. **Spectral studies on extracts**

Absorbance of the extracts was read at varying wavelengths from 370 700nm using a spectrophotometer. Readings were at intervals of 5nm and when a peak absorbance was obtained, reading of 1nm intervals were recorded around the peak. Data obtained was used in the plotting of spectral curves.

b. **Chlorophyll**

Chlorophyll content (Total chlorophyll, chlorophyll a and b) of the extracts was determined using the spectrophotometric method described by AOAC (1975) Method 3.105 with some modifications.

i Sample preparation

Twenty five to fifty milliliters of the extract was pipetted into a separator containing about 50ml ether. Water was carefully added until all fat soluble pigments apparently enter the ether layer and the water layer was drained and discarded. The first separator containing the ether layer was placed at the upper rack for support. A second separator containing 100ml of water was placed below the first one and the ether solution was allowed to drain slowly into it.

This was washed and the water layer was drained. Fresh water was then placed in the first separator and the same procedure followed. This step was repeated seven times and then the ether layer was transferred into a 100ml volumetric flask, diluted to volume and mixed well.

ii Spectrophotometric measurements

About two grams anhydrous Na_2SO_4 was poured into a 60ml reagent bottle which was later filled with ether solution of the pigment. Pure ether solution of the pigment was not diluted because its absorbance was in the stated range (0.2-0.8). The cuvettes to be used for the readings were first cleaned with alcohol and then with dry cotton wool. Absorbance readings of solution against solvent was done at 1nm intervals from 658-665nm. The highest value was found to be at 660nm as required, so no adjustments were made on the instrument. Absorbance of ether solution of pigment was read at 660nm and 642.5nm for each of the samples, using the spectrophotometer. Triplicate determinations were made and calculated as indicated below :

$$\begin{aligned}
 \text{Total Chlorophyll} &= 7.12 A_{660.0} + 16.8 A_{642.5} \\
 \text{Chlorophyll a} &= 9.93 A_{660.0} - 0.777 A_{642.5} \\
 \text{Chlorophyll b} &= 17.6 A_{642.5} - 2.81 A_{660.0} \\
 A_{660.0} &= \text{Absorbance at 660nm} \\
 A_{642.5} &= \text{Absorbance at 642.5nm}
 \end{aligned}$$

3.2.4 **Processing of Cashew apples and Evaluation of Quality by Objective and Sensory Methods**

3.2.4.1 Effects of processing and storage on quality indices of cashew apple juice

a. Experimental design

A 4 x 4 factorial design was used for this study with principal factors as storage time (x 4) and processing methods (x 4).

<u>Factors</u>	<u>Levels</u>
Methods of processing	No processing (Control); Peeling; Steaming; Peeling before steaming
Storage time	0, 1, 4 and 7 days

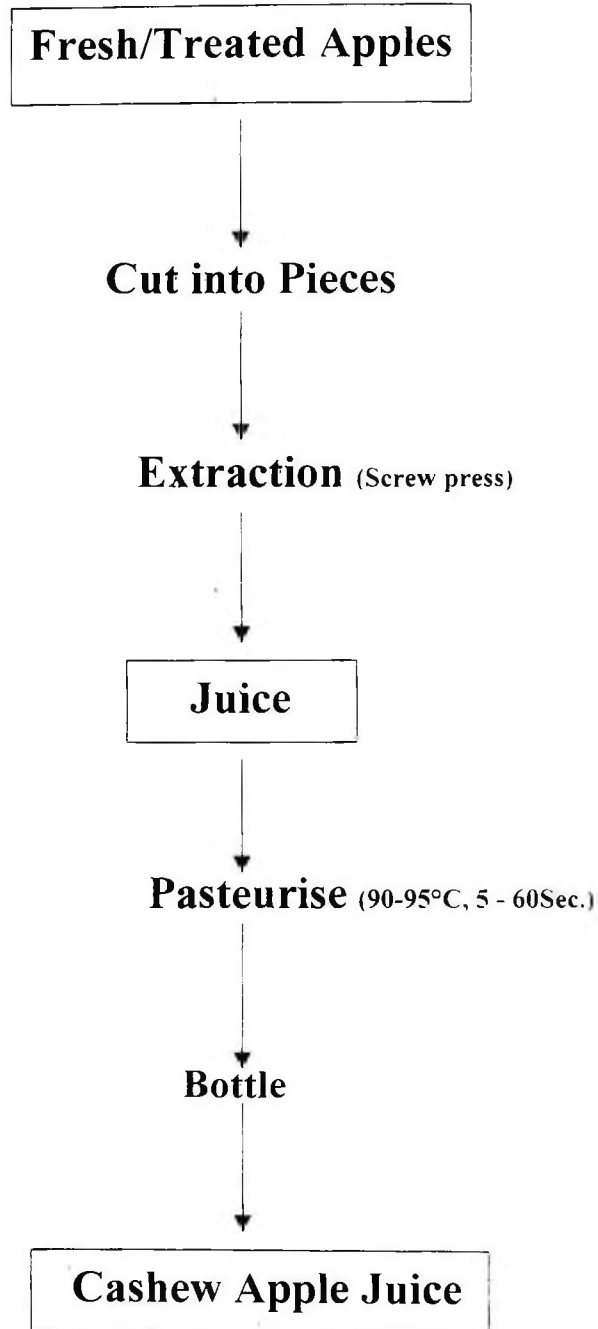
b. Sample preparation

Fresh and fully ripen cashew apple samples were used for the study. The nuts were detached from the apples and apples were thoroughly rinsed with clean water. The apples were then divided into four batches and each batch was treated differently. The treatments were peeling, steaming and peeling before steaming. One batch was left untreated i.e the control. Steaming of the apples was done using a steam exhaust box at 50 psi for 5 minutes. The samples obtained from the above treatments were then processed into juice as indicated in the flow diagram (Figure 3). Four different products were obtained after the treated and untreated apples were processed into juice and these were coded as follows:

- WAJ - Whole apples juice (control)
- PAJ - Peeled cashew apple juice.
- SAJ - Steamed cashew apple juice
- PASJ - Peeled before steamed cashew apple juice.

The bottled juices were stored at room temperature and analysed at 0, 1, 4 and 7 days.

Figure 3. Flow diagram for cashew apple juice processing



c Analysis**i. pH**

The pH of samples was measured with a glass electrode pH meter (TOA pH meter HM-305) with a thermo-sensor attached.

ii Titratable acidity

Ten milliliters of sample was diluted to 100ml with distilled water. Ten milliliters of the diluted sample was titrated against 0.01N NaOH to a phenolphthalein end point. Determinations were done in triplicates. Acidity was calculated as gram Malic acid per 100g

iii. Tannin

Triplicate determinations of the tannin content of the samples was determined as described in section 3.2.2.3 (e). The sample was diluted (1 in 100ml) but not boiled.

iv. Absorption Spectra

Absorbance of each sample at varying wavelengths of 380-550nm was obtained by scanning them through a spectrophotometer. Absorption spectra for each sample was plotted from the data obtained.

3.2.4.2 Sensory Evaluation

Juice obtained from processed samples including the control, were evaluated by sensory methods. Multiple comparison test (rating) described by Meilgard *et al.*, (1991) was used to evaluate quality characteristics of the cashew apple juices.

- | | | | |
|----|----------------|---|---|
| 1. | Cashew Flavour | - | A seven point hedonic scale with 1 representing none, 4-mild distinct and 7-very strong was used. |
| 2. | Astringency | | A seven point hedonic scale was used. 1-none, 4-very moderate, and 7-very high. |
| 3. | Colour | | Five point hedonic scale was used. 1- colourless, 3-yellow and 5-dark. |
| 4. | Sweetness | | A seven point hedonic scale was used. 1- none, 4- and 7-very sweet. |

Acceptability of the above quality indices were determined using acceptability test where 1 indicated most acceptable and 4 was least acceptable. Overall product acceptability was determined using a nine point hedonic scale, 1- like extremely, 5-neither like nor dislike and 9-dislike extremely. Samples of the ballot sheets used for the evaluation of quality characteristics of cashew apple juice are shown in Appendices 43-47.

Twenty panelists i.e. students from the department of Nutrition and Food science were selected based on their familiarity with cashew apples, liking for the fruit and availability. Samples were served chilled (about 5 min after being taken from the refrigerator). Samples were randomly coded and presented simultaneously to the panelists in clean transparent plastic cups. The categorical scores were converted into numerical ones and tabulated. The rank sum of each sample based on the various quality indices measured were also calculated.

4.1 PHYSICAL CHANGES DURING GROWTH AND MATURATION OF CASHEW

4.1.1 Field Observations during Growth and Maturation of Cashew

Some of the cashew cultivars used in the study are shown in Figures 4-6. The ripe apples look completely different from the nuts i.e. the apples are much bigger in size and more colourful in appearance. A series of physical transformations were observed in cashew apples and nuts during 5 weeks of growth (Figure 6 a-e). Some of these were changes in size and colour. The size of both apple and nut increased during the growth period of 5 weeks (Figure 6 a-e). Increase in the size of the apple was observed to be gradual from 1-3 weeks. The cashew nuts however appeared to increase in size significantly at the initial growth stages from 1-3 weeks (Figure 6 a-e). The apple and nut appeared green from 1-4 weeks of growth. At 5 weeks, the green colouration in the apples had started disappearing which indicated the onset of ripening (Figure 6 a-e).

4.1.2 Weight

4.1.2.1 Whole Cashew, Apple and Nut

Weight changes in whole cashew, the apple and nut were monitored during growth and maturation. Continuous increase in the fresh weight of whole cashew with increasing time of growth was observed for all cultivars (Figure 7a). At fruit set, the weights ranged from 0.67-0.97g. Initial slow increases in weight occurred at the early developmental stages up to 4 weeks, after which rapid increases occurred till the eighth weeks where maximum values ranging from 46.88 - 74.60g was attained (Figure 7a). The apple and nuts however showed

Figure 4. Red cashew cultivar at the ripe stage

- | | | |
|---|---|-----------|
| A | - | Red round |
| B | | Red long |

A



B



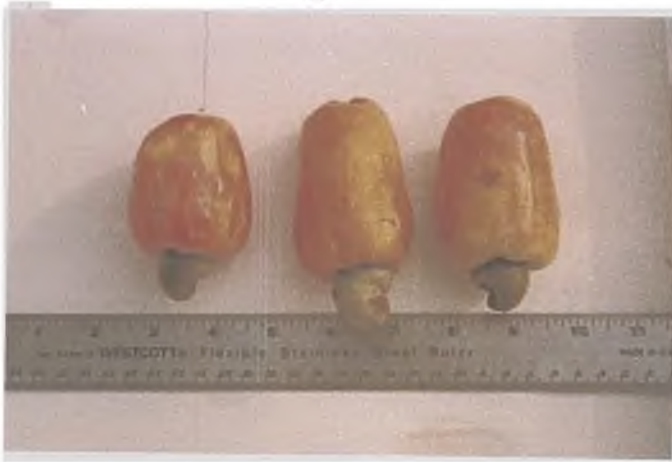
Figure 5. Orange and yellow cashew cultivar at the ripe stage

A		Orange round
B	-	Orange long
C	-	Yellow long

A



B



C

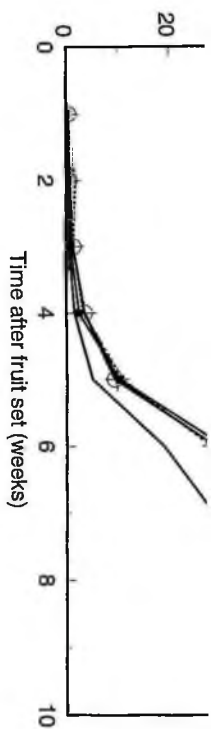


Figure 6. Physical changes during growth and maturation of yellow long cashew cultivar

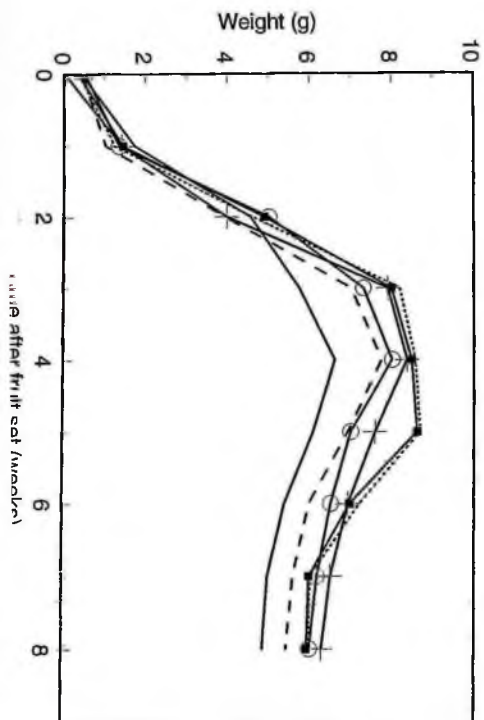
A		One week
B		Two weeks
C		Three weeks
D	-	Four weeks
E	-	Five weeks



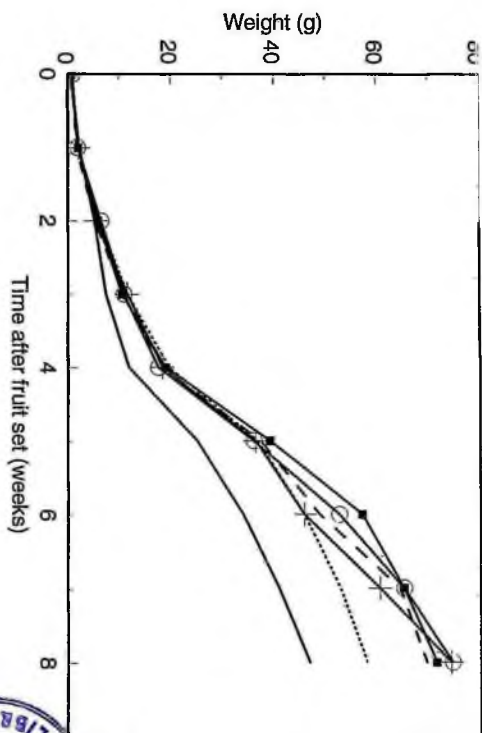
Figure 7. Weight changes in whole cashew (A), cashew apple (B) and cashew nut (C) during growth and maturation



C



A



B



different trend of changes in their weights during growth (Figure 7 b, c). Changes in the weight of apples followed the same trend as the whole cashew (Figure 7a, b). Increases in apple weight after fruit set to 4 weeks was minimal, this was followed by four weeks of rapid and continuous increases which includes the ripening period (Figure 7b). Maximum weights of apples occurred at 8 weeks and ranged from 41.99 ± 0.19 - 68.56 ± 0.32 g. Variation in weights of apple cultivars at fruit set was very narrow (0.31 ± 0.01 - 0.43 ± 0.01 g) compared to that which occurred at 8 weeks (Figure 7b). This may mean that, the weights of the various cultivars of apples become more differentiated as growth time increased.

Unlike the apples, changes in the weight of nuts occurred in two stages (Figure 7b, c). There was an initial rapid accumulation of biomass after fruit set reaching maximum values at 4 weeks for red round, yellow long, orange round and orange long cultivars and at 5 weeks for red long and yellow round cultivars. This was followed by decreases till the eighth week where nuts attained a proportion of their maximum weights (4.89 ± 0.09 - 6.33 ± 0.15) (Figure 7c). The period of decreasing weight can be termed as the drying period. Filgueiras *et al.*, (1995), reported that cashew nut loose about 15% of its weight during the drying period. In this study, percentage weight loss during this period ranged from 24.46 - 30.94% in the nuts.

Minimal increase in apple weight at early stages of growth (fruit set - 4 weeks) may be due to low concentrations of growth promoting substances. This could have shown their influence on slow material deposition at this period. Rapid weight increases at later stages of growth (4-8 weeks) could be attributed to rapid formation of tissues and cells, accumulation of moisture and other substances which contribute to the weight of the apples i.e. total solids and sugars etc. Decreases in weight of nuts after reaching maximum values is mainly attributed to loss of moisture, this causes the nut to dry and harden leading to shrinkage and decrease in

size. This stage is characterised by colour change from green to grey (Ohler, 1988).

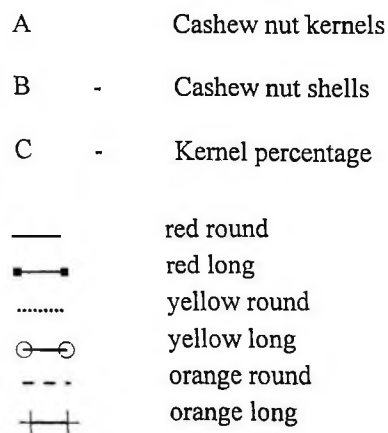
Results from this study generally showed that, the weights of apples ($0.31 \pm 0.01 - 0.43 \pm 0.01$ g) and nuts ($0.35 \pm 0.01 - 0.53 \pm 0.02$ g) were comparable at fruit set. As apples increased slowly at the early developmental stages (fruit set to 4 weeks), the nuts increased rapidly at the same period to attain maximum weight at 4 and 5 weeks. Whilst the nuts decreased in weight after this, weight of apples increased rapidly. Similar observations was made by Filgueiras *et al.*, (1995). At 8 weeks the apples were much higher in weight than the nuts (Figure 7b, c).

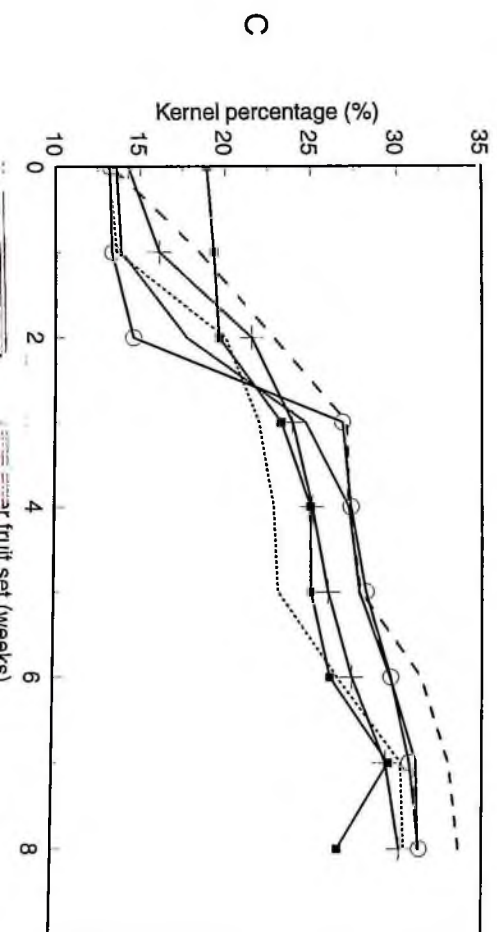
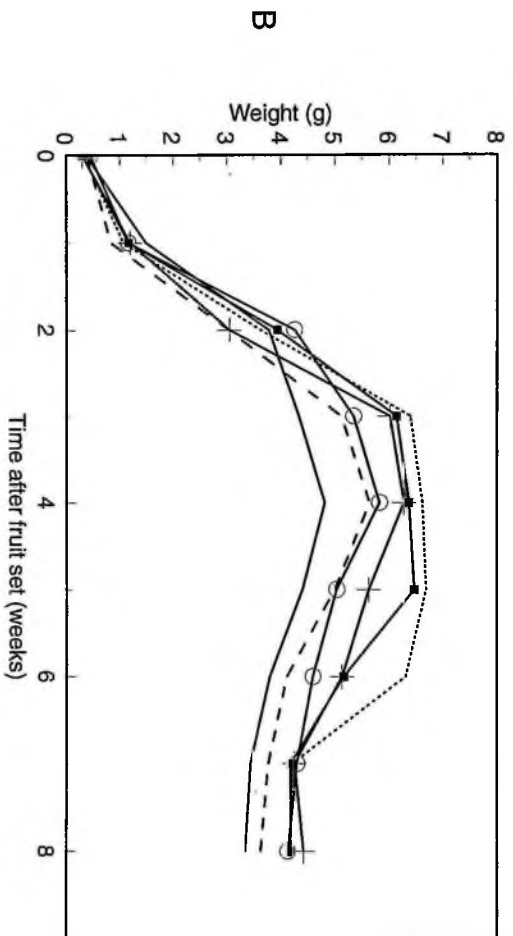
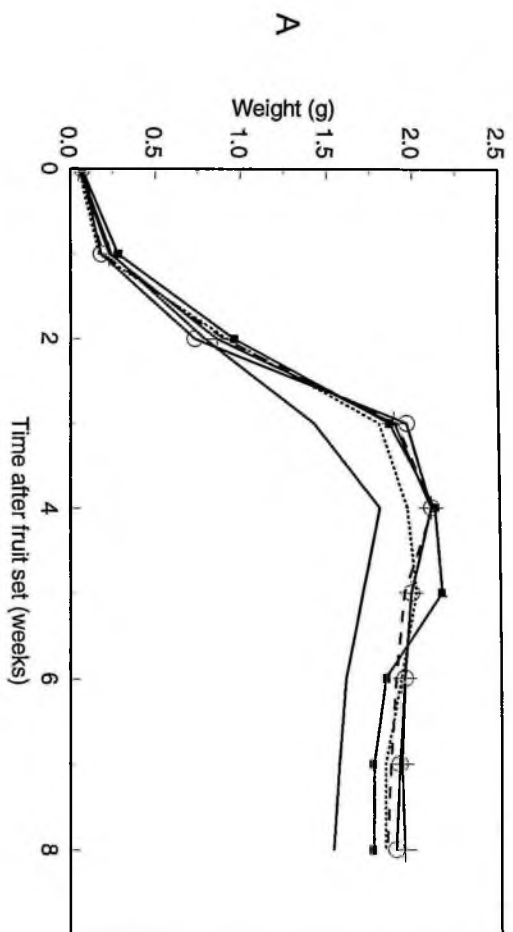
Analysis of variance of data showed that growth time and cultivar had significant effect on weights whole cashew, apple and nuts ($P < 0.05$) (Appendices 1-3). Multiple range analysis (LSD) on maturation time by the weights indicated significant differences in weight of whole cashew at 4 to 8 weeks, no differences were observed from fruit set to 2 and at 3 and 4 weeks. No differences were observed in weight of apples at fruit set to 4 and at 7 and 8 weeks, the differences occurred after 4 till 7 weeks. For the nut, differences occurred at fruit set to 2 weeks, 2 and 8 and at 3 and 6 weeks. No differences was observed at 3 - 5 weeks and 6-8 weeks.

4.1.2.2 Components of Cashew Nuts

Changes in the weight of cashew nut shell and kernel was determined during growth. The kernel percentage was then calculated (Figure 8a, b, c). Growth pattern with respect to weight changes in the shell and kernel of the nut appeared to follow a trend similar to the whole nut (Figures 7c and 8a, b). This was expected since shells and kernels are components of the nut. The shells had higher weights than the kernels with values ranging from $0.30 \pm 0.01 - 0.45 \pm 0.01$ g for the shells and $0.05 - 0.07$ g for the kernels at fruit set (Figure 8a, b).

Figure 8. Effect of growth and maturation on the weight of components of cashew nut





apid increases in their weight occurred after fruit set with the attainment of maximum values : 4 and 5 weeks depending on the cultivar (Figure 8a, b). Decreases occurred after this till weeks (Figure 8a, b). At the eighth week, the shell weight (3.34 ± 0.05 - 4.18 ± 0.05 g) was ill higher than that of the kernel (1.53 ± 0.01 - 1.94 ± 0.01 g).

hell to kernel ratio was obtained by dividing the weight of the shell with that of the kernel. he shell to kernel ratio decreased with increasing growth time, it ranged from 4.29 - 6.60% t fruit set and 1.97 - 2.38% at 8 weeks. This observation may be due to higher decreases in hell weight (6.69 ± 0.01 to 3.34 ± 0.05 g) compared to that of kernels (2.16 ± 0.01 - $1.53 \pm .01$ g) from 4 and 5 weeks to 8 weeks (Figure 8a, b). Faster increase in weight of kernels ompared to those of the shells at early growth stages (fruit set to 4 and 5 weeks) may also be .contributing factor. Decrease in shell to kernel ratio in nuts is desirable because the kernel s the edible and most important component of the nut (Wickens, 1995).

The kernel percentage was obtained by dividing the weight of kernel with that of the nut and multiplying by 100. Kernel percentage is a very important quality attribute of nuts. This is ecause the processing industries buy the nuts on weight basis and small differences may mean profit or loss (Ohler, 1988). Although all physical indices measured on nuts followed a two stage pattern, continuous increases in kernel percentage was observed from fruit set till 3 weeks (Figure 8c). Maximum values were attained at 8 weeks which is desirable and ranged from 29.60 - 33.64%. Harvesting at 8 weeks is therefore necessary to obtain nuts with optimal kernel percentage values.

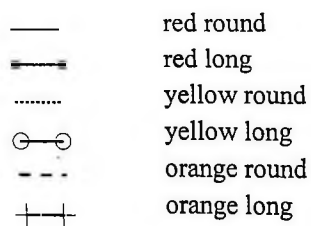
analysis of variance of results showed that the weights of kernel and shell were significantly influenced by growth time and cultivar (Appendices 4 and 5). Multiple range analysis on growth time showed that the differences observed in kernel weight was from fruit set to 3 weeks and at 3 and 8 weeks. From 6-8 weeks and 4 weeks no differences were observed. The same occurred at 4 and 5 as well as 5 and 6 weeks. From fruit set to 2 weeks and at 5 and 6 weeks, differences in shell weight was observed. At 7, 8 and 3 weeks and 3-6 weeks the shell weights were comparable. In terms of cultivar i.e. kernels, the difference was between yellow round and orange round and also red long and orange long. For the shells, it was between red round and orange long cultivars.

1.1.3 Dimensions

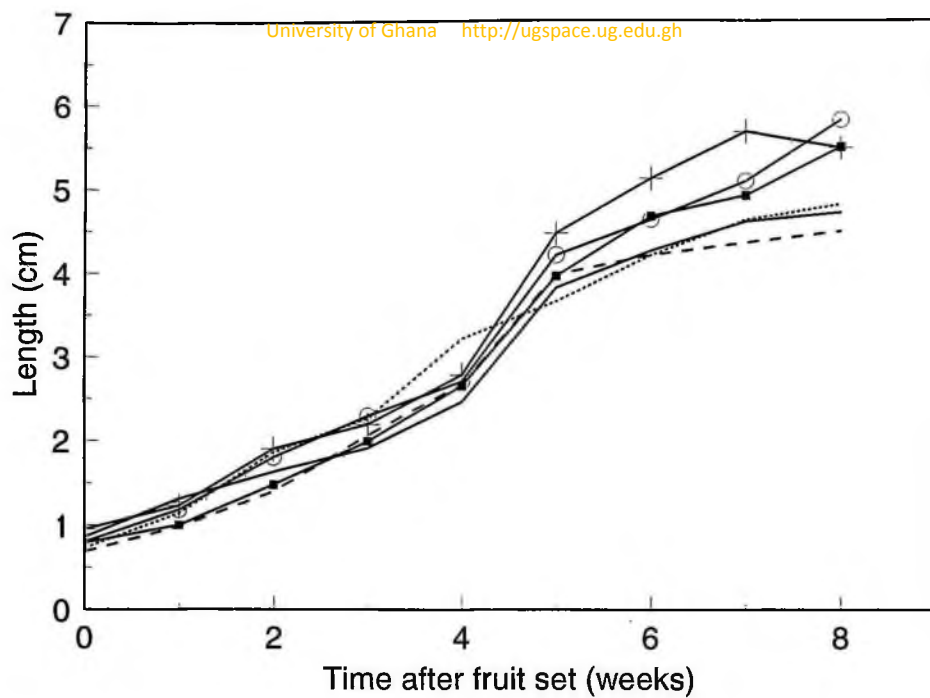
1.1.3.1 Length of apple and nut

Changes in the length of apple and nut followed different trends during growth and maturation (Figure 9a, b). A single phase occurred in the apples whilst the length of nuts followed a two stage trend, these were similar to changes in their respective weights (Figure 9a, b). The lengths of apples (0.69 ± 0.03 - 0.95 ± 0.01 cm) and nuts (0.72 ± 0.01 - 0.96 ± 0.02 cm) were comparable at fruit set. After fruit set, nut length increased more rapidly compared to the apples, reaching maximum values at 4 and 5 weeks depending on the type of cultivar (Figure 9a, b). The nuts experienced decreases in length after this till the eighth week, the apples however, increased more rapidly in length at the same period (Figure 9a). At 8 weeks, the apples attained maximum lengths (4.72 ± 0.11 - 5.82 ± 0.12 cm), and the nuts attained a proportion of their maximum lengths (2.41 ± 0.01 - 2.90 ± 0.02 cm). The percentage of maximum length attained by nuts during the drying period ranged from 73.24-85.03%. Ohler (1988) reported that cashew nuts at maturity attain about 75 % of their maximum size and this

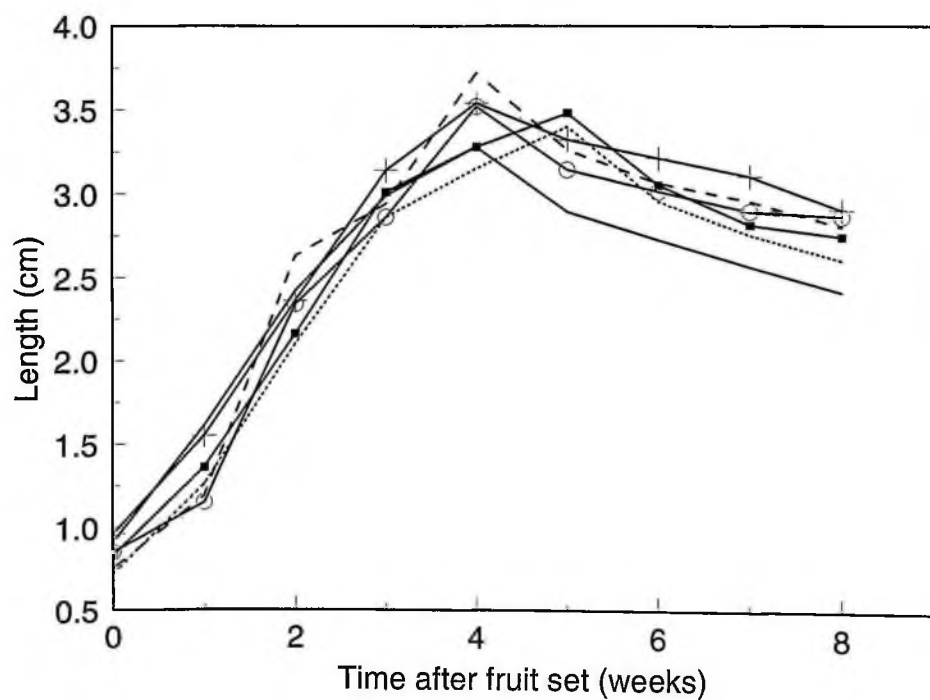
Figure 9. Changes in length of cashew apple (A) and cashew nut (B) during growth and maturation



A



B



is mainly due to moisture loss. The data suggests that loss in weight of the nut observed with maturation is accompanied by a shrinkage in the size of the nut.

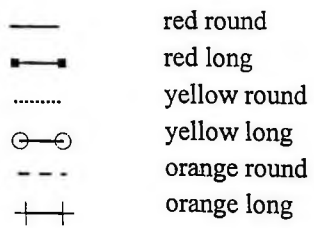
Analysis of variance (ANOVA) of results showed that, growth time and cultivar had significant effect on apple and nut length (Appendices 6 and 7). Multiple range analysis on growth time showed significant differences in apple length from 1 to 6 weeks. At fruit set and 1 week, and 7 and 8 weeks it was comparable. Nut length obtained from fruit set to 2 weeks and at 8 weeks were significantly different. No differences occurred at 5 to 7, 4 and 5 and at 7 and 8 weeks. Multiple range analysis on cultivar showed that the differences between yellow long and orange long apples were significant, for the nuts, it was between orange long and yellow round cultivars.

Correlations between nut weight and its length was high and positive with a coefficient (r) of 0.9604. Between the weight of apple and length a positive and high correlation was observed ($r = 0.9346$). This indicates that the size of apple and nut may be highly influenced by their respective weights.

4.1.3.2. Width and Thickness of cashew nuts

The changes in width and thickness of nuts are also indicators of changes in size during growth and maturation. They followed the characteristic trend that occurred in the physical indices of nuts during growth (Figures 10 and 11). That is initial rapid increases with the attainment of maximum values at 4 and 5 weeks followed by decreases till 8 weeks (Figures 10 and 11). At 8 weeks, the nuts attained widths ranging from 1.73 ± 0.02 - 1.89 ± 0.01 cm and thickness ranging from 1.65 ± 0.02 - 1.79 ± 0.01 cm. The width of the nuts at all stages

Figure 10. Width changes in cashew nut during growth and maturation



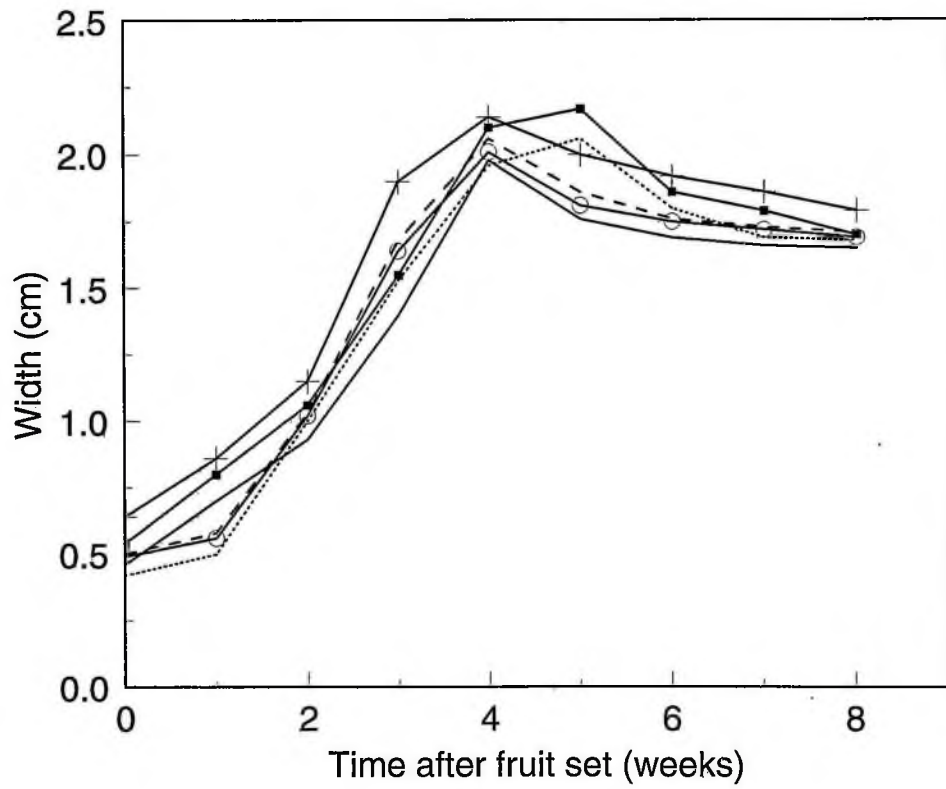
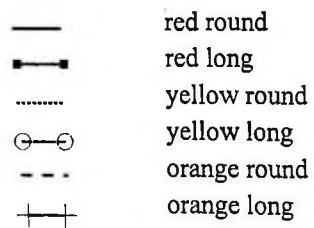
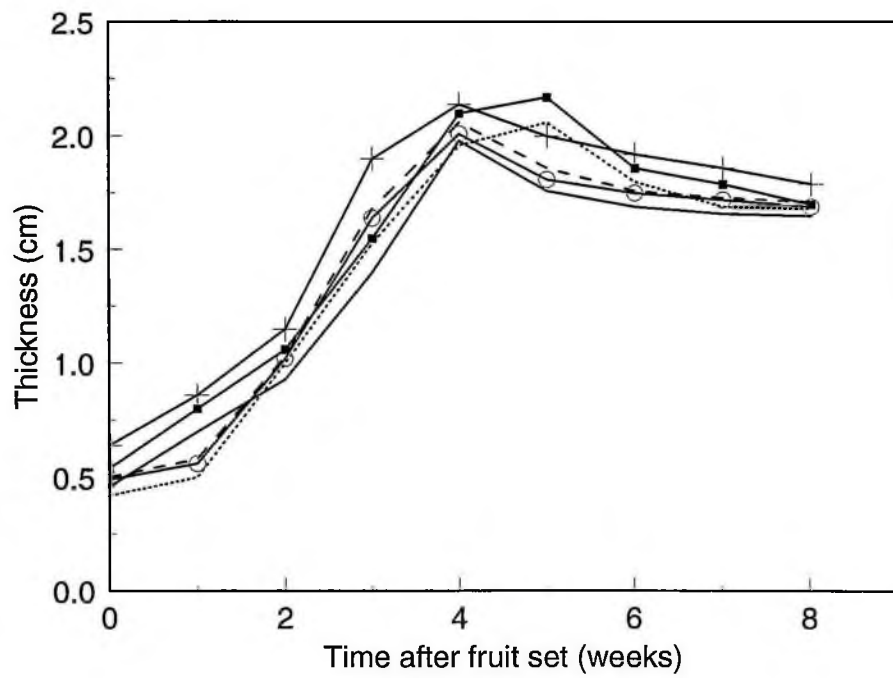


Figure 11. Changes in thickness of cashew during growth and maturation





of growth was found to be higher than that of its thickness although not by a very high margin (Figures 10 and 11).

Analysis of variance on data showed that nut width and thickness were significantly affected by growth time and cultivar (Appendices 8 and 9). Correlations between nut weight and its thickness ($r = 0.9440$) and width ($r = 0.9565$) was high and positive.

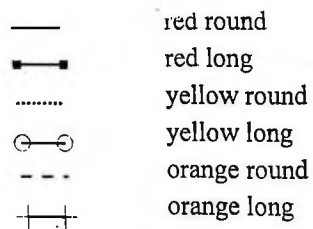
4.1.3.3 Diameter of cashew apples

Top diameter of cashew apples was measured around point of attachment to the nuts and bottom diameter was measured around point of attachment to the parent plant (Figure 2). Changes in the diameter (top and bottom) of apples followed trends similar as its weight during growth (Figure 12a, b). Minimal increases occurred after fruit set to 4 weeks, with rapid increases after this till 8 weeks (Figure 12a, b). At the eighth week, maximum values of top (4.05 ± 0.05 - 4.60 ± 0.05 cm) and bottom (2.95 ± 0.05 - 3.50 ± 0.35 cm) diameters occurred.

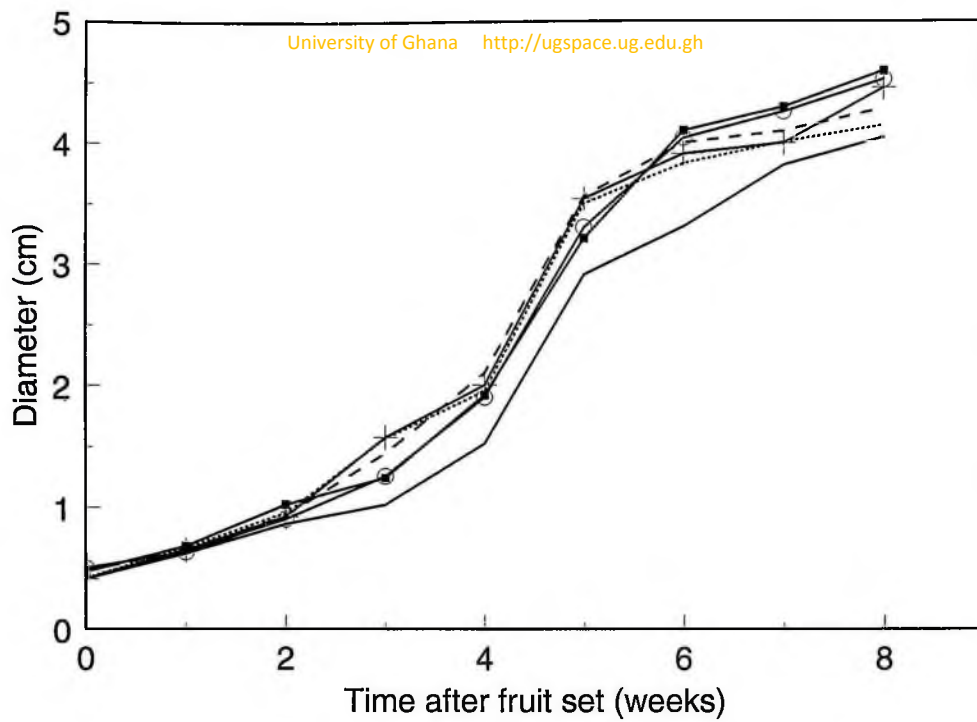
Analysis of variance on data showed that growth time and cultivar had significant effect on the diameter (top and bottom) of the apples (Appendices 10 and 11). Correlation coefficient (r) between weight of apple and its top and bottom diameter was 0.9564 and 0.9618) respectively. Rapid increases in diameter of the apples at the later stages of growth (4-8 weeks) may be due to rapid increases in weight at that same period.

Correlations between the physical indices of cashew (apples and nuts) and growth time were positive. This implies that the physical indices of cashew increased with maturation (Table 5). Physical indices of apples however had stronger correlations with growth time as compared to those of the nuts (Table 5).

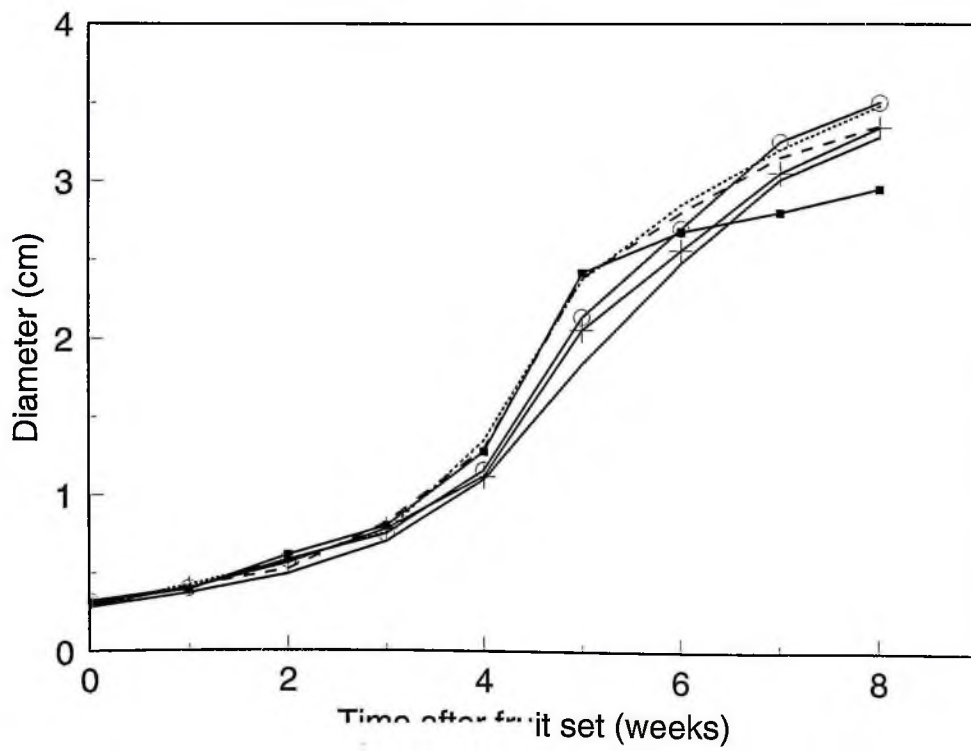
Figure 12. Changes in the top (A) and bottom (B) diameter of cashew apples during growth and maturation



A



B



They may therefore be better indicators of growth time. The highest correlation coefficient was for apple length ($r = 0.9712$) and the least was for cashew nut shell weight ($r = 0.5734$) (Table 5).

Table 5. Correlation coefficient between growth time and physical indices of cashew

Physical Indices	Correlation Coefficient (r)
Weight of whole cashew	0.9469
Weight of apple	0.9198
Weight of cashew nut	0.6521
Cashew nut shell weight	0.5734
Cashew nut kernel weight	0.7991
Apple length	0.9712
Nut length	0.7074
Nut width	0.7364
Nut thickness	0.7815
Top diameter of apple	0.9691
Bottom diameter of apple	0.9672

4.1.4 Physical indices of cashew after 8 weeks of growth

After 8 weeks of growth, the physical indices of apples i.e. weight and size (length and diameter) were at maximum values which is desirable. This is because the size of apple as an industrial raw material has direct bearing on the volume of sugar based liquid that could be extracted and products that could be produced from it (Nyamekye - Boamah, 1996). The nuts attained a proportion of their maximum weight and size (length, thickness and width) after 8 weeks which was mainly due to loss of moisture which is desirable. The kernel percentage which is one of the most important physical indices of the nut was maximum with the shell to kernel ratio being minimum after 8 weeks, this is desirable.

4.2 CHEMICAL CHANGES IN CASHEW DURING GROWTH AND MATURATION

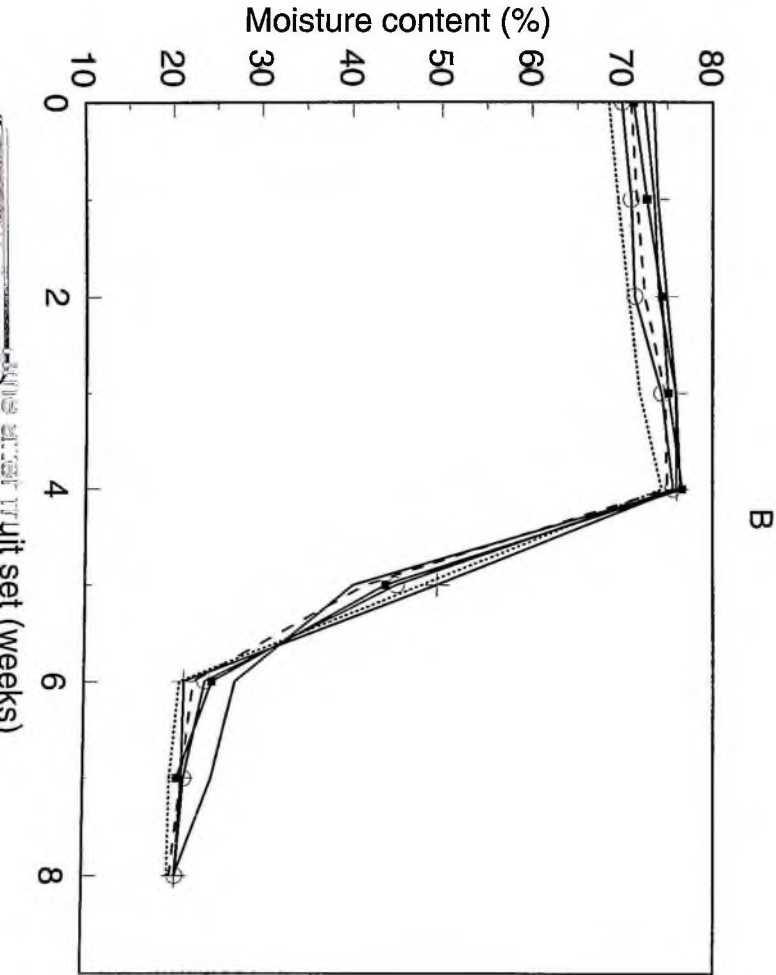
4.2.1 Moisture Content

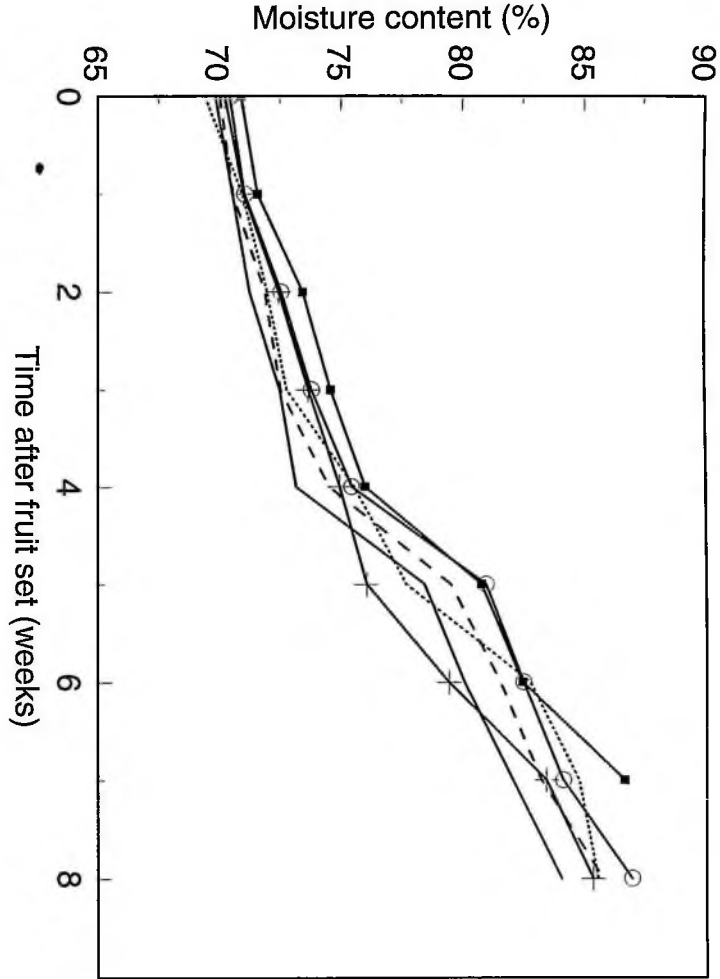
Moisture content of apple cultivars studied ranged from 69.42-70.90% at fruit set. All the cultivars showed consistent increase in moisture of apples after fruit set. At the eighth week of growth, maximum moisture ranging from 84.05-86.95% was attained (Figure 13a). Unlike the apples, the nut kernels showed a two stage pattern of moisture changes which involved slight increases till the 4th week, followed by drastic reductions till the eighth week after fruit set (Figure 13b). At 8 weeks, the kernels attained a proportion of their maximum values and this ranged from 19.46 - 20.42% (Figure 13b). The drastic reduction in moisture contents of the nuts at the later stages of growth is very important for their preservation and processing after harvest (Anstee, 1995). The study showed that cashew apples and nuts follow different metabolic path ways in order to attain their defined end characteristics i.e. dry and hard nuts attached to soft and juicy apples.

A high and positive correlation was obtained between moisture of apple and weight ($r = 0.9685$). This implies that the consistent increase in moisture of apples may be a contributing factor to the rapid increases in weights particularly at the later stages of growth (4-8 weeks). A negative and low correlation ($r = -0.5255$) between kernel weight and its moisture was observed. Analysis of variance of the data showed that growth time had significant effect on apple and kernel moisture. Cultivar had significant influence on apple moisture but not on the kernel (Appendices 12 and 13). Multiple range analysis on growth time showed no significant differences at fruit set and after one week of growth in the apples, the differences were at 1 to 8 weeks. In the kernels no differences were observed at fruit set to 4 weeks and from 6-8 weeks, the difference was at the fifth and sixth week.

Figure 13. Moisture changes in cashew during growth and maturation

A	Apple
B	Cashew nut kernel
—	red round
—■—	red long
.....	yellow round
○—○	yellow long
- - -	orange round
+ - +	orange long





4.2.2

Total solids

The trend of changes in the total solids of apples and nuts during growth and maturation was the opposite to that of moisture (Figure 14a, b). Apples decreased continuously in total solids after fruit set attaining minimum values of 13.05-15.95% at 8 weeks (Figure 14a). Rapid accumulation of dry matter occurred in the kernels after 4 weeks, with optimal values ranging from 79.58 - 80.85% attained at 8 weeks (Figure 14b). Ohler (1988) reported that, cashew apples accumulate dry matter at an increasing rate from the time it is first visible to maturity, although the dry matter percentage generally decreases through out its development.

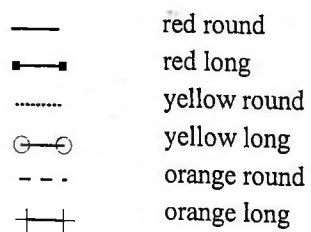
Analysis of variance of results showed that growth time and cultivar significantly affected the total solids of both apple and kernel ($P < 0.05$) (Appendices 14 and 15).

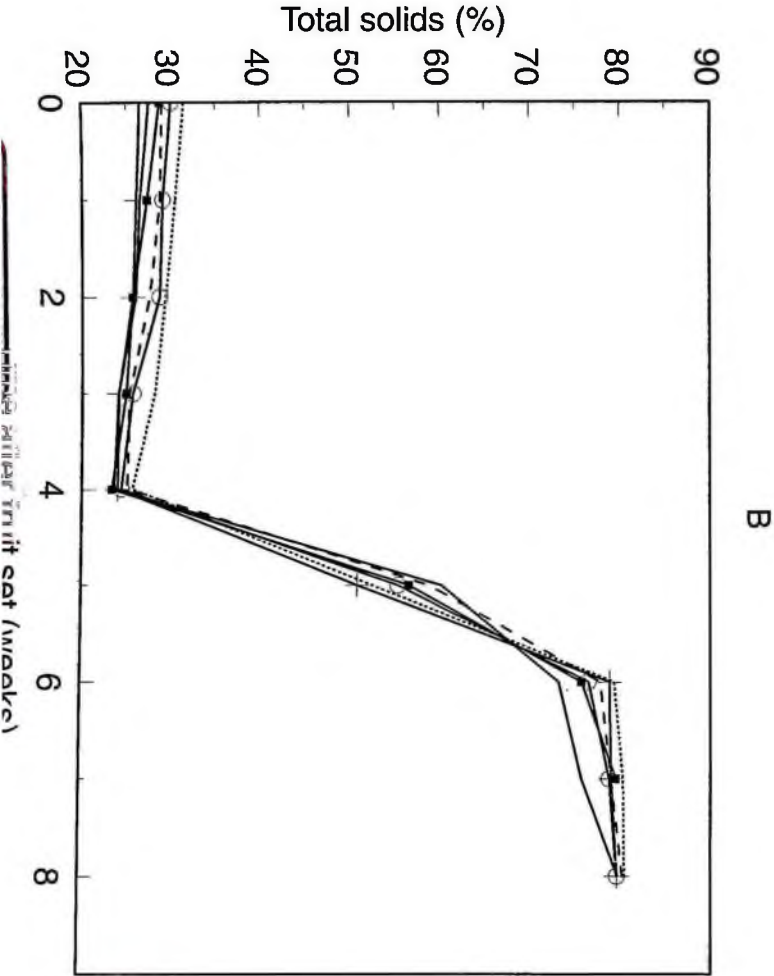
4.2.3

Total Sugars

Total sugars in nuts and apples were determined as percentage invert sugar and reported on dry matter basis. The data obtained showed changes in total sugars of both apple and kernel following similar trend during growth and maturation. This may indicate similar metabolic pathways in their accumulation of sugars i.e. increases with increasing growth time (Figure 15a, b). At fruit set, total sugars ranged from 0.84 - 0.92% for apples and 0.50-0.73% for the kernels. An initial slow increase occurred at the early developmental stages from fruit set to 5 weeks, after which rapid accumulation was observed till the eighth week. This included the ripening period (Figure 15a). At 8 weeks both the apple (9.85 -10.85%) and kernel (5.16 - 6.14%) attained maximum total sugar contents. Cashew apples are therefore more sweet than the kernels. Slight decreases occurred between the 7th and 8th week in red round and orange round apple cultivars (Figure 15a).

Figure 14. Changes in the total solids content of cashew apple (A) and cashew nut kernel (B) during growth and maturation





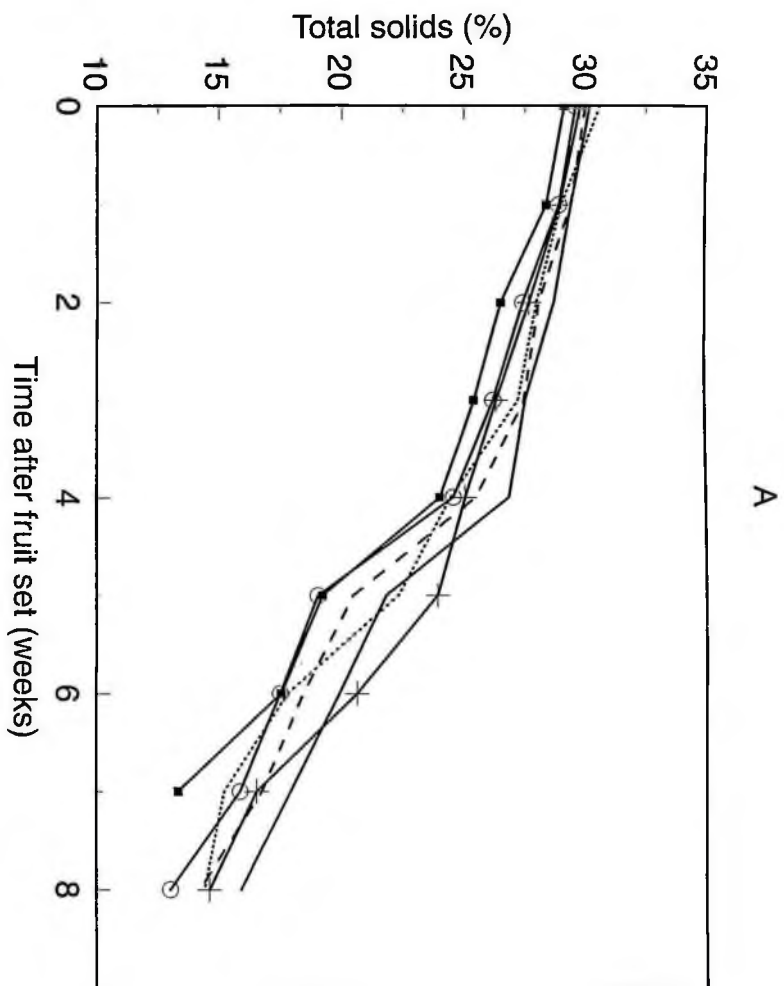
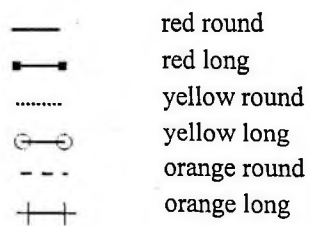
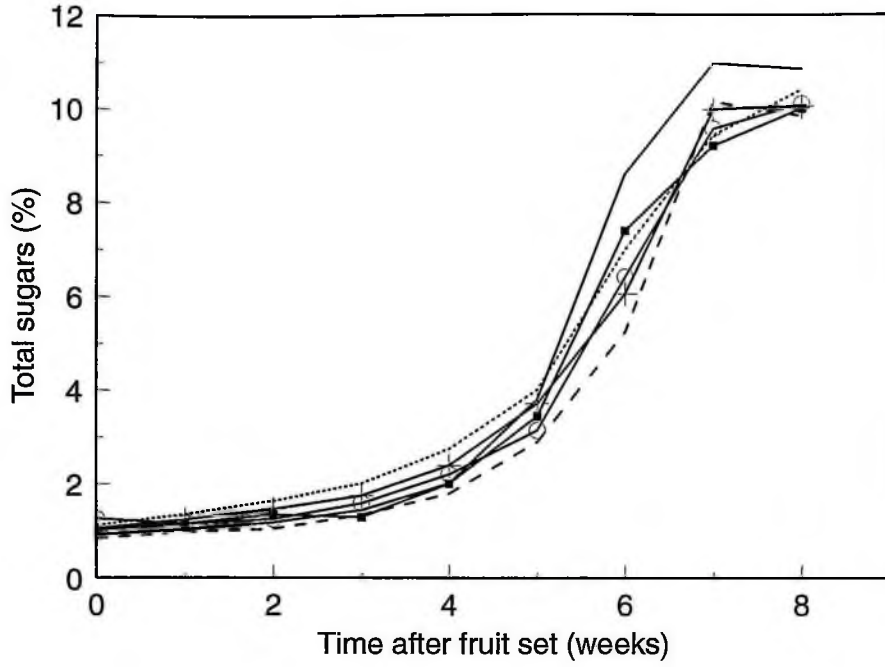


Figure 15. Changes in the total sugars content of cashew apple (A) and cashew nut kernel (B) during growth and maturation

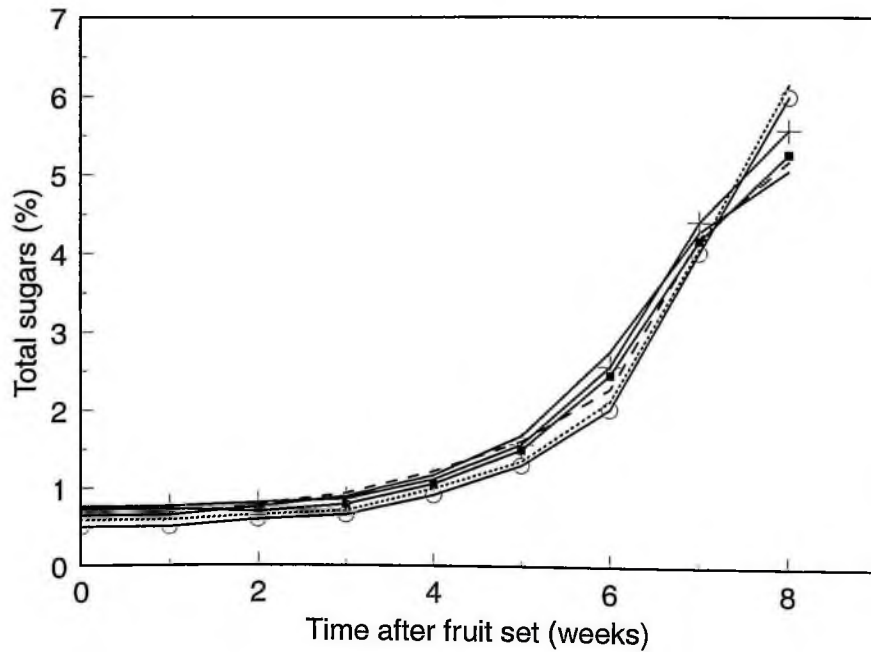


A

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B



Cashew apples intended for fresh consumption and processing must be harvested at the stage of optimal sugar concentration, in the study it occurred mostly at 8 weeks after fruit.

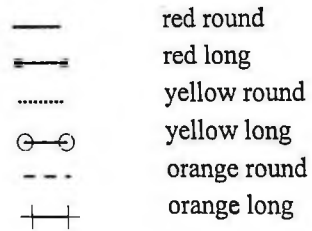
Similar trends were reported by Sawaya *et al.*, (1982) and Rashid *et al.*, (1997) during studies on guava and some Saudi Arabian date cultivars at varying growth stages. Filgueiras *et al.*, (1995) reported rapid accumulation of sugars during ripening of cashew apples. Rapid accumulation of sugars during ripening is due to hydrolysis of starch by specific enzymes (Amylases) to give sugars which produce characteristic sweetness of ripe fruits (Haard, 1985; Mastumoto *et al.*, 1983).

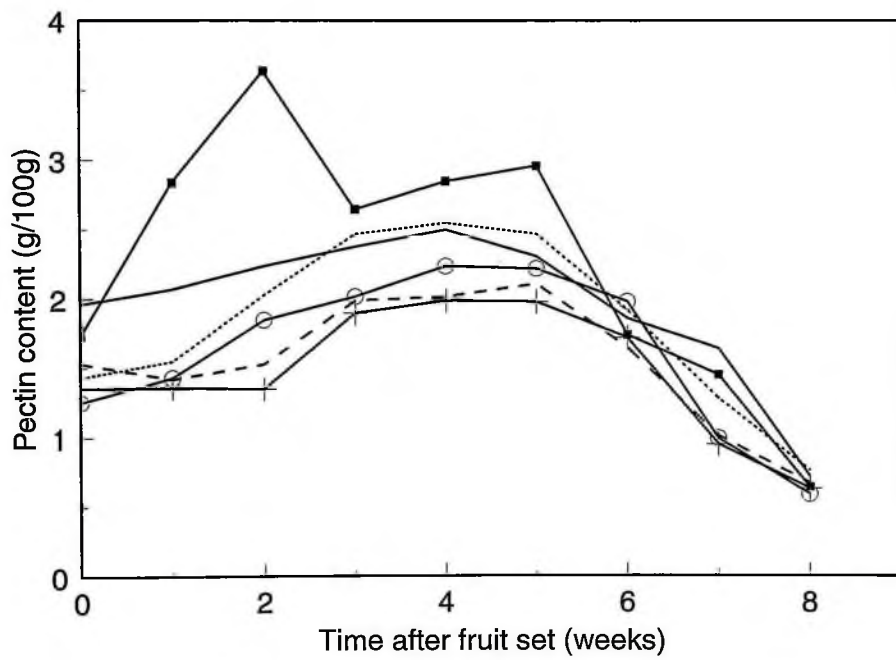
ANOVA of data showed that total sugars of both apple and kernel were significantly influenced by growth time. Cultivar influenced the total sugars of apples but not that of the kernels (Appendices 16 and 17). Multiple range analysis on growth time showed no difference in total sugar of apples attained at fruit set to 3 weeks, 4 and 5 weeks and at 7 and 8 weeks. The differences observed was from 4-7 weeks. Similar trend was observed in the kernel, differences however occurred at 4 and 8 weeks. Differences in cultivar was between orange round and red round apples.

4.2.4 Pectin Changes in Cashew Apples

Pectin substances act as cementing materials, holding the cells of plants together. They therefore contribute greatly to the texture of fruits (Proctor and Peng, 1989 ; Knee and Bartley, 1989). Figure 16 showed an initial increase in pectin content of apples at the early developmental stages reaching maximum concentrations of at 4 weeks for red round, yellow

Figure 16. Changes in pectin content of cashew apples during growth and maturation

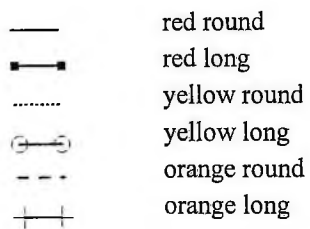


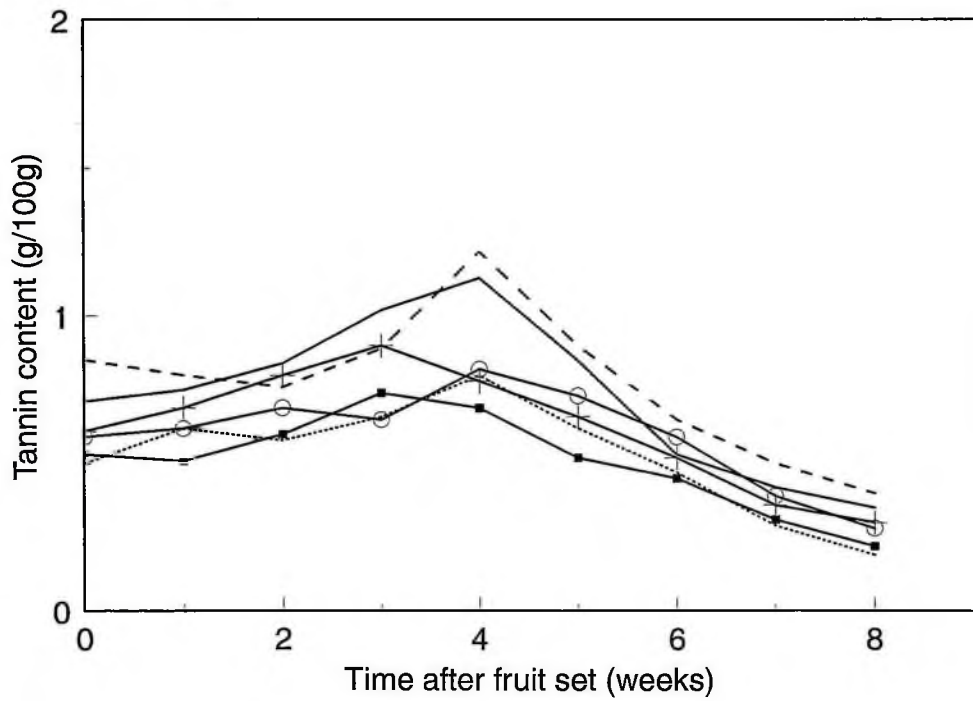


Increase in pectin content during the initial developmental stages may be due to a greater need for the supporting and holding together of rapidly growing cells and tissues. Degradation during the ripening period may be due to its depolymerisation and solubilisation by pectolytic enzymes such as pectin methyl esterase and polygalacturonase (Proctor and Peng, 1989). This causes the cells and tissues to gradually loosen, being torn apart more readily leading to the soft texture of most ripe fruits (Eskin, 1979).

ANOVA of data showed growth time and cultivar had significant effects on pectin content in the apples (Appendix 18). Multiple range analysis on growth time indicated no significant differences at 2-5 weeks. Differences occurred at 7 and 8 and 1 and 5 weeks. Pectin content of orange and yellow cultivars were comparable, differences occurred in orange long, yellow

Figure 17. Changes in the tannin content of cashew apples during growth and development





Depletion commenced after maximum deposition till the eighth week (Figure 17). The study showed that maximum concentration of tannin occurred while the apples were still in their green immature stage (3 and 4 weeks) and minimal values (0.19-0.40g/100g) were observed at 8 weeks where cashew apples had reached a consumable stage, this is desirable. Similar results were observed in guava, peach fruits and strawberries (Rashida *et al.*, 1997; Senter and Callahan, 1990 and Spayd and Moriss, 1981).

Sistrunk (1985) reported that loss of astringency and therefore improvement in the palatability and quality of developing fruits are related to changes in the tannin composition and quantity. Monomeric tannins synthesized at early growth stages are polymerised during further fruit development, leading to increase in the concentration of highly condensed tannins (Porter and Woodruffe, 1984). Decreases in tannins may be to the fact that highly condensed tannins are less soluble and tightly bound to cell and thus reducing assayable tannins (Senter and Callahan, 1990).

A negative correlation ($r = -0.7257$) was observed between moisture and tannin contents of apples. Analysis of variance on data showed that tannin content was significantly influenced by growth time and cultivar (Appendix 19). Multiple range analysis on growth time showed that at fruit set to 2 and 6 weeks, and at 7 and 8 weeks, no differences were observed. Differences occurred at 8, 6, 5 and 4 weeks. In terms of cultivar, the difference was between orange long and red round.

4.2.6 Vitamin C Content of Cashew Apples

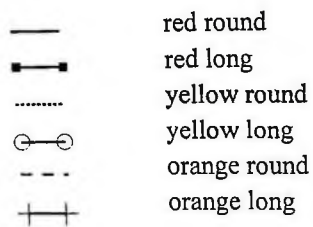
All the cashew apple cultivars showed increase in vitamin C content as growth proceeded (Figure 18). Peak concentrations ranging from 199.34-225.49mg/100g were attained in the apples by the eighth week of growth (Figure 18). Harvesting of apples should therefore be around this stage of growth to obtain maximum vitamin C content which is nutritionally significant. Slight decreases were observed in orange long, yellow round and red long cultivars between the 7th and 8th week (Figure 18). Similar trends were observed by Rashida *et al.*, (1997) and Rodriguez *et al.*, (1971) in guava at varying stages of growth.

ANOVA of the results showed that growth time and cultivar significantly influenced the tannin contents of apples (Appendix 20). Multiple range analysis on growth time showed no differences at 1 to 3 weeks and at 7 and 8 weeks. The differences occurred at 4 to 7 weeks and at fruit set, 4 and 8 weeks. In terms of cultivar, differences were observed between yellow long and red long.

4.2.7 pH and Titratable Acidity of Cashew Apples

pH of a fruit expresses its acidity and titratable acidity is a measure of all the acids in the fruit (Ulrich, 1970). Changes in pH of apples during growth and maturation was opposite to that of the titratable acidity (Figures 19 and 20) . A general decrease in pH with corresponding increase in acidity of the apples was observed as growth increased. Increase in pH and decreases in acidity of apples occurred at the early developmental stages of growth, reaching maximum and minimum values respectively by 3 to 5 weeks depending on the type of cultivar (Figures 19 and 20).

Figure 18. Changes in vitamin C content of cashew apples during growth and maturation



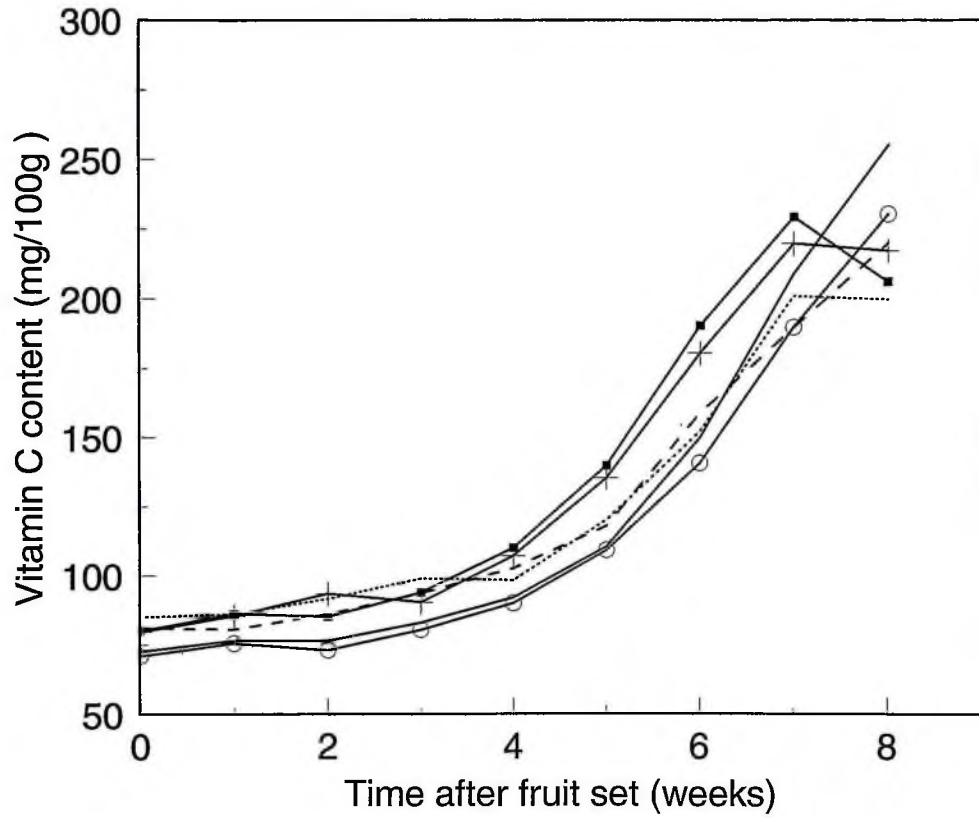
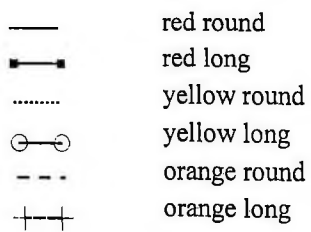


Figure 19. pH changes in cashew apples during growth and maturation



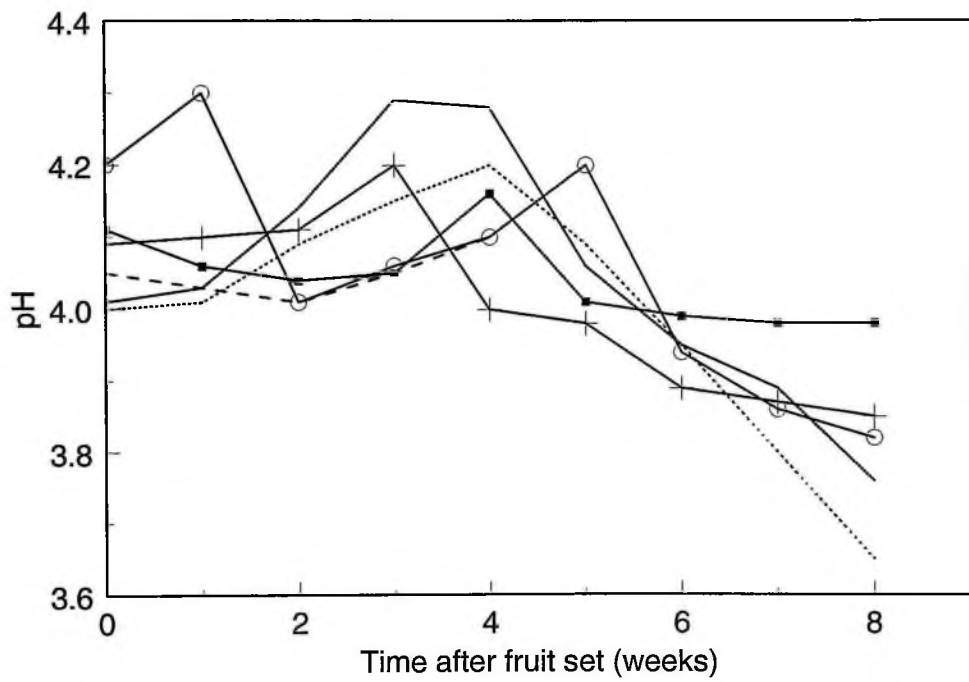
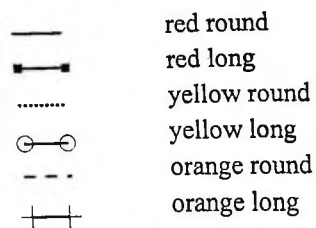
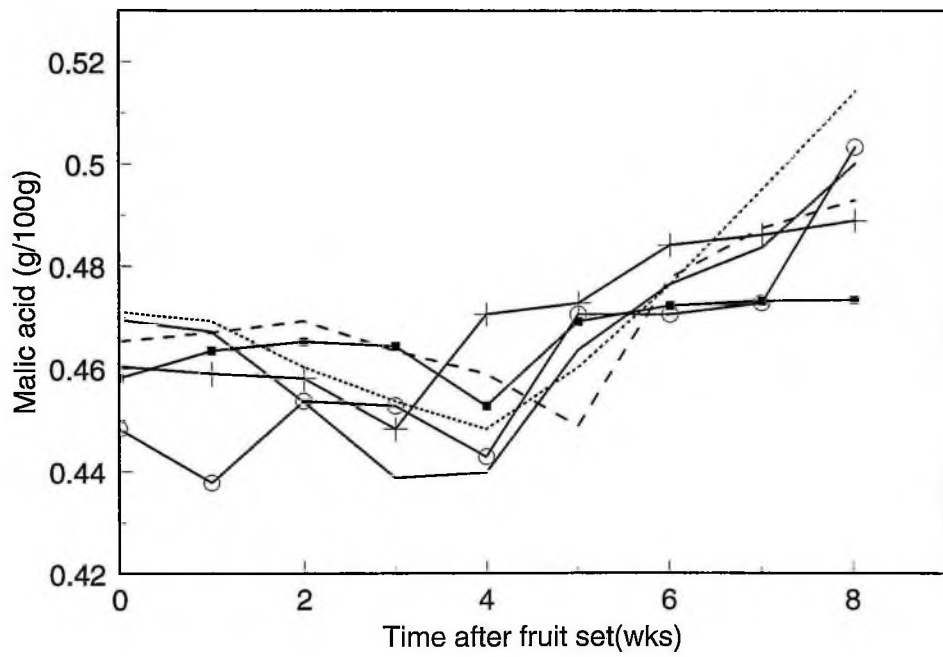


Figure 20. Changes in titratable acidity of cashew apples during growth and maturation





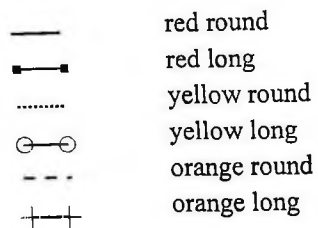
Decreases in pH and increases in acidity followed after this till the eighth week (Figure 19). At 8 weeks, minimum pH values ranging from 3.65 - 3.98 were observed (Figure 19). Ulrich (1970) reported that changes in acid concentration of fruits during their development varies. In bananas, a steady fall from the early to ripening stage was observed whilst peak values was observed in apples and grapes as the fruit matured.

Analysis of variance on data showed that, growth time had significant effect on the pH and acidity of apples, but cultivar did not (Appendices 21 and 22). Multiple range analysis on growth time indicated no significant difference in acidity of apples at fruit set to 5 weeks, at 6 and 7 and 7 and 8 weeks. Significant differences occurred at 4, 6 and 8 weeks. This was similar for pH, the difference was at fruit set, 4 and 8 weeks. A correlation coefficient (r) of -0.7632 was obtained between acidity and tannin contents of apples.

4.2.8 **Fat and Protein in Cashew Nut Kernels**

Accumulation of fat and protein in cashew nut kernels followed similar trends during growth and maturation i.e. they increased at the same rate (Figures 21 and 22). At fruit set fat and protein contents of kernels ranged from 1.81-2.12g/100g and 0.95-1.41g/100g respectively. Fat and protein deposition in kernels was initially slow, after 4 weeks, both constituents accumulated rapidly till 8 weeks where optimal concentrations ranging from 36.15-39.04g/100g for fat and 19.75-20.93g/100g for protein occurred (Figures 21 and 22). Transitional zone from slow to rapid accumulation of fat and protein generally occurred at 4 weeks which is the same time at which rapid loss of moisture and accumulation of dry matter started in the kernels (Figures 21 and 22).

Figure 21. Changes in the fat content of cashew nut kernels during growth and maturation



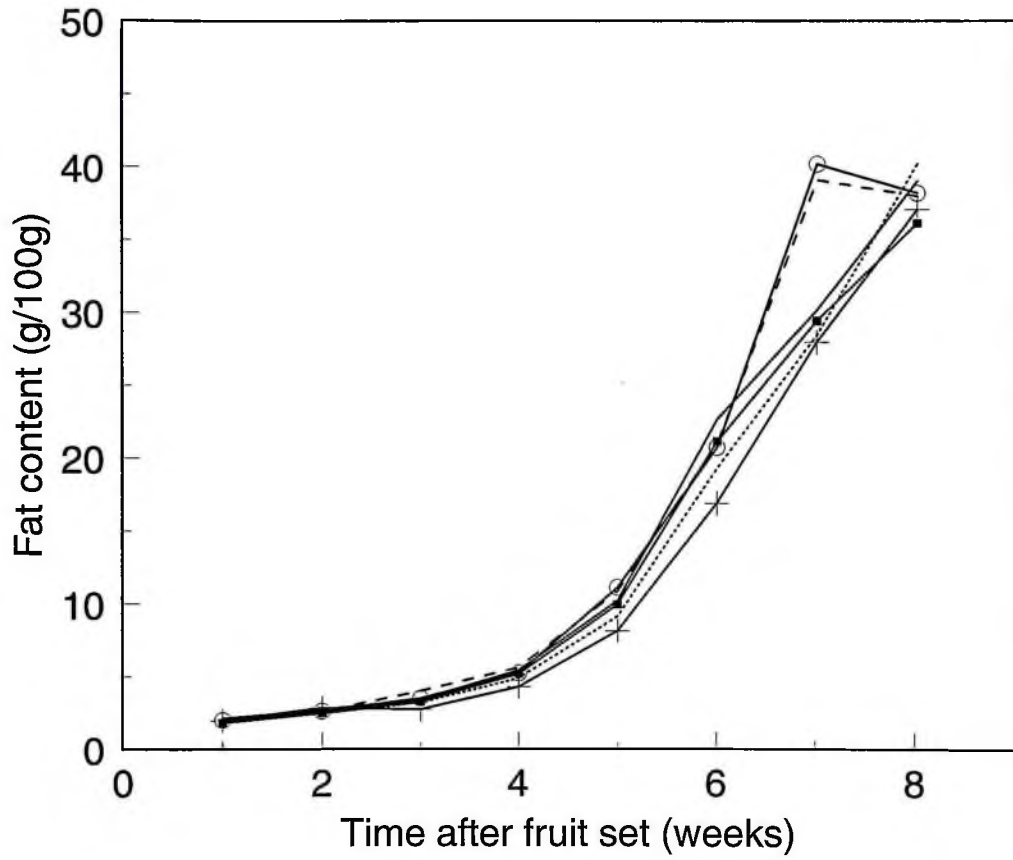
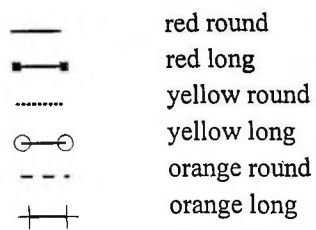
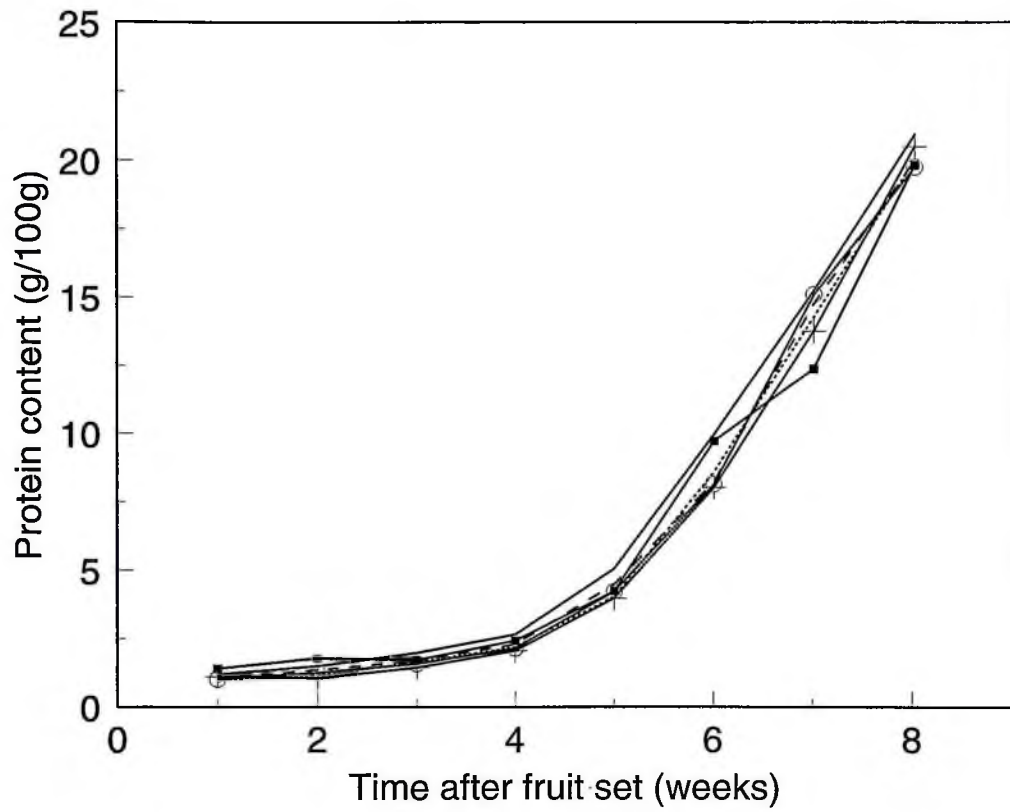


Figure 22. Changes in the protein content of cashew nut kernels during growth and maturation





Analysis of variance on results showed that time of growth had a significant effect on fat and protein contents of cashew nut kernels. Cultivar did not have any significant effect on both constituents. Multiple range analysis on growth time showed no differences in fat and protein contents at 1 to 4 weeks, fat content at 7 and 8 weeks and protein content at 4 and 5 weeks. Differences were observed at 4 - 7 weeks for fat and at 5 - 8 weeks for protein.

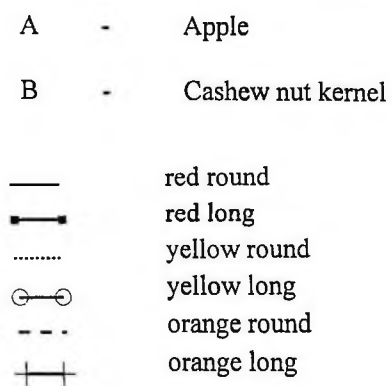
4.2.9 **Ash and Mineral of Cashew**

4.2.9.1 Ash

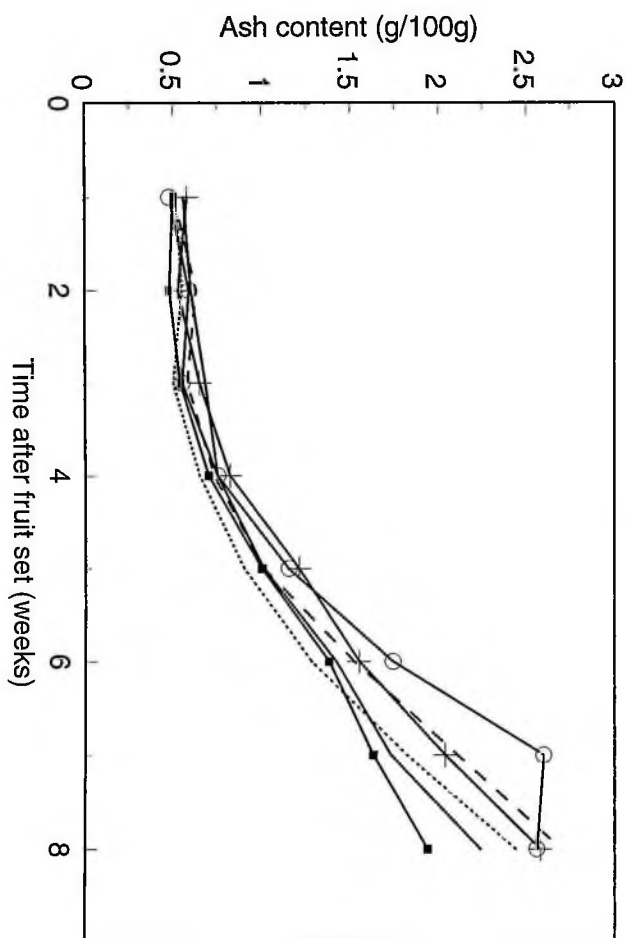
The ash content of foods give an indication of their total mineral content (Haard, 1985). Changes in the ash contents of apples and kernels followed different trends during growth. As the ash of apples decreased, that of kernels increased (Figure 23). Ash content of apples at 1 week ranged from 0.69 - 0.84g/100g. This was comparatively higher than that of kernels (0.51 - 0.58g/100g) at the same time. Consistent decrease in ash content was observed in the apples after 1 week, whilst that of kernels increased gradually and more rapidly after 4 weeks (Figure 23). Slight increases were observed in apples between 1 and 2 weeks for red round cultivar and 6 and 7 weeks for yellow round cultivar (Figure 23a). By the eighth week of growth the kernels attained maximum ash contents of 1.94 - 2.70g and the apples had minimum values 0.45 - 0.56g/100g.

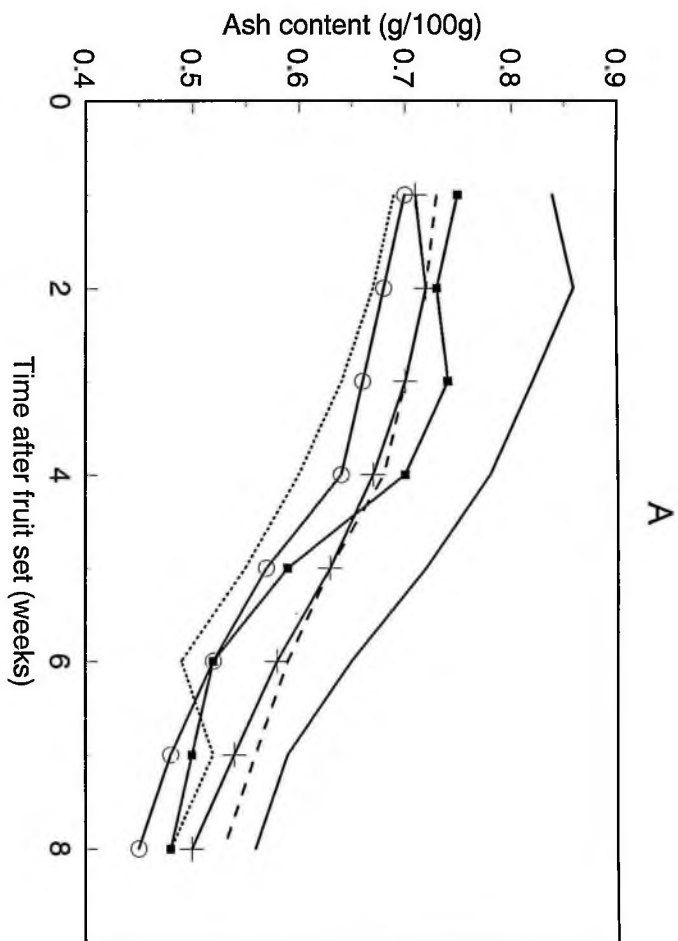
A high and negative correlation was obtained between the ash content of apple and its weight ($r = -0.8532$) as well as moisture ($r = 0.8462$). Correlations between kernel ash and moisture was high and negative ($r = -0.8908$). Between kernel ash and weight it was low and positive ($r = 0.1673$).

Figure 23. Ash content of cashew during growth and maturation



B



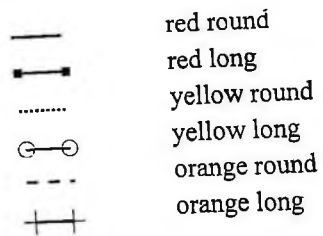


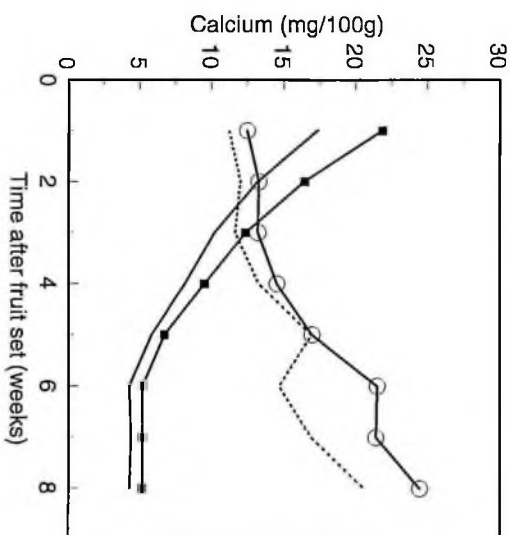
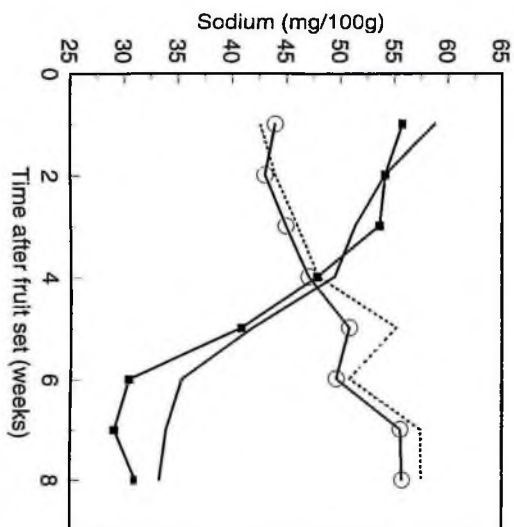
Analysis of variance on data showed that time of growth and cultivar significantly influenced the ash contents of both apples and kernels (Appendices 25 and 26). Multiple range analysis on growth time indicated no significant differences in ash contents of apples at 1-4, 6-8 and 5 and 6 weeks. At 3 and 5 significant differences were observed. For the kernels, no differences were observed at 1-4 weeks, differences occurred at 4-8 weeks. In terms of cultivar, the differences were between orange round and red round apples and that of red long and yellow long.

4.2.9.2 Minerals of Cashew Apples and Kernels

Eight nutritionally essential minerals potassium, phosphorous, magnesium, sodium, calcium, iron, zinc and copper were determined in red round and yellow long cultivars of cashew. Figures 24 and 25 show that changes in the mineral contents of cashew apple and kernel during growth are not the same. All the minerals studied accumulated in the kernels whilst decreases of the same occurred in the apples. At 1 week after fruit set, potassium, magnesium, sodium, calcium and zinc contents in apples were much higher compared to the kernels. For red round cultivar, potassium content was 243.04mg/100g in the apple and 20.81mg/100g in the kernel (Figures 24 a, b, c, d and 25 a). As growth proceeded, the concentration of these minerals in the apples decreased and the same in the kernels increased slowly but rapidly after 4 weeks till 8 weeks (Figures 24 a, b, c, d and 25 a). Peak values of these minerals were observed in the kernels by the eighth week of growth with potassium content of 491.35mg/100g. The apples attained minimal values of the same minerals with potassium content of 128.21mg/100g (Figures 24 a, b, c, d , and 25 a). From the study, apart from calcium, potassium, magnesium, sodium, and zinc content of both apples and kernels were comparable between 4 and 6 weeks after fruit set (Figures 24 a, b, c, d and 25 a).

Figure 24. Changes in potassium (A), magnesium (B), sodium (C) and calcium (D) contents of cashew during growth and maturation





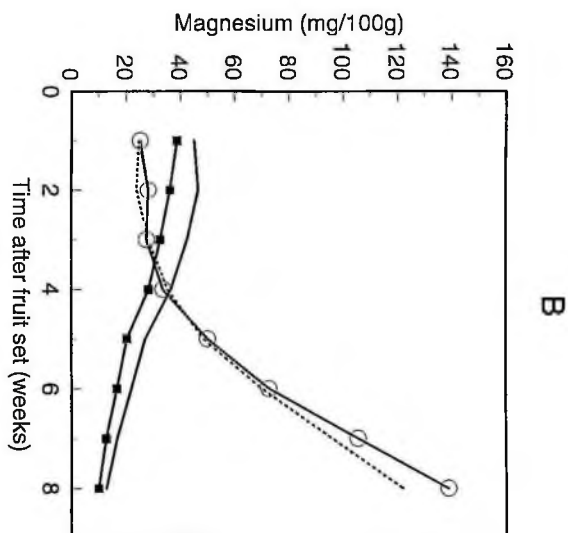
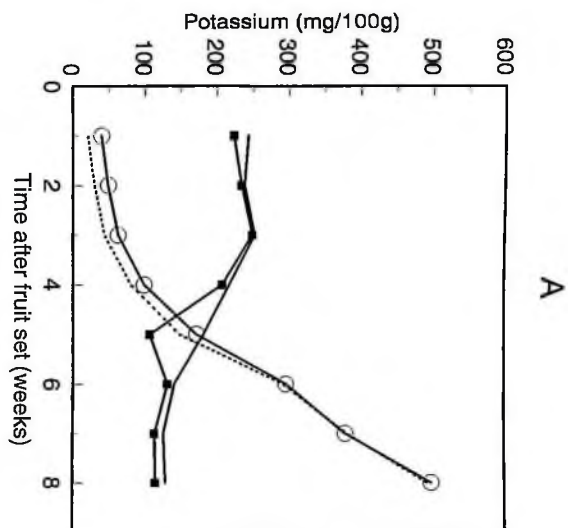
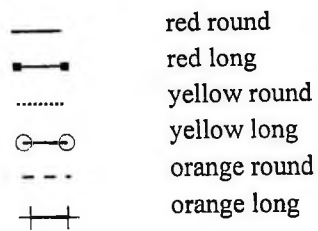
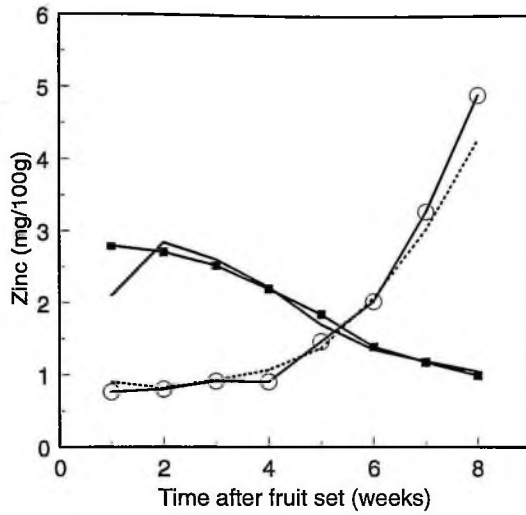


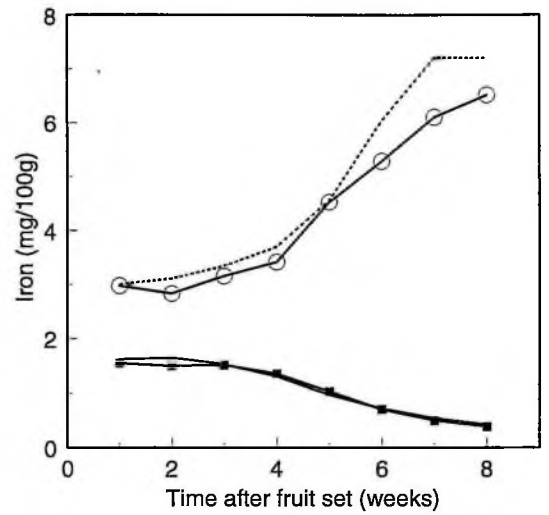
Figure 25 Changes in zinc (A), iron (B), copper (C) and phosphorous (D) content of cashew during growth and maturation



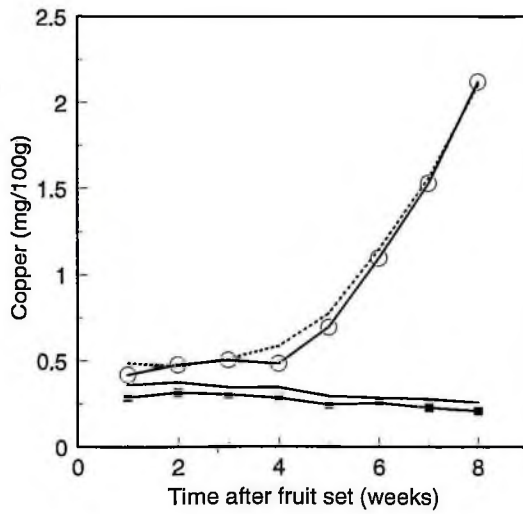
A



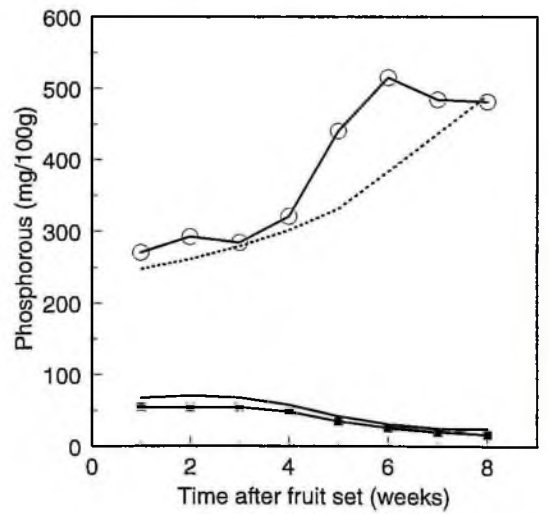
B



C



D



The trend of changes in phosphorous, iron and copper contents of cashew nut kernel and apple were similar (Figure 25 b, c, d). Unlike the other minerals, they were much lower in the apples as compared to the kernels at 1 week and all the other stages of growth (Figure 24 b, c, d). Decreases of these minerals in the apples was minimal with growth especially at the first four weeks where it was almost constant (Figure 24 b, c, d). The kernels however increased in these minerals more rapidly after 4weeks. Minimum concentrations of phosphorous, iron and copper occurred at 8 weeks with phosphorous content of 24.78mg/100g in apples. Cashew nut kernels however attained maximum concentration of minerals e.g phosphorous content of 489.75mg/100g was attained in red round cultivar (Figure 24 b, c, d).

Correlations between each mineral of apple and kernel was found to be negative (Table 6), supporting the observation that as the concentration of each mineral in the apples decreased during growth, there was an increase in the level of these minerals in the nut kernels. Highest correlation was observed for iron ($r = 0.9702$) and the least was for zinc ($r = 0.6900$) (Tab.6).

Table 6. Correlation coefficient between cashew apple and kernel minerals during growth and maturation

Mineral	Correlation Coefficient (r)
Potassium	-0.9442
Phosphorous	-0.9271
Magnesium	-0.8953
Sodium	-0.8865
Calcium	-0.7003
Iron	-0.9702
Zinc	-0.6900
Copper	-0.7295

A high and positive correlation coefficient was observed between moisture contents of apples and each mineral (Table 7). Similar trend was observed for the kernels but their correlation coefficients were generally slightly lower compared to the apples (Table 7). Rapid increases in mineral contents of the kernels at the later stages of growth (4-8weeks) may be partly due to rapid accumulation of dry matter at that same period. Zinc in both apples and kernels, correlated least with moisture, and the highest correlation was obtained for magnesium in the apple (0.9777) and iron in the kernel(0.9410) (Table 7).

Table 7. Correlation coefficient between mineral and total solid content

Mineral	Correlation Coefficient (r)	
	Cashew Apples	Cashew Nut Kernels
Potassium	0.9629	0.9180
Phosphorous	0.9695	0.9316
Magnesium	0.9777	0.9003
Sodium	0.9686	0.8777
Calcium	0.8311	0.8709
Iron	0.9722	0.9410
Zinc	0.7651	0.7565
Copper	0.8824	0.8798

4.2.10 Chemical indices of cashew after 8 weeks of growth

After 8 weeks of growth, the cashew cultivars studied showed varied characteristics. Apples had highest amounts of moisture (84.05-86.95%) and total sugars (10.01-10.85%). There was maximum and high vitamin C (199.34-225.49mg/100g) with minimal tannin contents (0.19-0.40g/100g) in apples which is desirable. Cashew nut kernels attained maximum amounts of protein (19.18-20.98g/100g) and fat (36.15-39.04g/100g) with highest amounts of minerals

(K : 491.35mg/100g in red round cultivar). Kernels are therefore the major sources of minerals in cashew, whilst apples are potent sources of vitamin C and total sugars. The predominant minerals in apples were observed to be potassium, phosphorous and sodium, in the kernels, it was potassium, phosphorous and magnesium.

4.3 **PIGMENT AND ABSORPTION SPECTRA CHANGES DURING GROWTH AND MATURATION OF CASHEW APPLES**

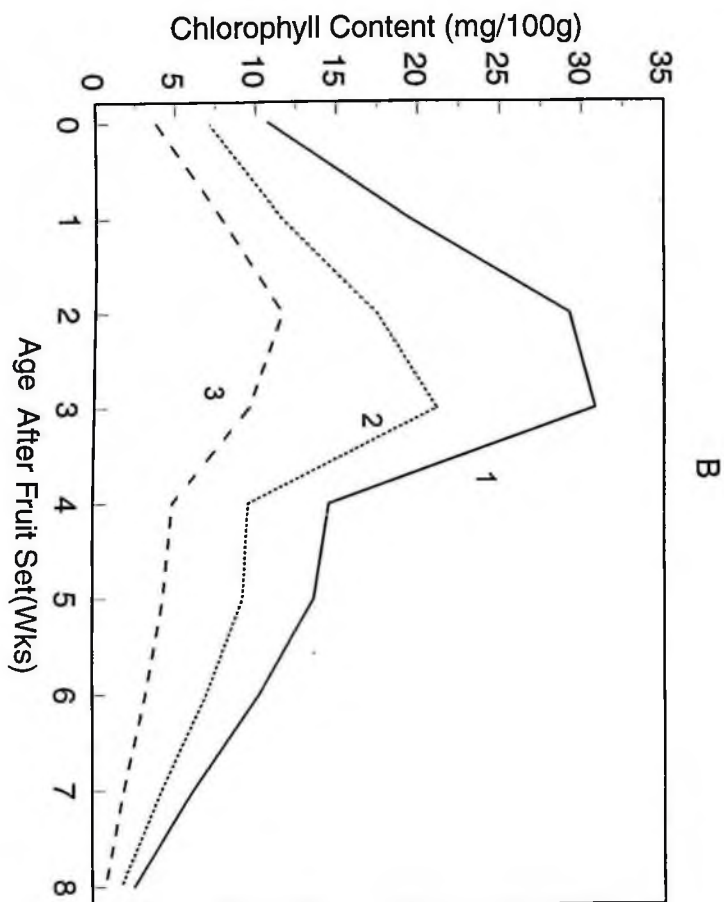
4.3.1 **Chlorophyll**

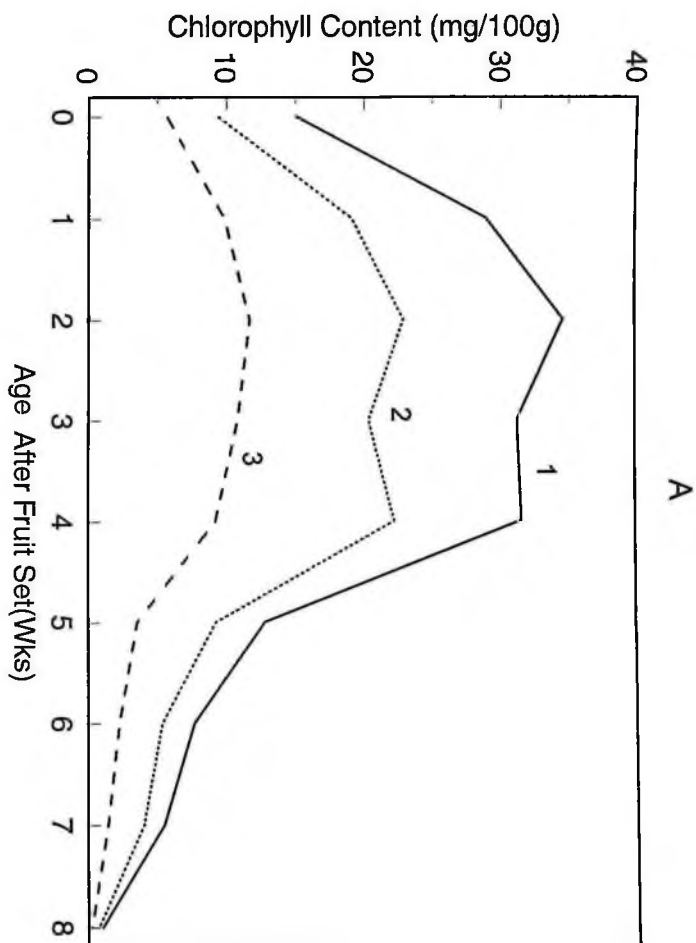
Pigment content or changes in their concentrations can be used as an index of physiological age of fruits. Chlorophyll contents of red round and yellow long apple cultivars were monitored during growth, these included total chlorophyll, chlorophyll a and b. A general decrease in chlorophyll content with maturation was observed in the apples (Figure 26 a, b). At fruit set, total chlorophyll in red round apple was 15.05mg/100g. Rapid increases occurred at the initial developmental stages of growth, reaching peak concentrations at 2 weeks in the yellow long cultivar and at 3 weeks in the red round apart from its chlorophyll b. Progressive depletion commenced after this till the eighth week of growth which included the ripening period (Figure 26a, b). Slight increases in total chlorophyll and chlorophyll a of red round cultivar occurred between 3 and 4 weeks (Figure 26a). At the eighth week, minimal chlorophyll concentrations was observed e.g. total chlorophyll in red round cultivar was 1.04mg/100g (Figure 26a, b). Minguez-Mosquera (1995) and Fuke *et al.*, (1985) observed similar trends in olive and kiwi fruits during growth and ripening respectively.

From the study it was observed that at the early growth stages (fruit set to 4 weeks), chlorophyll in the red round cultivar was higher than that of the yellow long ones, the opposite however occurred at the later stages i.e. 4 to 8 weeks (Figure 26a, b). This may be due to a higher degradation of chlorophyll in the red round cultivar. From the quantitative point of view, irrespective of the stage of development, chlorophyll a content was observed to be higher than chlorophyll b in both cultivars (Figure 26a, b).

Figure 26. Changes in chlorophyll content of cashew apples during growth and maturation

A		Red round
B	-	Yellow long
1	-	Total Chlorophyll
2	-	Chlorophyll a
3	-	Chlorophyll b





Increase in chlorophyll at the initial developmental stages may be due to increased photosynthetic activities in the young apples. Loss of chlorophyll during ripening may be attributed to increase in the concentrations of ethylene which initiates its catabolism (Haard, 1985) and its degradation by chlorophyllase into their respective chlorophyllides (Lonney and Patterson, 1967). Degradation of chlorophyll leads to the obvious loss of green colour and exposure or synthesis of other pigments which give characteristic colour of fruits (Minguez - Mosquera and Gallardo-Guerrero, 1995). Analysis of variance on data showed that, maturation time had significant effect on chlorophyll content (total chlorophyll, chlorophyll a and b) but cultivar did not have any significant effect (Appendices 27-29) .

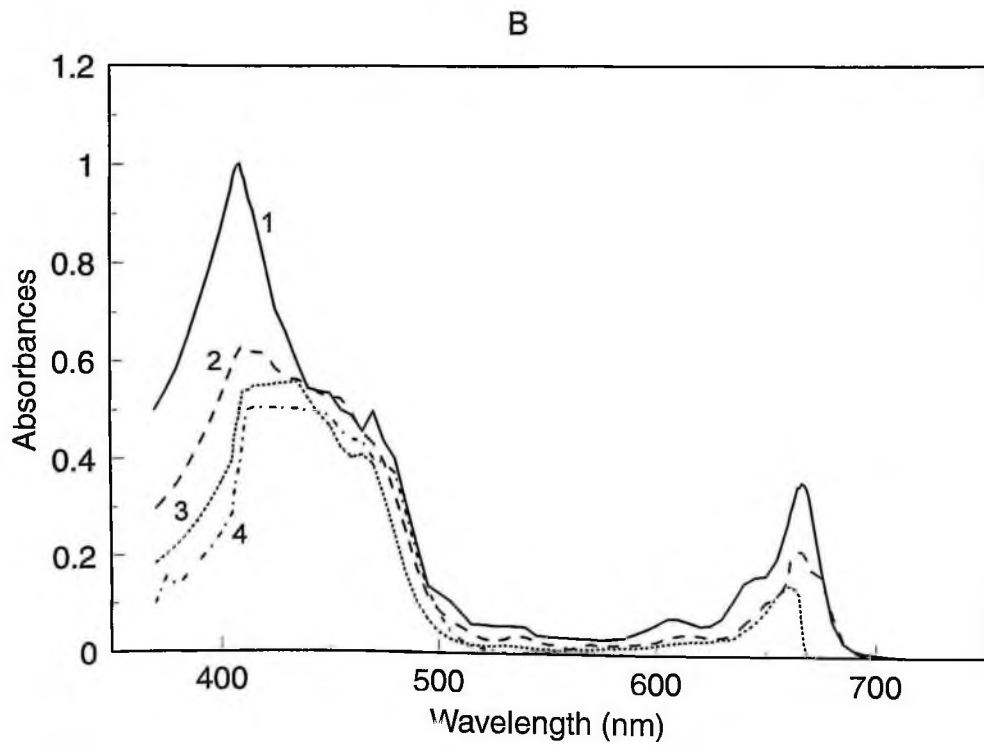
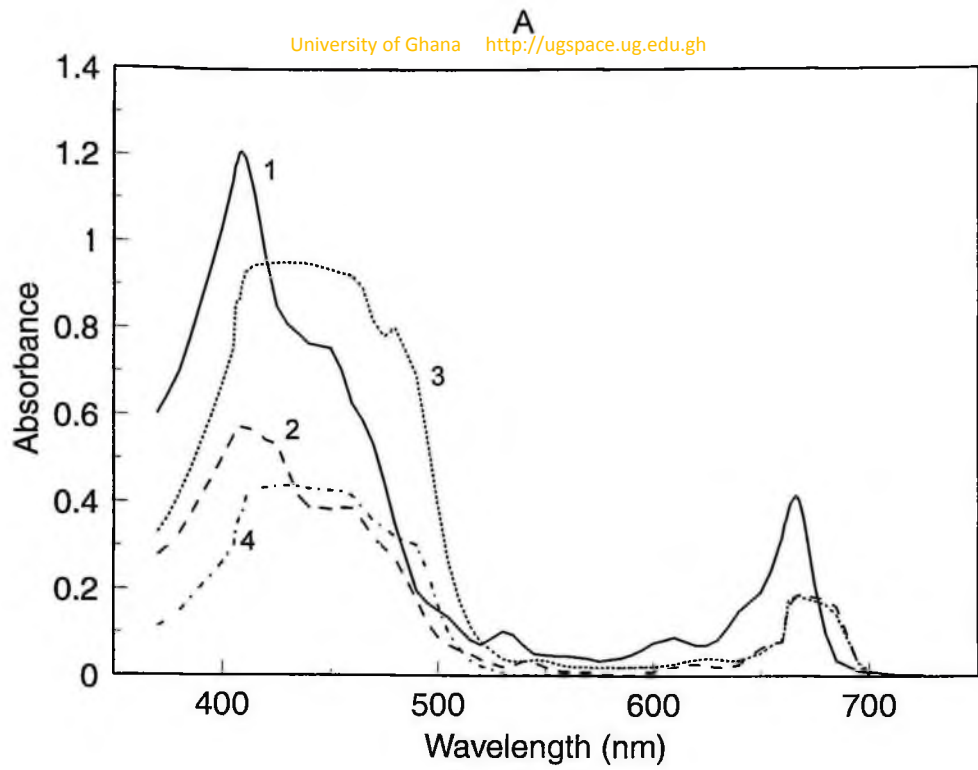
4.3.2 Changes in Absorption Spectra of Cashew Apples during Growth and Maturation

Extracts obtained from the epidermal tissues of red round and yellow long cultivars during growth were scanned through a spectrophotometer at varying wavelengths (370 - 700nm) to obtain their absorption spectra. A general decrease in initial absorbance at 370nm with increasing growth time was observed in both cultivars (Figure 27 a, b). Wavelength at a maximum absorbance is characteristic of the pure substance and is usually independent of the concentration (Saguy *et al.*, 1978). Peaks in the absorption spectra of apples were noted at wavelengths of maximum absorbance.

The number of peaks in the absorption spectra generally decreased with maturation (Figure 27 a, b). Five peaks including two main ones at 410nm and 666nm and three minor ones at 450nm, 530nm and 610nm in the red round and 450nm, 535nm and 605nm in the yellow long cultivars was observed at the first week of growth (Figure 27 a, b).

Figure 27. Absorption spectra of cashew apples during growth and maturation

A		Red round
B		Yellow long
1		One week
2	-	Five weeks
3	-	Six weeks
4	-	Eight weeks



The number of peaks remained constant after 1 week till 5 weeks, whilst the corresponding absorbances decreased. By the sixth week, only two main peaks were observed. These include the emergence of a new one at 439nm and an old peak which had occurred at 666nm at the earlier growth stages (Figure 27 a, b). Peaks which had occurred at the earlier stages of growth from 1 - 5 weeks (410nm, 450nm, 535nm, 530nm and 605nm) had almost or completely disappeared. At the eighth week of growth one main peak with a lower absorbance was observed i.e. the new peak which had occurred at 439nm (Figure 27 a, b).

Changes in number of peaks during growth may give some indications about changes in the pigment of the apples. From the study, decrease in peak number and emergence of a new one occurred from 5-8 weeks which coincided with the ripening period. This may probably be due to the decrease in the concentration and number of pigments and emergence or synthesis of new ones during the ripening period. One main peak observed at 8 weeks may indicate that, as the concentration of the old peaks decreased leading to their disappearance the new peak became more prominent.

Mínguez-Mosquera and Gallardo-Guerrero, (1995) reported that as fruit growth progresses, chlorophyll disappear, and carotenoids associated with them may be maintained or increase due to their synthesis. This means that during ripening, disappearance of some pigments (chlorophyll) with the appearance or accumulation of others occur. Similar trend was observed in the absorption spectra of apples during growth. Fuke *et al.*, (1985), observed maximum absorbance of chlorophyll a and b under reflected light at 410 and 470 nm respectively. In the study, maximum absorbances were recorded at 410 and 450 which is quite comparable.

4.4 PROCESSING OF CASHEW APPLES AND EVALUATION OF QUALITY BY OBJECTIVE AND SENSORY METHODS

4.4.1 Effects of Processing and Storage on Cashew Apple Juice Quality

Processing methods including peeling, steaming, peeling before steaming were applied to the cashew apples. Whole cashew apples were used as the control. The resultant juice obtained from the various treatments yielded four different products, WAJ, PAJ, SAJ, and PSAJ i.e juice obtained from whole, peeled, steamed and peeled before steamed cashew apples.

4.4.1.1 pH and Titratable acidity

pH and acidity of juice obtained from the processed cashew apples varied from that of the whole sample which was the control. Products PAJ and SAJ had lower pH and PSAJ had a higher pH when compared to the control (Table 8). This means that either peeling or steaming of apples may have caused a reduction in pH of resultant juices but peeling before steaming caused an increase. The opposite of these finding occurred for the acidity. Acidity of SAJ was much higher compared to the other samples (Table 8).

Table 8. Effects of processing and storage on pH and acidity of cashew apple juice

Products	Storage Time (Days)							
	pH				Malic acid (g/100g)			
	0	1	4	7	0	1	4	7
WAJ	4.31	4.30	4.19	4.12	0.5699	0.5712	0.6302	0.6785
PAJ	4.29	4.28	4.20	4.13	0.5565	0.5578	0.5632	0.6785
SAJ	4.26	4.24	4.16	4.08	0.8689	0.8716	0.9252	0.9427
PSAJ	4.41	4.39	4.25	4.15	0.4505	0.4519	0.5364	0.5632

WAJ - Whole apple juice (control);

PAJ - Peeled apple juice

SAJ - Steamed apple juice;

PSAJ - Peeled before steamed apple juice

During storage, decreases in pH with corresponding increase in acidity of all the products occurred (Table 8). This may be due to the onset of fermentation which involves the hydrolysis of carbohydrates by microorganisms into organic acids. Juice obtained from steamed apples (SAJ) increased least in acidity (Table 8). Steaming of the apples may have caused decreased microbial load hence this observation.

Analysis of variance on data showed method of processing and storage time had significant effect on pH and acidity of the apples (Appendices 30 and 31). Multiple range analysis on method of processing indicated no significant differences in pH of whole, peeled and steamed apple juice. These were however different from peeled before steamed apple juice. Peeling before steaming therefore affected the pH of the apples. Acidity of whole and peeled apples were comparable. The difference was between juice obtained from steamed and peeled before steamed apples. This means that peeling did not significantly affect the acidity of apples, steaming as well as peeling before steaming did. During storage, significant differences in pH was observed at 1 to 7 days, between zero and 1 day no difference occurred.

4.4.1.2 Vitamin C

All the processing methods applied to the apples caused a reduction in the vitamin C content of the resultant juice when compared with the whole sample (WAJ). Juice obtained from peeled before steamed apples (PSAJ) had the least vitamin C content (Table 9). Reduction in vitamin C content due to peeling and steaming of apples may be attributed to its occurrence in the skins and peels of fruits. Vitamin C is also known to be water soluble (readily lost through leaching from cut surfaces and blanching) as well as heat labile (Tannenbaum *et al.*, 1985).

The process of peeling before steaming which caused the highest reduction in vitamin C content of the apples may be attributed to the above reasons.

Table 9. Effects of Processing and Storage on Vitamin C contents of Cashew Apple Juice

Products	Vitamin C (mg/100ml) " as-is"			
	Storage Time (Days)			
	0	1	4	7
WAJ	266.42	265.36	261.06	225.36
PAJ	235.11	230.46	216.39	205.18
SAJ	219.36	215.61	206.14	190.48
PSAJ	203.56	202.71	199.57	155.42

WAJ - Whole apple juice (control);

PAJ - Peeled apple juice

SAJ - Steamed apple juice;

PSAJ - Peeled before steamed apple juice

Vitamin C content of the various juices decreased during storage with the highest reduction occurring in PSAJ i.e. 203.56-155.42mg/100g (Table 10). A similar trend was reported by Handwerck and Coleman (1988) and Lee and Nagy (1998) during the storage of orange juice. Degradation of vitamin C during storage may be due to oxidative and non oxidative mechanisms (Robertson and Samaniego, 1986; Saguy *et al.*, 1978).

Analysis of variance on data showed that method of processing and storage time had significant effect on vitamin C content of the apple (Appendix 32). Multiple range analysis on method of processing supported the observation that all the processing methods used caused significant differences in vitamin C content of the apples. During storage, differences were observed between 4 and 7 days, vitamin C contents were comparable from 0-4 days.

4.4.1.3 Tannin

Tannins in foods are usually associated with their astringency. The key problem limiting acceptability of cashew apples and their product is the astringency which is believed to originate from the waxy layer of the skin (Medina *et al.*, 1978).

Reduction in tannin content was observed when juice obtained from the various processing methods were compared with that from the whole apples (WAJ) (Table 10). Decreases due to the method of peeling and steaming may be due to the presence of tannins in the skin of apples (Medina *et al.*, 1978) and the fact that steaming breaks down tannin compounds thus reducing assayable tannins (Barbar *et al.*, 1988). The most effective processing method in reducing the tannin content of cashew apples was found to be peeling before steaming which was expected i.e. PSAJ had the least tannin content of 0.46g/100ml (Table 10). The tannin content of all the products were least affected during storage (Table 10).

Table 10. Effect of Processing and Storage on Tannin contents of Cashew Apple Juice

Products	Tannin Content (g/100ml)			
	Storage Time (Days)			
	0	1	4	7
WAJ	0.59	0.58	0.57	0.60
PAJ	0.53	0.52	0.52	0.54
SAJ	0.54	0.55	0.53	0.56
PSAJ	0.46	0.46	0.46	0.47

WAJ - Whole apple juice (control);

PAJ - Peeled apple juice

SAJ - Steamed apple juice;

PSAJ - Peeled before steamed apple juice

ANOVA showed that method of processing had significant effect on tannin content of the

apples but storage time did not have any significant effect (Appendix 33). Multiple range analysis on method of processing showed that all the processing methods used caused significant differences in the tannin content of the apple.

4.4.1.4 Spectra Analysis

Juice obtained from the processed and unprocessed apples were scanned through a spectrophotometer at varying wavelengths (380 - 700nm) to obtain their absorption spectra (Figure 28). This was used as a measure of coloured nature of the juice. Peeling with or without steaming of apples caused decreases in the maximum absorbance at 380nm. Steaming however of the unpeeled apple caused an increase when compared with the control (Table 11). The least absorbance was observed in PSAJ (0.272). Peeling of the apples reduces the concentration of pigments and coloured substances in the juice, as the pigments are mainly contained in the peel. The observed increase in absorbance of steamed whole apple (SAJ) may be due to the leaching of pigments and other coloured substances into the resultant juice

Table 11. Effects of Processing and Storage on the maximum absorbance of Cashew Apple Juice at 380nm

Sample	Storage Time (Days)		
	0	4	7
WAJ	0.400	0.476	0.533
PAJ	0.345	0.373	0.443
SAJ	0.814	1.069	0.924
PSAJ	0.272	0.239	0.314

WAJ - Whole apple juice (control);

PAJ - Peeled apple juice

SAJ - Steamed apple juice;

PSAJ - Peeled before steamed apple juice

Absorbances of all the juices decreased with increase in wavelength and maximum absorbance in all cases occurred at 380nm (Figure 28). An initial sharp drop was observed between 380 and 430nm after which steady decreases occurred . The trend of changes that occurred in the absorbance of all the products during storage followed a similar pattern as discussed above (Figure 28a, b, c). A general increase in absorbance was observed with increase in storage time (Figure 28a, b, c and Table 11). Increase in absorbance may be due to increased deposition of absorbing substances and compounds which may be due to the onset of non-enzymatic browning (Nagy *et al.*, 1989).

4.4.2 **Sensory Evaluation**

Juices obtained from the processed and unprocessed (WAJ) cashew apples were evaluated for colour, flavour, sweetness, astringency and overall acceptability.

4.4.2.1 Colour Intensity

A five point hedonic scale was used for the evaluation of colour intensity of the products. One corresponded to colourless, 3 was very yellow and 5 corresponded to dark. According to the panelists, WAJ had the highest score for colour intensity and the least score was for PSAJ. This results corresponded with the objective measurement of absorbance (Tables 11 and 12). The juice with the most acceptable colour intensity was obtained from steamed apples i.e SAJ and the least accepted was from WAJ (Table 12).

Figure 28. Effects of processing and storage on the absorption spectra of cashew apple juice

A	-	Zero day
B	-	Four days
C	-	Seven days
1	-	Whole cashew apple juice (WAJ)
2	-	Peeled cashew apple juice (PAJ)
3	-	Steamed cashew apple juice (SAJ)
4	-	Peeled before steamed cashew apple juice (PSAJ)

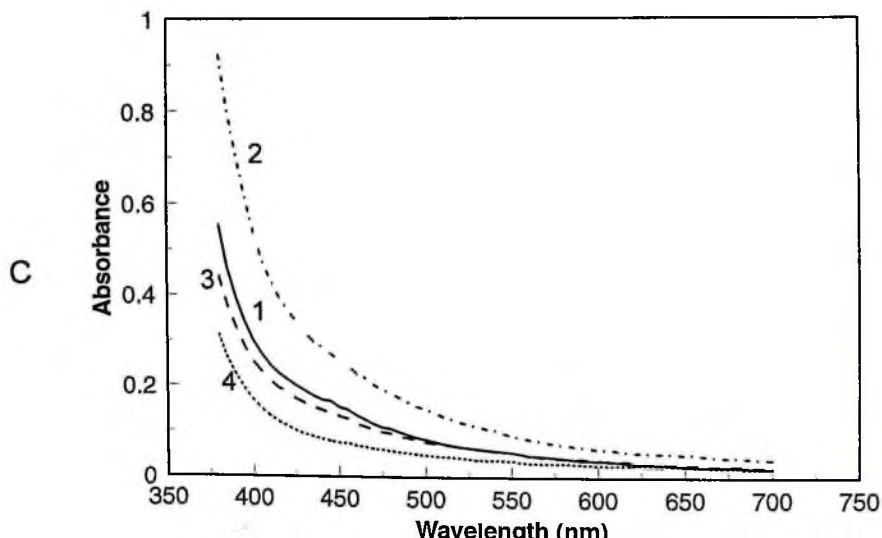
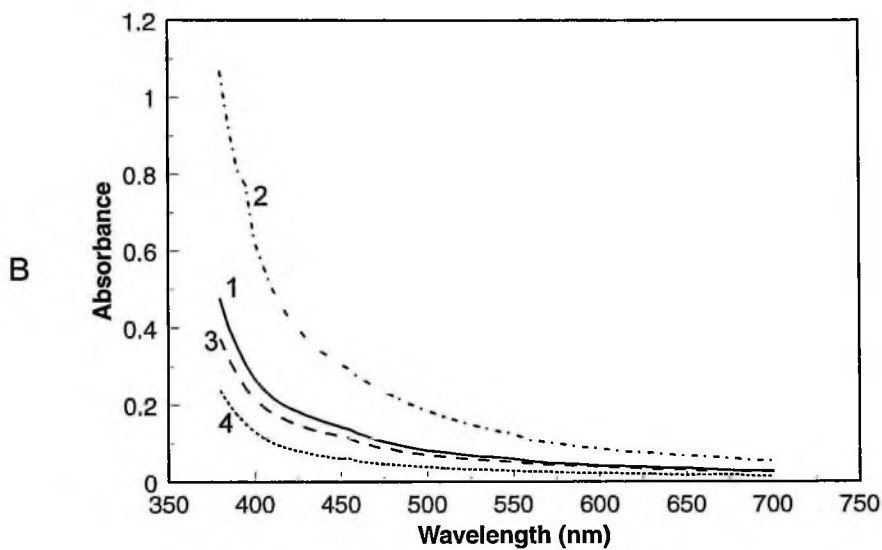
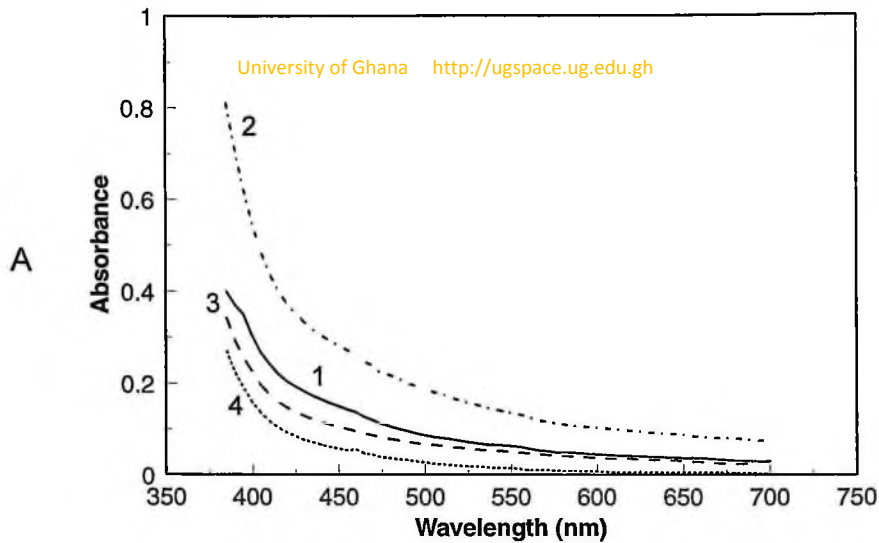


Table 12. Summary of Scores for Quality Indices of Processed Cashew Apple juices and their Acceptability

Quality Indices	Products	Rank sums	Acceptability rank sums
Colour	WAJ	76	66
	PAJ	40	49
	SAJ	69	40
	PSAJ	38	46
Flavour	WAJ	112	64
	PAJ	116	60
	SAJ	73	30
	PSAJ	58	44
Sweetness	WAJ	88	67
	PAJ	91	59
	SAJ	94	32
	PSAJ	92	41
Astringency	WAJ	123	65
	PAJ	118	58
	SAJ	71	34
	PSAJ	51	42

WAJ - Whole apple juice (control);

PAJ - Peeled apple juice

SAJ - Steamed apple juice;

PSAJ - Peeled before steamed apple juice

Analysis of variance of results showed that panelists did not have any significant effect on colour intensity and its acceptability, but the differences in colour intensity and acceptability of the colour of the products were statistically significant (Appendices 34 and 35). Multiple range analysis on products showed no difference in the colour intensities of PSAJ and PAJ and that of WAJ and SAJ. Products PSAJ and PAJ were significantly different from WAJ. This means that peeling and peeling before steaming affected the colour intensity of the resultant juice significantly. Acceptability of PSAJ, PAJ and SAJ were comparable.

A similar trend occurred in PSAJ, PAJ and WAJ, the difference was observed between samples SAJ and WAJ.

4.4.2.2 Flavour Intensity

Flavour intensity score was obtained from a seven point hedonic scale where 1 denoted none, 4 was mild but distinct and 7 was very strong. Product PAJ obtained the highest score for flavour intensity and the least was PSAJ (Table 12). Peeling before steaming may have increased the surface area for a greater destruction of volatile and non volatile flavour compounds hence the above observation. Juice from steamed apples (SAJ and PSAJ) had lower scores compared to the unsteamed ones i.e. WAJ and PAJ (Table 12). In terms of flavour acceptability SAJ was most accepted and WAJ was least accepted (Table 12). Panelists therefore preferred an intermediate cashew flavour in the juice.

From analysis of variance on data, panelists did not have any significant effect on flavour intensity and its acceptability but product had a significant effect (Appendices 36 and 37). Multiple range analysis on products indicated differences in the flavour intensities of WAJ and SAJ which means steaming affected the flavour intensity of apples. No differences were observed between PSAJ and SAJ, it was the same for WAJ and PAJ. Peeling of apples therefore did not influence the flavour. Flavour acceptability of juice obtained from steamed apples (SAJ and PSAJ) was significantly different from that of the unsteamed ones (WAJ and PAJ). Acceptability of SAJ and PSAJ were similar, the same was observed for WAJ and PAJ.

4.4.2.3 Astringency

Sistrunk (1985) reported that loss of astringency and therefore improvement in the palatability and quality of fruits are related to changes in the tannin concentrations. In evaluating astringency, 1 indicated none, 4 was very moderate and 7 was very high. Product WAJ, scored highest and PSAJ scored least for astringency, which was expected (Table 12). This results was similar to the objective determination of tannin (Table 10 and 12). The least accepted astringency occurred in WAJ and the most accepted was SAJ (Table 12). This means that although the panelists did not like high astringency, some amount of astringency was still preferred in the juice.

ANOVA showed that panelists did not have any significant effect on intensity of astringency and its acceptability but product had a significant effect (Appendices 38 and 39). Multiple range analysis on product showed that PSAJ and SAJ had similar intensity of astringency, the same was observed in WAJ and PAJ. The difference was between PSAJ and WAJ as well as SAJ and WAJ. This means that steaming and peeling before steaming significantly affected the astringency of the apples. Acceptability of SAJ and PSAJ was significantly different from that of WAJ and PAJ. No differences in acceptability was observed between WAJ and PAJ, the same occurred between SAJ and PSAJ.

4.4.2.4 Sweetness Intensity

Highest score for sweetness intensity occurred in SAJ and the least was in WAJ (Table 12). It was observed that the juice with the highest score of sweetness intensity was most accepted (SAJ) and the least accepted was WAJ which had the lowest score for sweetness (Table 12).

Analysis of variance showed that panelists and products did not have any significant effect on sweetness and its acceptability (Appendices 40 and 41). This means that the method of processing did not affect the sweetness of the apples.

4.4.2.5 Overall Acceptability

A nine point hedonic scale where 1 denoted like extremely, 5 was neither like nor dislike and 9 was dislike extremely was used in this evaluation. The most accepted juice was obtained from steamed apples (SAJ) followed by PSAJ and least accepted was from whole apples (WAJ) (Table 13).

Table 13. Summary of Scores for Overall Acceptability Processed Cashew Apple Juice

Products	Rank sums
WAJ	100
PAJ	97
SAJ	60
PSAJ	65

WAJ - Whole apple juice (control); PAJ - Peeled apple juice

SAJ - Steamed apple juice; PSAJ - Peeled before steamed apple juice

Analysis of variance showed that, product type significantly influenced the overall acceptability, but panelists did not have any significant effect (Appendix 42). Multiple range analysis on products indicated no significant differences in acceptability of SAJ and PSAJ, the same was observed for WAJ and PAJ. Significant differences were observed between PSAJ and PAJ. From the study it was observed that acceptability of juice obtained from unsteamed apple (WAJ and PAJ) was significantly different from that from steamed samples (SAJ and PSAJ).

5.0 CONCLUSIONS

1. Cashew apple and nut grow independently of each other. The growth pattern of apples (physical indices) occurred in a single phase of continuous increase whilst those of the nuts occurred in two stages i.e. initial rapid increases followed by decreases.
2. All the physical indices of apple attained maximum values by the eighth week of growth. Apart from the kernel percentage, the nuts attained a proportion of their maximum values at 8 weeks. Physical indices of apples had stronger correlations with growth time compared to those of the nuts, they may therefore be better indicators of growth time. Especially apple length and diameter.
3. Compositional constituents such as vitamin C, total sugars in apple, minerals, fat and proteins in kernels which are responsible for the calorie and vitamin characteristics of cashew reached maximum values mostly at 8 weeks. This indicates that ripe cashew has excellent nutritional qualities. Cashew apple is a potent source of vitamin C and sugars and cashew nut kernel is an excellent source of minerals.
4. Apart from sugar accumulation, cashew apple and cashew nut kernel do not experience the same compositional changes during growth and maturation. Rapid accumulation of most desirable chemical substances (vitamin C, sugars, moisture in apples, fat, protein and minerals in kernels) and depletion of undesirable ones (tannins in apples and moisture in kernels) occurred at the later stages of growth (4 - 8 weeks) which coincided with ripening. To obtain optimal quality indices cashew must

therefore be harvested after the later stages of growth.

5. Most of the physical and chemical indices in both apple and kernel were comparable at 7 and 8 weeks of growth. Harvesting at either 7 or 8 weeks can be done without much significant difference in quality.
6. Four to six weeks after fruit set is a critical period where drastic changes in the physical and chemical indices of apple and nut kernel occurred.
7. Changes in the absorption spectra of cashew apples may give preliminary information about changes in their pigments during growth and maturation. Maximum chlorophyll content occurred prior to ripening and changes in the concentration may give some information about the physiological age of the apple i.e the onset of ripening.
8. The methods of processing applied to the cashew apples affected their quality indices. Peeling before steaming was most effective in the reduction of tannin content, but it caused the highest decrease in vitamin C. Apart from tannin, storage time significantly influenced the quality indices of the cashew apple juice.
9. Quality indices of steamed apples (samples 3 and 4) were preferred and more acceptable than the unsteamed ones (samples 1 and 2). The most accepted juice was obtained from steamed apples i.e. sample 3. Steaming of cashew apples before processing into juice lowered the astringency, improved colour and gave an intermediate cashew flavour which was best accepted by the panelists.

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7.0 APPENDICES**Appendix 1. ANOVA summary table for weight of whole cashew during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	31220.515	13	2401.5781	113.350*
GROWTH TIME	30243.987	8	3780.4984	178.432*
CULTIVAR	716.320	5	143.2640	6.762*
RESIDUAL	847.49441	40	21.187360	
TOTAL (CORR.)	32068.010	53		

* - significant at $p \leq 0.05$ **Appendix 2. ANOVA summary table for weight of cashew apple during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	28268.435	13	2174.4950	100.958*
GROWTH TIME	27437.883	8	3429.7354	159.236*
CULTIVAR	625.301	5	125.0602	5.806*
RESIDUAL	861.54816	40	21.538704	
TOTAL (CORR.)	29129.983	53		

* - significant at $p \leq 0.05$ **Appendix 3. ANOVA summary table for weight of cashew nut during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	359.81860	13	27.678353	117.697*
GROWTH TIME	347.98646	8	43.498308	184.968*
CULTIVAR	9.16482	5	1.832965	7.794*
RESIDUAL	9.4066419	40	0.2351660	
TOTAL (CORR.)	369.22524	53		

* - significant at $p \leq 0.05$

Appendix 4. ANOVA summary table for cashew nut kernel weight during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	29.733932	13	2.2872255	292.739*
GROWTH TIME	28.928320	8	3.6160400	462.813*
CULTIVAR	0.391140	5	0.0782279	10.012*
RESIDUAL	0.3125271	40	0.0078132	
TOTAL (CORR.)	30.046459	53		

* - significant at $p \leq 0.05$ **Appendix 5. ANOVA summary table for cashew nut shell weight during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	189.24574	13	14.557365	79.143*
GROWTH TIME	181.54927	8	22.693659	123.378*
CULTIVAR	6.82261	5	1.364521	7.418*
RESIDUAL	7.3574593	40	0.1839365	
TOTAL (CORR.)	196.60320	53		

* - significant at $p \leq 0.05$ **Appendix 6. ANOVA summary table for cashew apple length during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	138.37453	13	10.644195	162.892*
GROWTH TIME	133.58166	8	16.697708	255.531*
CULTIVAR	2.38180	5	0.476359	7.290*
RESIDUAL	2.6138037	40	0.0653451	
TOTAL (CORR.)	140.98833	53		

* - significant at $p \leq 0.05$

Appendix 7. ANOVA summary table for length of cashew nut during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	37.851530	13	2.9116561	82.926*
GROWTH TIME	36.485183	8	4.5606478	129.891*
CULTIVAR	0.515193	5	0.1030385	2.935*
RESIDUAL	1.4044574	40	0.0351114	
TOTAL (CORR.)	39.255987	53		

* - significant at $p \leq 0.05$ **Appendix 8. ANOVA summary table for cashew nut width during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	16.745882	13	1.2881448	157.707*
GROWTH TIME	16.138037	8	2.0172546	246.972*
CULTIVAR	0.235949	5	0.0471898	5.777*
RESIDUAL	0.3267176	40	0.0081679	
TOTAL (CORR.)	17.072600	53		

* - significant at $p \leq 0.05$ **Appendix 9. ANOVA summary table for cashew nut thickness during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	15.670691	13	1.2054378	183.405*
GROWTH TIME	15.047966	8	1.8809957	286.191*
CULTIVAR	0.254899	5	0.0509798	7.756*
RESIDUAL	0.2629011	40	0.0065725	
TOTAL (CORR.)	15.933593	53		

* - significant at $p \leq 0.05$

Appendix 10. ANOVA summary table for top diameter of cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	119.37213	13	9.182472	379.403*
GROWTH TIME	117.63800	8	14.704751	607.573*
CULTIVAR	0.78259	5	0.156517	6.467*
RESIDUAL	0.9680969	40	0.0242024	
TOTAL (CORR.)	120.34023	53		

* - significant at $p \leq 0.05$ **Appendix 11. ANOVA summary table for bottom diameter of cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	70.566936	13	5.4282259	400.794*
GROWTH TIME	70.305142	8	8.7881427	648.874*
CULTIVAR	0.231636	5	0.0463272	3.421*
RESIDUAL	0.5417472	40	0.0135437	
TOTAL (CORR.)	71.108683	53		

* - significant at $p \leq 0.05$ **Appendix 12. ANOVA summary table for moisture content of apples during growth**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	1652.6136	13	127.12412	427.715*
GROWTH TIME	1628.6677	8	203.58346	684.965*
CULTIVAR	23.9459	5	4.78919	16.113*
RESIDUAL	11.888689	40	0.2972172	
TOTAL (CORR.)	1664.5023	53		

* - significant at $p \leq 0.05$

Appendix 13. ANOVA summary table for moisture content of cashew nut kernels during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	30429.040	13	2340.6954	101.445*
GROWTH TIME	30222.685	8	3777.8356	163.730*
CULTIVAR	206.355	5	41.2711	1.789
RESIDUAL	922.94092	40	23.073523	
TOTAL (CORR.)	31351.981	53		

* - significant at $p \leq 0.05$ **Appendix 14. ANOVA summary table for total solid content of cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	1623.1061	13	124.85431	436.391*
GROWTH TIME	1601.0816	8	200.13521	699.513*
CULTIVAR	22.0244	5	4.40489	15.396*
RESIDUAL	11.444263	40	0.281066	
TOTAL (CORR.)	1634.5503	53		

* - significant at $p \leq 0.05$ **Appendix 15. ANOVA summary table for total solid content of cashew nut kernels during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	30626.814	13	2355.9087	803.224*
GROWTH TIME	30577.992	8	3822.2490	1000.000*
CULTIVAR	48.821	5	9.7643	3.329*
RESIDUAL	117.32256	40	2.9330639	
TOTAL (CORR.)	30744.136	53		

* - significant at $p \leq 0.05$

Appendix 16. ANOVA summary table for total sugars of cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	690.08131	13	53.083178	249.707*
GROWTH TIME	687.01944	8	85.877430	403.973*
CULTIVAR	3.06188	5	0.612375	2.881*
RESIDUAL	8.5032741	40	02.125819	
TOTAL (CORR.)	698.58459	53		

* - significant at $p \leq 0.05$ **Appendix 17. ANOVA summary table for total sugars of cashew nut kernels during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	150.80209	13	11.6000161	281.572*
GROWTH TIME	150.57073	8	18.821342	456.853*
CULTIVAR	00.23136	5	0.046271	1.123
RESIDUAL	1.6479111	40	0.0411978	
TOTAL (CORR.)	152.45000	53		

* - significant at $p \leq 0.05$ **Appendix 18. ANOVA summary table for pectin content of cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	19.591707	13	1.5070544	17.817*
GROWTH TIME	15.510893	8	1.9388616	22.922*
CULTIVAR	4.080815	5	0.8161630	90.649*
RESIDUAL	3.3834185	40	0.0845855	
TOTAL (CORR.)	22.975126	53		

* - significant at $p \leq 0.05$

Appendix 19. ANOVA summary table for tannin content of cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	2.3968685	13	0.1843745	36.820*
GROWTH TIME	1.8699481	8	0.2337435	46.680*
CULTIVAR	0.5269204	5	0.1053841	21.046*
RESIDUAL	0.2002963	40	0.0050074	
TOTAL (CORR.)	2.5971648	53		

* - significant at $p \leq 0.05$ **Appendix 20. ANOVA summary table for vitamin C content of cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	153247.44	13	11788.264	84.478*
GROWTH TIME	151272.79	8	18909.098	135.508*
CULTIVAR	1974.65	5	394.930	2.830*
RESIDUAL	5581.7079	40	139.54270	
TOTAL (CORR.)	158829.14	53		

* - significant at $p \leq 0.05$ **Appendix 21. ANOVA summary table for pH of cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	0.6878852	13	0.0529142	6.707*
GROWTH TIME	0.6560259	8	0.0820032	10.394*
CULTIVAR	0.0318593	5	0.0063719	0.808
RESIDUAL	0.3155741	40	0.0078894	
TOTAL (CORR.)	1.0034593	53		

* - significant at $p \leq 0.05$

Appendix 22. ANOVA summary table for acidity of cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	0.0107543	13	0.0008273	9.393*
GROWTH TIME	0.100731	8	0.0012591	14.297*
CULTIVAR	0.0006813	5	0.0001363	1.547
RESIDUAL	0.0035228	40	8.80710E-005	
TOTAL (CORR.)	0.0142772	53		

* - significant at $p \leq 0.05$ **Appendix 23. ANOVA summary table for fat content of cashew nut kernels during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	8853.2554	12	737.7713	103.772*
GROWTH TIME	8811.1481	7	1258.7354	177.048*
CULTIVAR	42.1073	5	8.4215	1.185
RESIDUAL	248.83462	35	7.1095605	
TOTAL (CORR.)	9102.0901	47		

* - significant at $p \leq 0.05$ **Appendix 24. ANOVA summary table for protein content of cashew nut kernels during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	2048.8452	12	170.73710	76.8546*
GROWTH TIME	2045.5229	7	292.21756	131.536*
CULTIVAR	3.3223	5	0.66446	0.299
RESIDUAL	77.755450	35	2.2215843	
TOTAL (CORR.)	2126.6007	47		

* - significant at $p \leq 0.05$

Appendix 25. ANOVA summary table for ash content of cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	0.5306750	12	0.0442229	16.913*
GROWTH TIME	0.4340583	7	0.0620083	23.715*
CULTIVAR	0.0966167	5	0.0193233	7.390*
RESIDUAL	0.9151678	35	0.0026148	
TOTAL (CORR.)	0.6221917	47		

* - significant at $p \leq 0.05$ **Appendix 26. ANOVA summary table for ash content of cashew nut kernels during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	22.896150	12	1.9080125	97.828*
GROWTH TIME	22.528131	7	3.2183045	165.010*
CULTIVAR	0.368019	5	0.0736038	3.774*
RESIDUAL	0.6826312	35	0.0195037	
TOTAL (CORR.)	23.578781	47		

* - significant at $p \leq 0.05$ **Appendix 27. ANOVA summary table for total chlorophyll in cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	1987.3170	9	220.81300	10.599*
GROWTH TIME	1931.0309	8	241.37887	11.586*
CULTIVAR	56.2860	1	56.28605	2.702
RESIDUAL	166.66650	8	20.833313	
TOTAL (CORR.)	2153.9835	17		

* - significant at $p \leq 0.05$

Appendix 28. ANOVA summary table for chlorophyll a in cashew apples during growth and maturation

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	837.33903	9	93.03767	7.770*
GROWTH TIME	802.31058	8	100.28882	8.376*
CULTIVAR	35.02845	1	35.02845	2.925
RESIDUAL	95.790000	8	11.973750	
TOTAL (CORR.)	933.12903	17		

* - significant at $p \leq 0.05$ **Appendix 29. ANOVA summary table for chlorophyll b in cashew apples during growth and maturation**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	251.39289	9	27.932543	17.947*
GROWTH TIME	248.76320	8	31.095400	19.979*
CULTIVAR	2.26969	1	2.629689	1.690
RESIDUAL	12.451111	8	1.5563889	
TOTAL (CORR.)	263.84400	17		

* - significant at $p \leq 0.05$ **Appendix 30. ANOVA summary table for pH of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	0.1782052	6	0.0297009	150.143*
PROCESSING METHOD	0.1647286	3	0.0549095	277.578*
STORAGE TIME	0.0134766	3	0.0044922	22.709*
RESIDUAL	0.0017804	9	1.97817E-004	
TOTAL (CORR.)	0.1799856	15		

* - significant at $p \leq 0.05$

Appendix 31. ANOVA summary table for acidity of cashew apple juice

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	2188.5950	6	364.76583	155.698*
PROCESSING METHOD	2025.1300	3	675.04333	288.138*
STORAGE TIME	163.4650	3	54.48833	23.258*
RESIDUAL	21.085000	9	2.3427778	
TOTAL (CORR.)	2209.6800	15		

* - significant at $p \leq 0.05$ **Appendix 32. ANOVA summary table for vitamin c content of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	12890.139	6	2148.3566	46.682*
PROCESSING METHOD	9187.278	3	3026.4259	66.544*
STORAGE TIME	3702.862	3	1234.2872	26.820*
RESIDUAL	414.19070	9	46.021189	
TOTAL (CORR.)	13304.330	15		

* - significant at $p \leq 0.05$ **Appendix 33. ANOVA summary table for tannin content of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	0.0362375	6	0.0060396	51.462*
PROCESSING METHOD	0.0351688	3	0.0117229	99.888*
STORAGE TIME	0.0010688	3	0.0003563	3.036
RESIDUAL	0.0010562	9	1.17361E ⁻⁰⁰⁴	
TOTAL (CORR.)	0.0372938	15		

* - significant at $p \leq 0.05$

Appendix 34. ANOVA summary table for colour intensity of cashew apple juice

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	83.575000	22	3.798864	4.024*
PANELISTS	26.137500	19	1.375658	1.457
PRODUCTS	163.4650	3	19.145833	20.280*
RESIDUAL	53.812500	57	0.9440789	
TOTAL (CORR.)	137.38750	79		

* - significant at $p \leq 0.05$ **Appendix 35. ANOVA summary table for colour acceptability of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	19.100000	22	0.8681818	0.612
PANELISTS	0.000000	19	0.0000000	0.000
PRODUCTS	19.100000	3	6.3666667	4.486*
RESIDUAL	80.900000	57	1.4192982	
TOTAL (CORR.)	100.000000	79		

* - significant at $p \leq 0.05$ **Appendix 36. ANOVA summary table for flavour intensity of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	157.37500	22	7.153409	5.187*
PANELISTS	33.73750	19	1.775658	1.287
PRODUCTS	123.63750	3	41.212500	29.882*
RESIDUAL	78.612500	57	1.3791667	
TOTAL (CORR.)	235.98750	79		

* - significant at $p \leq 0.05$

Appendix 34. ANOVA summary table for colour intensity of cashew apple juice

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	83.575000	22	3.798864	4.024*
PANELISTS	26.137500	19	1.375658	1.457
PRODUCTS	163.4650	3	19.145833	20.280*
RESIDUAL	53.812500	57	0.9440789	
TOTAL (CORR.)	137.38750	79		

* - significant at $p \leq 0.05$ **Appendix 35. ANOVA summary table for colour acceptability of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	19.100000	22	0.8681818	0.612
PANELISTS	0.000000	19	0.0000000	0.000
PRODUCTS	19.100000	3	6.3666667	4.486*
RESIDUAL	80.900000	57	1.4192982	
TOTAL (CORR.)	100.000000	79		

* - significant at $p \leq 0.05$ **Appendix 36. ANOVA summary table for flavour intensity of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	157.37500	22	7.153409	5.187*
PANELISTS	33.73750	19	1.775658	1.287
PRODUCTS	123.63750	3	41.212500	29.882*
RESIDUAL	78.612500	57	1.3791667	
TOTAL (CORR.)	235.98750	79		

* - significant at $p \leq 0.05$

Appendix 37. ANOVA summary table for flavour acceptability of cashew apple juice

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	34.975000	22	1.589773	1.438
PANELISTS	0.237500	19	0.012500	0.011
PRODUCTS	34.737500	3	11.579167	10.474*
RESIDUAL	63.012500	57	1.1054825	
TOTAL (CORR.)	97.987500	79		

* - significant at $p \leq 0.05$ **Appendix 38. ANOVA summary table for intensity of astringency in cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	219.77500	22	9.989773	5.924*
PANELISTS	32.13750	19	1.691447	1.003
PRODUCTS	187.63750	3	62.545833	37.093*
RESIDUAL	96.112500	57	1.6861842	
TOTAL (CORR.)	315.88750	79		

* - significant at $p \leq 0.05$ **Appendix 39. ANOVA summary table for acceptability of astringency of in cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	30.675000	22	1.394318	1.084
PANELISTS	0.237500	19	0.012500	0.010
PRODUCTS	73.312500	3	10.145833	7.888*
RESIDUAL	73.312500	57	1.2861842	
TOTAL (CORR.)	103.98750	79		

* - significant at $p \leq 0.05$

Appendix 40. ANOVA summary table for sweetness intensity of cashew apple juice

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	38.875000	22	1.7670455	0.926
PANELISTS	37.937500	19	1.9967105	1.046
PRODUCTS	0.937500	3	0.3125000	0.164
RESIDUAL	108.81250	57	1.9089912	
TOTAL (CORR.)	147.68750	79		

* - significant at $p \leq 0.05$ **Appendix 41. ANOVA summary table for sweetness acceptability of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	38.975000	22	1.771591	1.603
PANELISTS	0.237500	19	0.012500	0.011
PRODUCTS	38.737500	3	12.912500	11.680*
RESIDUAL	63.012500	57	1.1054825	
TOTAL (CORR.)	101.98750	79		

* - significant at $p \leq 0.05$ **Appendix 42. ANOVA summary table for overall acceptability of cashew apple juice**

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	108.60000	22	4.936364	1.623
PANELISTS	42.95000	19	2.260526	0.743
PRODUCTS	65.65000	3	21.883333	7.196*
RESIDUAL	63.012500	57	3.0412281	
TOTAL (CORR.)	281.95000	79		

* - significant at $p \leq 0.05$

Appendix 43. Scoring for cashew apple flavour intensity**Name:**.....**Date:**.....**Product Type: Cashew apple juice****Attributes under study: Cashew apple flavour**

Rinse your mouth with the water provided before you start tasting the samples. Please evaluate the coded samples from left to right by tasting them. Rate the extent of the cashew flavour of the coded samples according to the scale given below. E.g. if you taste a coded sample and you perceive the cashew flavour is **very strong** then you rate it as 7, if you **do not detect** (none) any cashew flavour then you rate it as 1.

CASHEW APPLE FLAVOUR

1- none

3- mild

5-distinct

7- very strong

2- detectable

4- mild distinct

6- strong

Sample code**Cashew Flavour**

Ranking for cashew flavour acceptance

Assign the sample with the most acceptable flavour a rank value of 1 followed by the next acceptable one with a value of 2 and the sample with the least acceptable cashew flavour a rank value of 4.

Sample code**Rank assigned**

Appendix 44. Scoring for colour intensity**Name:**.....**Date:**.....**Product Type: Cashew apple juice****Attributes under study: Colour** of cashew apple juices

Please evaluate the coded samples from left to right by just looking at them. Rate the extent of the colour of the coded samples you perceive according to the scale given below. E.g. if you perceive a coded sample to be **colourless** then you rate that sample as 1 or if you perceive a coded sample as **dark** then you rate that sample as 5.

COLOUR

1- colourless

2- pale yellow

3- yellow

4- Brown

5- Dark

Sample code**Colour**

Ranking for cashew apple juice colour acceptance

Assign the sample with the most acceptable colour a rank value of 1 followed by the next acceptable one with a value of 2 and the sample with the least acceptable cashew apple juice colour a rank value of 4.

Sample code**Acceptability**

Appendix 45. Scoring for intensity of Sweetness**Name:**.....**Date:**.....**Product Type: Cashew apple juice****Attribute under study: Sweetness of cashew apple juice**

Rinse your mouth with the water provided before you start tasting the samples. Please evaluate the coded samples from left to right by tasting them. Rate the extent of the sweetness of the coded samples according to the scale given below. E.g. if you taste and the sample has **very high** sweetness then you score it as 7. If you **do not detect** (none) any sweetness in the coded samples, then you rate that sample as 1.

SWEETNESS

1- none

3- low

5- moderate

7- very
high

2- very low

4- very moderate

6- high

Sample code**Sweetness**

Ranking for the acceptance of sweetness in cashew apple juice

Please taste each of the coded samples from left to right. Assign the sample with the most acceptable sweetness a rank value of 1 followed by the next acceptable one with a value of 2 and the sample with the least acceptable sweetness a rank value of 4.

Sample code**Rank assigned**

Index 46. Scoring for intensity of Astringency

:.....

Date:.....**Product Type: Cashew apple juice****Samples under study: Astringency in cashew apple juices**

Wash your mouth with the water provided before you start tasting the samples. Please taste the coded samples from left to right by tasting them. Rate the extent of the astringency of the coded samples according to the scale given below. E.g. if the astringency is **high**, then rate it as 7. If you **do not detect** (none) any astringency in the coded sample, you rate that sample as 1.

ASTRINGENCY

1- none	3- low	5- moderate	7- very high
2- low	4- very moderate	6- high	

Sample code**Astringency**

**Ranking for the acceptance of cashew apple juice astringency**

Taste each of the coded samples from left to right. Assign the sample with the most acceptable astringency a rank value of 1 followed by the next acceptable one with a value of 2, and so on, until you reach the sample with the least acceptable cashew flavour a rank value of 4.

Sample code**Rank assigned**

Appendix 47. Ranking for acceptability of products**Date.....****Name.....**

Please look at and taste each of the coded samples from left to right. Indicate how much you like or dislike each of the coded samples using the scale below.

1 - like extremely

2 - like very much

3-like moderately

4-like slightly

5-neither like nor dislike

6-dislike slightly

7- dislike moderately

8- dislike very much

9- dislike extremely

Sample code**Acceptability**
