QUALITY CRITERIA FOR MANGO EXPORT IN GHANA

by

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DECLARATION

I hereby declare that this submission is my own work towards the PhD degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Field and laboratory studies were conducted to determine and establish quality criteria for harvesting export mango fruits from Ghana. Methods studied were mainly of physicochemical properties such as age control, visual aids, physical and chemical analyses. Early, mid and late harvest days after fruit-set were established for the four varieties. All determinations were made in relation to the age control criterion because of its precision in measuring or determining harvest maturity stage. Visual aids such as changes in fruit peel/skin colour, changes in colour on the flesh around the stone/seed, fruit shape/indentation, development of a purplish–red blush colour of the pedicel, starch iodine test and the leathery fruit peel that were noticed at maturity in all the varieties were very subjective. Fruits of all the varieties maintained a constant weight, length, width, volume, density and indentation at maturity. Palmer did not show indentation at maturity; rather, this is represented by the intensity of ridges/grooves around the stylar scar/end of its fruit. For latex content, an index value was assigned for the minimal acceptable harvest maturity for Haden, Kent, Palmer and Keitt varieties as 0.075ml, 0.150ml, 0.425ml and 0.116ml, respectively since these results tallied with the other harvest maturity index values. Thus, in fixing maturity indices for mango fruits, days from anthesis to harvest and morphological changes may be taken as criteria. The pattern of chemical changes was strikingly similar in all the varieties. Thus, the increase in total soluble solids (TSS) and TSS/acid ratio and the decreasing trend in titratable acidity (TA) could be used as another criterion for fixing the maturity standard of mango. While TSS and pH values showed an increasing trend, ascorbic acid and TA showed a decreasing trend as maturation/ripening progressed. Also selection of TSS, dry matter and starch as harvesting indices is appropriate since starch is the source of sugar production at the mature stage. Thus, four quality criteria or technical methods (age control, visual, physical and chemical) have been determined and established for harvesting mango fruits for export. Chemical, physical and age control methods necessitated determination and establishment of appropriate harvest maturity indices quite objectively whereas the visual method was subjective, though required no sophisticated equipment, and was easy to operate. Fruits intended for distant markets should be harvested around 112days, 126days, 133days and 140days after fruit set for

Haden, Kent, Palmer and Keitt, respectively, i.e., early harvest if they are to be transported by sea, and can be harvested at the early stages of ripening, i.e., mid or late harvest if the fruit is to be transported by air. Fruit skin colour break, pale yellow pulp colour close to the seed, fruit indentation/depression around the peduncle, purplish–red blush colour of the pedicel and leathery fruit peel should be conspicuous at physiological maturity. Fruits should maintain a constant weight, length, width, volume, density and indentation at maturity. TSS, TSS/acid ratio, pH, ascorbic acid and dry matter contents increase to a peak while TA and moisture contents reduce at harvest maturity. A combination of several methods of assessing maturity is therefore recommended in order to establish appropriate quality criteria for export since a single harvest maturity index figure would not always reflect the harvest index in all giving situations. Other methods outside this study such as sinks and floats, growth of seed hairs, development of lenticels, development of abscission layer and others should be investigated under the same conditions to complement the study to make better decisions. Future research should consider easy–to–apply harvest indices and non–destructive methods that correlate positively to enable a computerised system of checking fruit maturity.

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LIST OF ABREVIATIONS

ACP	African Caribbean Pacific
AD	After Death of Christ
ADRA	Adventist Development Relief Agency
AGM	Annual General Meeting
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BC	Before Christ
CAS	Controlled Atmosphere Storage
CPIMS	Centre for the Promotion of Imports from Developing Countries Market Survey
CCARD	Consultative Committee for Agricultural and Rural Development
CEPS	Customs, Excise and Preventive Services
CFA	Credit Facility Account
CRI	Crops Research Institute
CSIR	Council for Scientific and Industrial Research
C15th	Fifteenth Century
DFI	Designated Financial Institutions
DRI	Dietary Reference Intake
EDIF	Export Development and Investment Fund
EDPA	Export Development and Promotion Account
EFC	Export Finance Company Ltd
EU	European Union
EUREP	Euro-Retailer Produce Working Groups
EUREPGAP	Euro-Retailer produce working group Good Agricultural Practices
EUSMG	European Union Strategic Marketing Guide
FAGE	Federation of Association of Ghanaian Exporters
FAO	Food and Agriculture Organisation
FBOs	Farmer based organisations
FDB	Food and Drugs Board
FMSL	Farm Management Services Ltd
FRI	Food Research Institute
GAP	Good Agricultural Practices
GCAA	Ghana Civil Aviation Authority
GDP	Gross Domestic Product
GEPC	Ghana Export Promotion Council
GFPED	Ghana Fresh Produce Exporters' Directory
GFPMIR	Ghana Fresh Produce Market Intelligence Report
GGS	Ghana Grades and Standards
GhIH	Ghana Institute of Horticulturists
GIHOC	Ghana Industrial Holding Corporation
GIPC	Ghana Investment Promotion Centre
GPHA	Ghana Ports and Harbours Authority
GRAS	Generally Recommended As Safe
GSB	Ghana Standards Board
GTZ	Gesellschaft fur technische Zusammenarbeit GmbH

HAG	Horticulturists Association of Ghana
HEII	Horticultural Exports and Imports Initiative
IARI	Indian Agricultural Research Institute
IBPGR	International Board for Plant Genetic Resources
IBPGR-IUCN	International Board for Plant Genetic Resources -International Union for the Conservation of Nature
IPEP	Increased Private Enterprise Performance
IPGRI	International Plant Genetic Resources Institute
IPM	Integrated Pest Management
INS	Indian News Scape
ISHS	International Society for Horticultural Science
ITFC	Integrated Tamale Fruit Company
ITFCWR	Integrated Tamale Fruit Company Weather Report
LSD	Least Significant Difference
MAS	Modified Atmosphere Storage
MCA	Millennium Challenge Account
MiDA	Millennium Development Authority
MIR	Market Intelligence Report
MOAP	Market Oriented Agriculture Programme
MoFA	Ministry of Food and Agriculture
MoTI/PSI	Ministry of Trade, Industry and the President's Special Initiatives
MRL	Maximum Residue Level
MSTQA	Meteorology, Standards, Testing and Quality Assurance
MSU	Michigan State University
MTSS	Mango Trial Sea Shipment
NGOs	Non Governmental Organisations
NTE	Non-Traditional Exports
OECD	Organisation for Economic Cooperation and Development
OMOA	Organic Mango Outgrowers Association
PAMPEAG	Papaya and Mango Producer and Exporter Association of Ghana
PE	Pectinesterase
PEPC	Phosphoenol pyruvate carboxylase
PFIDP	Private-Public Partnership/Food Industry Development Program
PG	Polygalacturonase
PMO	Primary Marketing Organisation
PPRSD	Plant Protection and Regulatory Services Division
RCBD	Randomized Complete Block Design
R–V transition	Reproductive-to-vegetative
SARI	Savanna Agricultural Research Institute
SANAS	South African National Accreditation System
SMEs	Small to Medium Scale Enterprises
TIPCEE	Trade and Investment Programme for a Competitive Export Economy
TIRP	Trade and Investment Reform Program
TPMN	Tropical Produce Marketing News
TSS	Total Soluble Solids
UK	United Kingdom

UNDP	United Nations Development Programme
USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
US$	United States Dollar
USFDA	United States Food and Drug Administration
VREL	Volta River Estates Ltd
V-R transition	Vegetative-to-reproductive
WAFFC	West Africa Fair Fruit Company
WWF	World Wildlife Fund

1.0 INTRODUCTION

Exports of fruits and vegetables are one of the most vibrant sectors of the Ghanaian economy. Over the last years the sector has grown by leaps and bounds. For example pineapple is the kingpin of this development with Ghana being among the top three providers of the fruit to the EU. Exports of papaya aren't as high as pineapple but Ghana remains the largest African Caribbean Pacific (ACP) exporter of the fruit to the EU (GFPMIR, 2008). On the other hand, Ghana began exporting mango in 1987 but to the EU in 2003 for a total of 119t, making mango one of the country's largest fresh produce exported to the EU (GEPC, 2008). But Ghana's mango industry is still in an infant stage. It has not developed extensively with the times. Its productivity and exports are low. It contributed about 0.3% of total agricultural exports in 2009. The export performance of fresh mango fruits from Ghana in 2009 indicated a value of US$ 234950. Between January and December 2007 Europe's import of mango from Ghana was 1,071t, representing only 1% as Ghana's share on the EU market. All the same, Ghana recorded the highest annual growth (73%) as well as the highest total growth (799%) amongst the exporters within the period suggesting that mango has the potential as a foreign exchange earner in Ghana (Abu *et al*., 2011).

The success of the fruits and vegetable sector in Ghana is not due to the presence of a few large foreign-owned corporations, unlike other countries exporting similar produce. Rather, the Ghanaian export industry has relied on several dozen larger producers and great number of smaller out-growers. Today Ghana is the fifth largest ACP exporter of fruits and vegetables to the EU (GFPMIR, 2008). Despite these successes the country

has embarked on a policy of crop diversification, making mango Ghana's next big entry to the EU market (GFPED, 2007).

The importance of mango to many Ghanaians is epitomized in the descriptions for the crop; 'Golden tree', 'gold mine', 'next cash crop', 'Ghana's future', amongst others (GFPED, 2007). This put mango ahead of most tree crops if not all, in the nation's quest to alleviate poverty through the improvement in incomes of farmers. Mango is one of the most highly esteemed fruits of the tropics. After bananas, mangoes are the most important fruits grown in the tropical areas around the world (CPIMS, 2008; Eurostat, 2008). Mango is being touted as 'the next big product in Ghana', with the potential to replace cocoa as the nation's most valuable cash crop. Having been a fruit crop growing widely in the country, the crop has found commercial value in the cultivation of improved exotic varieties. Over the last 10-15 years, there has been widespread interest in the cultivation of the crop not only by development agencies under various environmental protection and poverty reduction programmes, but also by private individuals and companies for export (GFPED, 2007).

The mango has many other uses; fruits are used in the raw state (vegetable), the mature green stage, ripe stage or as mango waste (peel and stone). The fruits are very much relished for their succulence, exotic flavour and delicious taste. They are also an excellent source of dietary fibre, provitamin A and vitamin C. It is a fruit with versatile properties and has naturally found application for processing into several products (Litz, 2003). According to Litz (2003) these products include juices, mango nectar, ice cream,

canned mango pulp, fruit bars, pies, chips, milkshakes, sliced mango as a dessert, pickles with fish sauce and mango salad with fish sauce and dried shrimps. Perfectly ripe mango fruit is used as a symbol of attainment. Culturally, mango blossoms are used in the worship of Goddesses and the leaves are used to decorate archways and doors in houses, during weddings and in religious celebrations by different communities (Ensminger, 1995). Nanjundaswamy (1991) reported that mango waste (stones and peels), which constitute 35–55% of fruit mass, could be utilized for recovering useful products and generation of biogas.

Various maturity indices for harvesting mangoes have been suggested for several varieties (Anonymous, 1972), but on the whole, little effort has been made to determine indices that have practical significance. Mango farmers in Ghana therefore have difficulty in determining when to harvest fruits for the export and local markets (Abu *et al*., 2011). The lack of established methods or criteria (harvest indices) of practical significance for determining when to harvest mango fruits has many disadvantages that adversely affect quality.

The disadvantages include variation in maturity in a single consignment which causes lack of uniformity in ripening resulting in fruit being offered for sale at different stages of ripeness at any particular time. Mitra (1997), Litz (2003) and Twum (2008) observed that one of the major problems currently restricting international trade in mangoes is the variation in physiological maturity in a single consignment. It is also impossible to schedule harvesting, handling and marketing operations efficiently, all of which lead to

poor quality of produce (Litz, 2003). Besides, quality and presentation standards fail to meet the requirements of fresh mango importing countries from Ghana (Norman, 2003). Thus importers' demand cannot be met. In a value chain analysis for mango, Ava *et al*. (2008) reported that Ghanaian mango producers find it hard to meet certain export quality standards, and that sufficient quantities of mango demanded by some importers cannot be met. The authors added that when some mango producing countries in Africa (Ghana, Cote d'ivoire and Senegal) were compared in their performances, Ghana was trailing in quality, volume, timeliness and sustainability.

Another disadvantage is the high wastage of fruits during the harvesting season, particularly of the exotic varieties (Abu *et al*., 2011). The bulk (64%) of mango produced in Ghana is handled by local retailers which represent the non-exportable class (low quality), 10% by processors, 11% postharvest losses and only 15% by exporters. The statistics indicate a meagre figure for export which is probably related to the lack of established criteria for harvesting mango fruits among other factors. These, coupled with poor seedling quality (undesirable seedling characteristics), poor agronomic practices, pests and diseases incidences, poor post-harvest management, low technical training to meet export requirements, inadequate research, etc, accelerate postharvest losses during both production and marketing.

Data on post-harvest losses of mango are scarce. This is probably because studies on losses are too cost-intensive. Thus, most data on local or national post-harvest losses result from casual estimates, as serious research studies are rarely undertaken on mango

(Ava *et al*., 2008). There has been concern in recent years about unreliability and lack of standardisation of observations on postharvest losses, particularly in tropical countries and in the fruit and vegetable field including the mango industry (Cecilia *et al*., 2007). The authors added that for many years the estimation of such losses has been based on extrapolation of comparatively non-standardised studies together with subjective assessment.

Kouno *et al*. (1994) in their investigation on improvements in product quality and performance of the mango fruit concluded that ''future research should consider easy–to–apply harvest indices and non–destructive methods for checking fruit maturity which could be incorporated in an automated grading system''. Due to differences among mango types {Indian (monoembryonic) and Indochinese (polyembryonic)} (Litz, 2003), varieties, production conditions and locations, there is no consensus on maturity indices. Unfortunately, no attempts have been made to establish reliable and replicable time and methods/procedures of harvesting mango fruit in order to determine and establish the quality criteria for mango fruits exported from Ghana. However, high demand for mango and mango products from developing countries by the international community, especially the EU, USA, Canada, Japan, etc has resulted in the evolution in the quality of the mango fruit in Ghana (GFPMIR, 2008).

Domestic and international trade of fresh mango has also been limited by its highly perishable nature and its susceptibility to post-harvest diseases, extremes of temperature and physical injury (Litz, 2003). The fruit requires a short period to ripen and this short

period seriously limits its commercialization in distant markets (Iqbal, 2001). For all of these reasons, mangoes are still considered as luxurious, expensive items in the markets in many industrialised countries (Litz, 2003). Clearly, other alternatives are, therefore, required to reverse Ghana's trailing trend in quality, volume, timeliness and sustainability in mango export as reported by Ava *et al*. (2008). Thus, it is important to study the appropriate harvest criteria of a group of mango cultivars e.g. Keitt, Palmer, Kent and Haden that currently are known in the commerce and/or horticulture of one or more countries.

The main objective of this study was to establish the quality criteria for mango fruits exported from Ghana.

Specifically, the objectives were;

(i) to establish the criteria for harvesting mango fruits through age control and the study of fruit development and maturation.

(ii) to determine the ripening quality of mango fruits for the export and local markets.

2.0 LITERATURE REVIEW

2.1 OVERVIEW OF THE MANGO INDUSTRY

Mango is being touted as 'the next big product in Ghana' with the potential to replace cocoa as the nation's most valuable cash crop. Having been a fruit crop growing widely in the country, it has found commercial value in the cultivation of improved exotic varieties. Over the years there has been widespread interest in the cultivation of the crop not only by development agencies under various environmental protection and poverty reduction programmes, but also by private individuals and companies for export (Ava *et al.*, 2008). The Centre for the Promotion of Imports from Developing Countries Market Survey (CPIMS) (2008) reported that the mango fruit is one of the most highly esteemed fruits of the tropics.

The importance of mango to many Ghanaians is epitomized in the description for the crop as 'Golden tree', 'next cash crop', 'gold mine', 'Ghana's future', amongst others (Ava *et al.*, 2008).

Mangoes account for approximately 50% of all tropical fruits produced worldwide (FAO, 2008). The Food and Agriculture Organization of the United Nations estimated worldwide production of mangoes at more than 33 million tons in 2007 and that the aggregate production of 10 countries is responsible for roughly 80% of the entire world mango production (FAO, 2008).

The European Union Strategic Marketing Guide (EUSMG) (2001) reported that many countries in Africa, South America and Asia have become aware of the possibility to

penetrate the market for mangoes in Europe. According to the report favourable climatic conditions and low labour cost leading to low production cost give the South American and African countries a strong position on the European markets. However, there is also a strong competition between the low wage countries. Currently, summer mango from South Africa and South America are in Europe all the year round (EUSMG, 2001). The report further stated that 'Ghana compared to some of the countries in the southern region is closer to Europe and thus gives it the urge in terms of market opportunities due to lower transportation cost and shorter delivery times'. Irrespective of these opportunities, Ghana is unable to take advantage due to the uncompetitive state of the industry. For example a report on a baseline study on the mango industry in Ghana (Abu *et al*., 2011) indicated overwhelmingly among other challenges that mango farmers in Ghana have difficulty in determining when to harvest fruits for the export and local markets. According to Litz (2003) lack of simple and reliable methods for determining the stage of fruit maturity also affect quality. For Mitra (1997) one of the major problems currently restricting international trade in mangoes is the variation in physiological maturity in a single consignment.

2.2 THE MANGO PLANT

According to McGovern and LaWarre (2001) mangoes belong to the kingdom *Plantae*, division *Angiospermae*, class *Magnoliopsida*, order *Sapindales*, family *Anacardiaceae*, genus *Mangifera* and species *Indica*, consisting of numerous species of tropical fruiting trees in the flowering plant family. The mango is indigenous to India. Cultivated in many tropical and subtropical regions and distributed widely in the world, mango is one

of the most extensively exploited fruits for food, juice, flavour, fragrance and colour. In several cultures, its fruit and leaves are ritually used as floral decorations at weddings, public celebrations and religious ceremonies (McGovern and LaWarre, 2001).

2.2.1 DESCRIPTION

2.2.1.1 The Tree and its Flowers

Kaur *et al.* (1980) indicated that the mango tree is believed to have evolved as a canopy layer species in the tropical rain forest of south and south-east Asia. Litz (2003) mentioned that the mature mango trees can attain a height of 30 meters with a crown radius of 10 m and can survive for more than 100 years and still fruiting. The root system consists of a long, vigorous tap root and abundant surface feeder roots. In deep soil the taproot descends to a depth of 6 metres, and the profuse, wide-spreading feeder roots also send down many anchor roots which penetrate for several feet. The tree is an arborescent evergreen one with simple, alternate, oblong ovate to oblong lanceolate leaves, 15–35 cm long and 6–16 cm broad; when young they are orange-pink, rapidly changing to a dark glossy red, then to dark green as they mature. They are spirally arranged and produced in flushes (Litz, 2003).

According to Litz (2003) the flowers are borne on terminal pyramidal panicles 10–40 cm long, glabrous or pubescent; the inflorescence is rigid and erect and is widely branched, usually densely flowered with hundreds of small flowers, 5-10 mm in diameter. The flowers are small, monoecious and polygamous. Both male and perfect flowers are found within a single inflorescence; the pistil aborts in male flowers. The

ratio of male to perfect flowers is strongly influenced by environmental and cultural factors. The flowers have four to five sepals that are ovate to ovate oblong and also highly pubescent (Litz, 2003).

Litz (2003) further stated that there are four to five petals 5–10 mm long, with a mild sweet odour suggestive of lily of the valley, oblong to ovoid to lanceolate and also thinly pubescent. The floral disc is four to five-lobbed, fleshy and large, and located above the base of the petals. There are five large, fleshy nectaries that form a five lobed receptacle. Although there are four to five stamens, only one or two of them are fertile; the remainder are sterile staminodes that are surmounted by a small gland. In addition, two or three smaller filaments arise from the lobes of the nectaries. The stamens are central and that it is believed the flowers are cross–pollinated by flies (Litz, 2003).

2.2.1.2 The Fruit

Litz (2003) describes the mango fruit as a large, fleshy drupe, containing edible mesocarp of varying thickness. The fruit is highly variable in size, shape and colour, and may be yellow, orange, red or green when ripe, depending on the cultivar. When ripe, the unpeeled fruit gives off a distinctive resinous sweet smell. Chlorophyll, carotenes, anthocyanins and xanthophylls are all present in the fruit, although chlorophyll disappears during ripening where as anthocyanins and carotenoids increase with maturity (Lakshminarayana, 1980). Fruit colour at maturity is genotype–dependent. The exocarp is thick and glandular. The mesocarp can be fibrous or fibre–free with flavour ranging from turpentine to sweet. In its centre is a single flat oblong

pit that can be fibrous or hairy on the surface, depending on the cultivar. Inside the pit 1–2 mm thick is a thin lining covering a single seed, 4–7 cm long, 3–4 cm wide, and 1 cm thick. The seed contains the plant embryo. The endocarp is woody (Litz, 2003).

2.2.2 CULTIVARS

Knight and Schnell (1994) stated that some of the Florida cultivars of mango, most notably "Haden", have been important in aiding the establishment of a modern mango industry in other parts of the world and that the phenomenon first observed in Florida is occurring elsewhere. According to them the mango industry is now presented with the prospect of the importation/exportation of cultivars of outstanding merit from their countries of origin to be grown; first experimentally and later commercially, in new regions. For this reason it is important to become familiar with the characteristics of a group of cultivars that currently are known in the commerce and/or horticulture of one or more countries and that may have potential for expanded culture or use in breeding (Knight and Schnell, 1994).

2.2.2.1 Criteria for Cultivar Description

The International Plant Genetic Resources Institute (IPGRI) (1989) publications that cover the subject of criteria for cultivar description also provide morphological criteria to identify cultivars. The description list used by IPGRI (1989) provides i) passport data (identifying the accession and information recorded by collectors); ii) characterization (recording characters considered to be highly heritable which can be easily seen in the field and are expressed in all environments); and iii) preliminary evaluation, which

records a limited number of additional traits thought desirable by a consensus of users of the crop. By the publication, plant data that are important in preliminary evaluation, include i) for the tree; habit and height of the mature tree, ii) for the leaf; shape, length and width, and colour of the young leaf, iii) for the inflorescence; position, shape, density of flowers, length, colour, hairiness, presence or absence of leafy bracts, and percentage of perfect flowers in an average inflorescence.

Additional plant data used in initial evaluation include those for i) the flower; diameter in millimetres, type (pentamerous, tetramerous or both), nature of disc (swollen, broader than ovary or narrow, reduced or absent), and number of stamens. The other is the fruit; length, width and thickness, weight, shape, skin colour (which may be compared with reference cultivars), skin thickness, skin texture, ratio of pulp to skin and stone, texture of pulp, adherence of skin to pulp, fibre in pulp and its quantity and length, and stem insertion. The third is the stone; length, weight, veins and pattern of venation, presence or absence of fibres and their length (IPGRI, 1989). Also additional plant data for leaves, inflorescence and fruit have been collected and some of these, notably season (maturity period), productivity, eating quality and attractiveness are quite important. Other important characters that have been evaluated or proposed for evaluation are susceptibility to stress (drought, wind, flood etc), susceptibility to specific pests and diseases, alloenzyme composition, and cytological characters and identified genes (IPGRI, 1989). Because of the extreme comprehensiveness of this list and the limited availability of many of the proposed descriptor evaluations at this time, scientists have

tried to utilize such information as is available to make the comparison, identification and evaluation of specific well-known cultivars a practical possibility (Litz, 2003).

2.2.2.2 Cultivars (world-wide distribution)

Cultivars that are of interest in areas other than their places of origin and other names by which they are identified are outlined by Litz (2003) (see Appendix B2).

According to Watson and Winston (1984) the distribution of mango cultivars outside their centres of domestication (see Appendix B3) can be attributed primarily to three historical events: (i) the movement of Indian varieties (monoembryonic) along the trade routes of the Portuguese to Africa and South America; (ii) the spread of southeast Asian varieties (Polyembryonic) across the Pacific Ocean to Central and South America by the Spaniards; and (iii) the creation of a secondary centre of mango diversity in South Florida as a result of the systematic introduction of mango germ-plasm from India and Southeast Asia. The authors added that further information about many of the mango cultivars, including their fruit characters is available in publications by i) Burns and Prayag (1921) for mangoes of Maharashtra; ii) Naik and Gangolly (1950) for south India mangoes; and iii) Singh and Singh (1956) for Florida mangoes.

Litz (2003) reported that because many clonally propagated mango cultivars have unique local and/or regional names, there is considerable confusion in nomenclature. According to the author, the Indian Agricultural Research Institute (IARI), New Delhi has been recognized by the International Society for Horticultural Science (ISHS) as the

international registration authority for Mango. The Society's mission is to consolidate superfluous names of mango cultivars. The potential for molecular [e.g. random amplified polymorphic DNA (RAPD)] markers to resolve much of this confusion has been demonstrated by Schnell *et al*. (1995).

According to Litz (2003) there is little variation among seedlings derived from polyembryonic mangoes. Nonetheless, evidently a certain amount of variability does occur probably as a result of somatic mutation. Thus, in Indonesia there are several 'Arumanis' selections that are denoted numerically, e.g. 'Arumanis 1', 'Arumanis 2' etc. In addition, although Philippine mango cultivars are distinguished by different names e.g. 'Carabao', 'Manila', 'Philippine', etc., the differences among them are quite subtle (Litz, 2003).

2.3 REPRODUCTIVE PHYSIOLOGY OF THE MANGO TREE

2.3.1 PHENOLOGY

Verherij (1986) reported that flowering flushes of many plants generally occur after extended periods of stem rest in the low-latitude tropics or during cool winter months in the high latitude tropics and subtropics. The author added that like vegetative flushes, reproductive flushes are usually asynchronous in tropical climates. In the subtropics, however, trees exposed to periodic low winter temperatures, produced by strong cold fronts that lower the night temperatures to a range of 5–10^{o}C, display synchronized flowering flushes throughout the canopy. As a result, subsequent vegetative flushes also tend to be synchronous for one or two growth cycles depending upon the presence of

fruit (Verherij, 1986). Chadha and Pal (1986) found that variations in flowering patterns can be found in all cultivars depending on their age and whether they are planted in dry or humid tropics or subtropics. According to Davenport (1993), Kinet (1993) and Litz (2003) growth of mango and other tropical trees is not continuous and that it occurs as intermittent, short–lasting flushes of shoots from apical or lateral buds of resting stems before returning to a quiescent state. Litz (2003) added that periods of extended dormancy are generally short in young plants but usually last several months between flushing episodes in mature trees.

According to Davenport (1993) a fundamental understanding of mango flowering in the tropics and subtropics is essential to efficiently utilize cropping management systems which extend both the flowering and crop production seasons. The author reported that flowering of mango can be enhanced during its normal season or manipulated to occur at other times of the year in tropical climates; one notable example being the use of potassium nitrate (KNO_3) to stimulate out–of–season flowering of some cultivars growing at tropical latitudes. However, this treatment is not always dependable (Davenport, 1993). Litz (2003) stated that flowering and fruit set are the most critical of all events occurring after establishment of a tree crop, and that given favourable growth conditions, the timing and intensity of flowering greatly determines when and how much fruit are produced during a given season. Understanding and controlling this phenomenon has been of prime interest to scientists for over a century (Kinet, 1993).

2.3.2 FLOWERING MECHANISM

Nunez–Elisea *et al*. (1996) reported that light pruning for example during warm, summer months results in initiation of vegetative shoots from axillary buds whereas pruning during cool, winter months usually results in initiation of axillary inflorescences. Kinet (1993) defined shoot induction as the temporary commitment of buds to evoke a particular shoot type, i.e. vegetative shoot (vegetative induction), generative shoot (floral induction) or mixed shoot (combined vegetative–floral induction) and differs from the definition of induction developed from herbaceous plant flowering models. In other flowering models a critical photoperiod or vernalisation treatment or both induces production of a putative floral stimulus which may comprise several translocatable components. Unlike mango, initiation in these models refers to the onset of floral bud evocation (Huala and Sussex, 1993). According to Batten and McConchie (1995) and Nunez–Elisea *et al*. (1996) the inductive signal can be shifted from reproductive to vegetative or vegetative to reproductive by altering temperatures to which the plants are exposed during early shoot development. This treatment produces reproductive-to-vegetative (R–V) transition shoots or vegetative-to-reproductive (V–R) transition shoots respectively (see Appendix C) (Nunez–Elisea *et al*., 1996).

Kulkarni (1991) found out that floral stimulus is also graft transmissible. According to the author, early flowering of seedling stems was stimulated by grafting them onto mature trees or by grafting the mature stems onto juvenile plants. Similar results were obtained by approach-grafting seedling plants to mature trees (Kulkarni, 1991). Nunez–

Elisea (1985) reported that use of KNO_3 to stimulate early flowering in certain cultivars in the tropics works consistently only on shoots which are at least 7 months old.

2.3.3 ENVIRONMENTAL INFLUENCE ON GROWTH AND REPRODUCTIVE DEVELOPMENT

Environmental influences, i.e. temperature, plant water relations and photoperiod on determination of growth and reproductive development of mango have been addressed in numerous reviews (Schaffer *et al*., 1994; Chaikiattiyos *et al*., 1994; Nunez–Elisea, 1994; Nunez–Elisea *et al*., 1996). Schaffer *et al*. (1994), Chaikiattiyos *et al*. (1994), Nunez–Elisea (1994) and Nunez–Elisea *et al*. (1996) indicated that the developmental fate of mango buds is strongly influenced by temperature. According to the authors, plants exposed to cool night temperatures between 8 and 15ºC in combination with day temperatures below 20°C typically induce flowering if shoot initiation occurs. It has also been demonstrated that mango trees develop vegetative shoots when shoot initiation occurs in warm temperatures (30ºC day/25ºC night) whereas inflorescences develop when shoots initiate growth at cool temperatures (18ºC day/10ºC night or 15°C day/10ºC night) (Nunez–Elisea and Davenport, 1995; Nunez–Elisea *et al*., 1996). Issarakraisila *et al*. (1992) found out that the age of stems at the time of shoot initiation becomes the dominant factor determining the fate of the shoots. The authors added that floral induction is thus more likely on older stems.

According to Whiley (1993), in the absence of cool temperatures (less than 15ºC) mango trees in the tropics may flower in response to irrigation or rains following water

stress of 6–12 weeks or more since plant water stress has generally been presumed to provide the stimulus for flowering. But some experiments with container–grown mango trees failed to produce inflorescences after 8 weeks of water deficit as determined by soil moisture content (Nunez–Elisea and Davenport, 1995). Similarly only vegetative growth was obtained after container-grown trees were deprived of irrigation for 36 days during summer. These results indicate that cool temperatures provide the inductive condition whereas relief of water stress accelerate initiation of shoots during exposure to cool, inductive temperatures (Chaikiattiyos *et al*., 1994). According to Davenport (1993) and Schaffer *et al*. (1994) evidence shows that the primary impact of water stress on mango is to prevent vegetative flushing during the stress period. The authors added that the accumulating age of stems is greater in water–stress trees than in trees maintained under well–watered conditions which can vegetatively flush more frequently. This delay in flushing may provide more time for accumulation of a proposed floral stimulus (Schaffer *et al*., 1994) or reduction in the level of a putative vegetative promoter.

Kozlowski *et al*. (1991) found out that flowering in most woody perennials does not appear to be under photoperiodic control. Nunez–Elisea and Davenport (1995) also reported that photoperiod had no effect on the vegetative or reproductive fate of buds, and the promotive effect or reproductive fate of buds, and the promotive effect of cool temperatures on flowering was independent of photoperiod. The authors concluded that floral induction is caused by cool temperatures and not by short photoperiods and that flowering is inhibited by warm temperatures, not by a long photoperiod.

In many mango varieties, flower-bud induction, fruit size and colour are reduced when low light levels occur due to crowding within and between tree canopies. Skin colouration of mature fruit is partly due to anthocyanins which develop when tissues are exposed to light (Procto and Creasey, 1971; Yahia, 1999). Studies in Australia with the polyembryonic cultivar 'Kensington' which develop a blush only on the exposed side of the fruit, indicated that the position of fruit on trees had a significant effect on the development of colour due to differences in the penetration of light into the canopy during fruit ontogeny (Schaffer *et al.*, 1994). The intensity of redness was greatest on fruit from the eastern side of the tree followed by fruit from the south-western and northern sides of the tree (Schaffer *et al*., 1994).

Larson *et al*. (1989) showed that irrigation of mango trees particularly during the first 4–6 weeks following fruit set will increase individual fruit size and yield since it is a time when cell division is most rapid and cell walls are developing. Although drought tolerance of the tree is well known, this comes at a considerable cost to tree performance, particularly in areas with prolonged dry seasons that extend through flowering and fruiting (Litz, 2003).

Larson *et al*. (1993) reported that vegetative growth of mango trees generally declines when trees become flooded for more than 2–3 days and that flooding for approximately 10 days resulted in a 57% reduction in shoot extension growth. For Litz (2003), these adverse effects of flooding on the growth of mango trees are expected as reduced net

photosynthesis and presumably higher root respiration limit the availability of carbon–based assimilates required for growth.

Wind causes abrasions to the skin of fruits, particularly when they are small, which develop into unsightly blemishes by the time they were fully grown thereby reducing quality and market value. Van der Meulen *et al.* (1971) reiterated that until recently wind protection in South Africa was not recommended for mangoes due to the loss of potential cropping space by "living" shelter, their potential to create frost pockets, and the likelihood of promoting the incidence of flower and fruit diseases through increased humidity. In studies with 'Kensington" mangoes in Australia, where artificial windbreaks were constructed to shelter trees from the prevailing south-easterly winds in summer, a 600% increase in yield was recorded in the first year following wind protection (Mayers *et al*., 1984).

2.3.4 FRUIT SET AND RETENTION

Generally, most fruit are set on the distal portion of panicles (Nunez–Elisea and Davenport, 1983). According to Gunjatee *et al*. (1983) fruit loss has several causes and has often been associated with embryo abortion, resulting in blackened or shrivelled embryos. Prakash and Ram (1984) reported that of the 8 to 13% of flowers setting fruit, less than or equal to 1% reach maturity.

2.3.5 FRUIT DEVELOPMENT

According to Whiley *et al*. (1988) seedlessness is caused by embryo abortion and is not a result of failure of fertilization, and that the phenomenon is referred to as 'stenospermocarpy'. According to the authors embryo abortion appears to be caused by low or high temperatures during the first few days following fruit set. Early abscission of fruitlets from non–fertilized and fertilized flowers is therefore normal since fruitlet abscission from pea–size is often associated with embryo abortion (Schaffer *et al*., 1994).

2.3.6 FRUIT MATURATION AND RIPENING

Peacock (1986) considered that fruit maturity referred to the stage of ontogeny at any given time; fruit of different maturities being at different stages of ontogeny. As fruit size and dry matter levels peak, climacteric fruit such as mango undergo ripening; colour, texture, flavour and aroma may change (Watada *et al.,* 1984). In climacteric fruit, a sharp rise followed by a decline in respiration also accompanies the transformation from inedible (unripe), to edible (ripe) and to senescence (over-ripe) (Watada *et al*., 1984). According to Litz (2003) fully mature mango fruit are strictly those which have produced a fully developed seed and which have reached their full physiological potential for size increase and dry matter accumulation within the constraints of the growth environment.

Oosthuyse (1995) pointed out that softening and sweetening of fruit flesh and colour changes can occur at any stage of ontogeny; even in pea-sized fruit. Fruit drop at any

stage of development is preceded by these events, and the likelihood of their occurrence increases as fruit size and dry matter levels approach their maxima. Although the changes constitute some of the components of ripening, they can only be regarded as such if the fruit have attained physiological maturity i.e. the stage of development when a plant or plant part will continue ontogeny even if detached (Watada *et al*., 1984). Litz (2003) indicated that when fruits are removed from the tree before the onset of ripening, they are initially hard and green. The fruit progressively softens, change colour and develop aroma at a rate determined by storage environment and at-harvest maturity. According to the author there is a range of maturity levels within which detached fruit will develop acceptable ripe fruit attributes. The author added that measurements of variables such as dry matter or flesh colour provide indices which can be related to accumulated information on storage life, ripening attributes and marketability of fruit.

The rate at which ripening occurs under particular storage conditions will depend upon the stage of ontogeny at harvest. More mature fruit will ripen more rapidly than less mature fruit (Litz, 2003).

Asker and Treptow (1993) stated that maturity assessment may be on the basis of dry matter, flesh colour, skin colour, fruit shape, brix, specific gravity or days from flowering. According to the authors, in South Africa flesh colour is favoured, while in Australia, skin colour and dry matter determination may be considered as well. Information would be cultivar–specific (Asker and Treptow, 1993).

Schaffer *et al*. (1994) outlined two important measures of fruit maturity to include i) the legal minimum standard of maturity and ii) the horticultural maturity. According to them legal minimum standards rely on application of a prescribed test e.g. dry matter and flesh colour which confirms that the fruit should be acceptable for consumption (or processing) when ripe. Assessment of horticultural maturity may rely on prescribed tests to assess product suitability for more stringent or narrower quality specifications as may be required for contract sales or sea export consignments. In both cases, easy–to–assess harvest indices relying on visual attributes are needed and they must correlate with the recognized variables measured in prescribed tests (Schaffer *et al*., 1994). The authors added that workers who harvest and grade fruit should be trained and tested for their ability to accurately select fruit according to the preferred non–destructive index. Visual assessment of maturity is complicated by the fact that cultivars differ and fruits on the same tree may vary significantly in maturity levels due to prolonged or uneven flowering (Schaffer *et al*., 1994).

Variation in maturity between fruit can also be influenced by where fruit hang on the tree. In the southern hemisphere, fruit on the northern side mature more quickly than fruit on the southern side (Oosthuyse, 1995). Jacobi *et al*. (1995) indicated that fruit maturity is an important factor determining fruit quality in overseas markets. If fruits in a carton are of uneven maturity, it is impossible to find an effective storage regime which will ensure good quality on arrival. One fruit of more advanced maturity in a box can accelerate the ripening of all fruit, which can then arrive with disease symptoms and

short shelf life. Variable maturity within treatment lots can also adversely affect product quality after heat disinfestation (Jacobi *et al*., 1995).

Kouno *et al*. (1994) attested that on-farm record keeping of seasonal product maturity, orchard management schedules, environmental data, transport regimes, market destinations and out-turn problems may enable some prediction of future product performance. The authors added that improvements in product quality and performance resulting from the effective use of such records can provide considerable competitive advantages when developing product brand loyalty. Future research should consider easy–to–apply harvest indices and non–destructive methods for checking fruit maturity which could be incorporated in an automated grading system (Joyce *et al*., 1993; Kouno *et al*., 1994).

Ripe mango peel shows a wide range and mixture of colours from green to greenish–yellow, red, violet and yellow. Litz (2003) reported that skin colour can affect saleability of fresh mango fruits, with most markets preferring red blush. According to the author, fruit position on the tree affects colour development, which is greatest on the exposed faces of the tree. Nitrogen levels have been found to affect significantly red and yellow colour on ripening. Thus nitrogen should only be applied immediately after picking, so that levels are relatively low during fruit set and development. This results in better fruit colour and reduced sap–burn. Some cultivars are also marketed green, including the green–eating cultivars which are consumed mature green before softening and colour development occur (Litz, 2003).

The external colour of the fruit is an important factor in consumer preference (Litz, 2003). Litz (2003) stated that the principal pigments in the fruits include chlorophylls, carotenes, xanthophylls and anthocyanins which are synthesized via terpenoids or phenylpropanoids. Lizada (1993) had earlier reported that water treatments at high temperatures (50–55^{o}C) often result in enhancement of peel colour intensity and a detectable increase in total carotenoids, although prolonged high temperature treatments may result in lack of colour development (Medlicott *et al.*, 1986).

Different mango cultivars can be distinguished on the basis of flavour and aroma. Ackerman and Torline (1984) identified two novel unsaturated acid esters (2–butenoic and 3–butenoic acid esters) and suggested those compounds may be responsible for the characteristic aroma of mango.

Litz (2003) stated that the aroma produced by a ripening mango can help attract customers. Variation in the constituent aromatic compounds in mango cultivars results in aroma and flavour diversity (MacLeod *et al.*, 1988). Kostermans and Bompard (1993) considered that fibreless fruit flesh was linked to an absence of aroma and flat taste and smell; however, 'Kensington' has low fibre and a distinctive flavour and aroma profile (MacLeod *et al.*, 1988).

2.3.6.1 Effect of Respiration and Ethylene Production on Ripening

Mango is a climacteric fruit and as such undergoes increased (autocatalytic) ethylene production (Mattoo and Modi, 1969), along with a breakdown in carotenoids in the peel

(yellowing), enhanced respiration and softening (Krishnamurthy and Subramanyam, 1970; Akamine and Goo, 1973; Salunkhe and Desai, 1984). Together with the ethylene evolution and respiratory climacteric in mangoes, the catalase and peroxidase activities were found to increase considerably, due to the disappearance of the heat-labile and non-dialysable inhibitor of these enzymes (Mattoo and Modi, 1969).

The patterns of respiration and ripening behaviour vary among the varieties, the climatic conditions and the places of production (Krishnamurthy and Subramanyam, 1970). In 'Alphonso' mangoes, the respiratory peak was observed at five days after harvest and fruits ripen within seven or eight days (Karmarkar and Joshi, 1941), while in 'Kent' and 'Haden' varieties the peak was observed at the ninth and eleventh days respectively (Burg and Burg, 1962). In 'Pairi' mangoes, respiratory peak was on the ninth day after harvest (Krishnamurthy and Subramanyam, 1970). The respiration decreases as the fruit matures, and the respiratory rise then commences with ripening. Ethylene production also decreases as the fruit matures, is then undetectable for a time and re-appears upon ripening (Akamine and Goo, 1973). Although Burg and Burg (1962) stated that ethylene rises during the period or before carbon dioxide production rises in ripening mangoes, Bialete and Young (1981) included mangoes among the fruit in which ethylene rises after carbon dioxide production rises.

Ethylene production by mango fruit tissue, as in many other climacteric fruit, is maximal at the onset of the climacteric phase of fruit ripening (Burg and Burg, 1962; Mattoo and Modi, 1969). The small amount of ethylene present in the fruit at harvest is

sufficient to initiate ripening (Burg and Burg, 1962), but the ethylene production starts before full ripeness is reached (Burg and Burg, 1962; Cua and Lizada, 1990). In 'Carabao' mangoes, the peak of ethylene production was found to be at 110 days after flower initiation, which declined as the fruits approached full maturity (Cua and Lizada, 1990).

2.3.6.2 Effect of Carbohydrate Metabolism on Ripening

During ripening the accumulated starch hydrolyses, with formation of sugars. The hydrolysis of starch granules in the chloroplast continues until ripening (Medlicott *et al.*, 1986; Selvaraj *et al.*, 1989; Kumar *et al.*, 1994). Glucose, fructose and sucrose constitute most of the monosaccharides, and have been reported to be in similar concentrations in ripe mangoes (Shashirekha and Patwardhan, 1976), with sucrose being the predominate sugar (Krishnamurthy and Subramanyam, 1970; Selvaraj *et al.*, 1989; Kumar *et al.*, 1994). Sucrose contributed 57% of total sugar in ripe Keitt mangoes, with fructose and glucose making up 28 and 15% respectively (Medlicott and Thompson, 1985). Several reports (Krishnamurhty *et al.*, 1971; Lakshminarayana, 1973, 1975; Shashirekha and Patwardhan, 1976) suggest simultaneous increase of glucose, fructose and sucrose during ripening, but Vazquez-Salinas and Lakshminarayana (1985) observed a gradual reduction in both glucose and fructose and a continuous increase of sucrose during ripening in Florida mango cultivars (Haden, Irwin, Kent and Keitt).

The hydrolysis of starch and formation of sugars have been associated with amylase activity (Mattoo and Modi, 1969; Fuchs *et al*., 1980). The high activities of both sucrose synthetase and invertase in the mesocarp during ripening are indicative of active sucrose metabolism (Kumar *et al*., 1994). Hexoses and hexose phosphates can be formed from pyruvate by gluconeogenesis (Selvaraj and Kumar, 1994). The activity of glucose–6–phosphatase was reported to increase as the fruit ripened up to the three-quarter-ripe stage, whereas fructose - 1, 6 - diphosphatase activity increased as the fruits ripened from the three-quarter–ripe to full-ripe stage (Kumar and Selvaraj, 1990). The glycolytic enzyme hexokinase activity was detected only at the ripe stage. The phosphofructokinase showed maximum activity in the ripe stage, while pyruvate kinase activity was found to increase until the three-quarter-ripe stage and declined at ripening (Selvaraj and Kumar, 1994); the pattern of change in hexokinase, phosphofructokinase and pyruvate kinase activities suggests the activation of glycolysis in ripening mango fruit.

2.3.6.3 Effect of Ripening and Pigmentation on Peel and Flesh Colour

The peel colour of fruits changes on ripening from dark green to olive-green; sometimes reddish, orange-yellow or yellowish hues appear from the base colour, depending on the cultivar. Chloroplasts in the peel are transformed into chromoplasts containing red and yellow pigments (John *et al*., 1970; Lakshminarayana, 1980; Parikh *et al*., 1990; Lizada, 1993). Some cultivars also develop a reddish blush, which has been attributed to anthocyanins, while some remain green (Lizada, 1993).

Several authors have studied the qualitative and quantitative changes in the carotenoid pigments during ripening (Jungalwala and Cama, 1963; John *et al*., 1970; Medlicott *et al*., 1986). Substantial losses in peel chlorophyll content of 'Keitt' mangoes occur after the fruit begins to soften (Medlicott and Thompson, 1985). The carotenoid level in 'Tommy Atkins' mangoes increases, with a gradual decrease in anthocyanins (Medlicott *et al*., 1986)

Parikh *et al*. (1990) observed well-arranged grana and osmiophilic globules in the chloroplasts of the cells in the peel of unripe mangoes. This granal membrane loses integrity during ripening and osmiophilic globules appear, indicating the transformation of the chloroplast to a chromoplast containing red or yellow carotenoid pigments.

The pulp carotenoid level in the ripe fruit varies among the cultivars. In ripe 'Alphonso' mangoes, Jungalwala and Cama (1963) reported the presence of 16 different carotenoid fractions. There was a further study by John *et al*. (1970), who observed 17 different fractions of carotenoids. Both groups of workers, however, found that more than 50% of total carotenoids consisted of β-carotene.

While investigating the mechanism of carotenogenesis in mango, Mattoo *et al.* (1967) observed an increase in the mevalonic acid and geraniol content with a concomitant increase in carotene content. The geraniol concentration in unripe 'Alphonso' mangoes varies from 0.5 to 3.0 µmol and that of mevalonic acid, 0.0 to 0.5 µmol; in ripe mangoes the corresponding levels are 5 to 10 and 1 to 5 µmol respectively. The increase in free geraniol and mevalonic acid indicate that these compounds are dephosphorylated during

ripening. It is believed that the enzyme phosphatase regulates carotenogenesis in ripe mangoes (Mattoo *et al*., 1968).

Mangoes stored at low temperatures and subsequently ripened at room temperature failed to synthesise as much carotenoids as do fruits held continuously at room temperature (Krishnamurthy and Subramanyam, 1973; Thomas, 1975). However, a hot water dip (52–55°C) for 5–10 min increased the colour intensity of both the pulp (Medlicott *et al*., 1986) and the peel (Esguerra and Lizada, 1990).

2.3.6.4 Effect of Pectic Substances and Cell Wall Constituents on Fruit Softening

Ripening of the mango fruit is characterized by softening of the flesh. The peak of ripeness is associated with a fairly narrow range of firmness (Roe and Bruemmer, 1981). Limited information is available on mango cell walls and the softening process during ripening (Lazan *et al*., 1986; Brinson *et al*., 1988; Seymour *et al*., 1990; Mitcham and McDonald, 1992; Ali *et al*., 1995), and there are considerable differences among cultivars (Selvaraj and Kumar, 1989). Softening of mango fruit is characterised by an increase in the solubility of cell wall pectins (Roe and Bruemmer, 1981; Lazan *et al*., 1986; Nasrijal, 1993), and the tissue softness is believed to be initiated in inner mesocarp tissue close to the seed, and to progress outward (Lazan and Ali, 1993). While pectin solubilisation in inner and outer mesocarp tissues was comparable, pectin depolymerization appeared to begin earlier in the inner mesocarp than in the outer mesocarp tissue (Lazan and Ali, 1993). Physiological maturity in tree-ripened mango fruit was reported to be associated with a drop in pectinesterase (PE) activity and the

peel of mango was reported to have higher PE activity than the pulp (Ashraf *et al*., 1981).

The presence of polygalacturonase (PG), the enzyme responsible for degrading the (1→ 4) – linked galacturonic acid residues, has been reported in ripening mangoes (Abu-Sarra and Abu-Goukh, 1992; Lazan *et al*., 1993). Pectinesterase (PE), which catalyses the de-esterification of methyl groups from acidic pectins is also detectable in ripening mangoes (Tahir and Malik, 1977; Roe and Bruemmur, 1981; Ali *et al*., 1991, 1995; Abu-Sarra and Abu-Goukh, 1992). Other cell wall hydrolases detected in ripening mangoes are cellulase (Lazan *et al*., 1986; Abu-Sarra and Abu-Goukh, 1992), β–galactosidase (Ali *et al*., 1990, 1995; Lazan and Ali, 1993), galactanase (Ali *et al*., 1990) and oxylarase (Ali *et al*., 1990). In general, water–soluble polysaccharides increased during ripening (Lazan *et al*., 1986; Brinson *et al*., 1988); in 'Keitt' mangoes, however, water–soluble and alkali–soluble pectin declined and ammonium oxalate–soluble pectin increased as the fruit lost its firmness and became soft (Roe and Bruemmer, 1981).

Mitcham and McDonald (1992) studied the cell wall modification during ripening of 'Keitt' and "Tommy Atkins' mango fruit. They observed that cell wall neutral sugars, particularly arabinosyl, rhamnosyl, and galactosyl residues, decreased with ripening in both cultivars. 'Keitt' had more loosely associated, chelator-soluble pectin, accumulated more soluble polyuronides and retained more total pectin at the ripe stage than did "Tommy Atkins'. Both cultivars had similar polygalacturonase activity, which

increased with ripening. The molecular mass of cell wall hemicellulose decreased with ripening. They indicated that enzymatic and/or non-enzymatic processes, in addition to polygalacturonase activity, are involved in the extensive softening of fruit. In 'Sensation' mangoes, galactose was the only cell wall neutral sugar to show a significant decrease during ripening (Seymour *et al*., 1990). Such losses of neutral sugars could possibly be attributed to hydrolysis of galactans and arabionogalactans by β–galactosidase having galactanase activity. β–galactosidase activity showed a parallel increase to tissue softening during ripening, and the close correlation between changes in β–galactosidase activity, tissue softness, and increased pectin solubility and degradation suggests that β–galactosidase might play an important role in the cell wall pectin modification and softening of mango fruit during ripening (Ali *et al*., 1995). Various postharvest treatments such as modified–atmosphere packaging and modified-atmosphere coating, as well as storage at low temperatures, retarded softening and resulted in corresponding retardation of both polygalacturonase and galactosidase activity (Lazan *et al*., 1990; Nasrijal, 1993; Lazan and Ali, 1993).

2.4 MANGO FRUIT QUALITY

Swiader *et al*. (1992) stated that the quality of fresh fruit is combination of characteristics, attributes and properties that give a commodity value to humans for food. The connotation is that the important attributes of quality vary according to the individual(s) defining the term. The authors indicated that growers are interested in disease resistance, high yielding, uniform maturity, desirable size and ease of harvest; post-harvest characteristics have not been one of their main interests. Shippers and handlers are concerned with shipping quality and market quality; firm fruit that can endure

inexpensive handling and transport and still maintain high market quality is desirable. Consumers care about appearance, price, and table quality, including texture, flavour, colour, and nutritive value of mango. Villareal (1980) earlier on stated that an effective quality control system throughout the handling steps between harvest and retail display is essential to providing a consistently good-quality supply of fresh fruit to the consumer and to protecting the reputation of a given marketing label.

Litz (2003) concluded that large numbers of mango varieties with variable attributes affect the quality and uniformity of the processed products. Similarly, lack of simple and reliable methods for determining the stage of fruit maturity also affect quality (Litz, 2003).

2.4.1 CHEMICAL COMPOSITION AND NUTRITIVE VALUE

Doreyappa and Ramanjaneya (1994) stated that physio-chemical composition of mango is an important factor in the selection of suitable cultivars for processing, and that mangoes can be processed at both unripe (green mature) and ripe stages of maturity for conversion into a wide range of products as in Appendix B4.

Green mangoes (firm fruit with developed stone but unripe) are processed into traditional products like brine stock, pickles, chutneys and dried powder. Instant mango pickles, drum-dried green mango powder and raw mango beverage base are the latest developments (Chau *et al.,* 1989). Chau *et al.* (1989) indicated also that unripe mango slices are preserved with salt for later conversion into pickles, chutney or as salt stock

for export. Chemical composition of some important cultivars grown in different countries is presented in Appendix B5.

It has been reported that when raw mango slices are dried in the sun or in a mechanical drier and powdered it is referred to as "amchur" in the trade and is used in culinary preparations for traditional Indian cooking (Anonymous, 1989). According to the author studies have been conducted to improve the process by using slices of mangoes at an optimum stage of maturity (9–10 weeks after fruit set) and by sulphite treatment of the slices to improve retention of colour and vitamin C.

Chau *et al.* (1989) stated that raw mango beverage is a traditional product prepared and consumed in most households in India. The authors added that baking green mangoes (firm mature fruit with developed stone but unripe) at 200°C for 25 minutes is useful for extracting good quality pulp with higher yield and more retention of vitamin C; and that squash and nectar prepared from this pulp is acceptable. Chemical composition of green mango pulp and flake is shown in Appendix B6.

Franklin (1991) reported that ripe mangoes (mature and post–climacteric ripe fruit with full flavour development) are processed into: i) frozen mango products e.g. slices in syrup, pulp and beverage base; ii) canned products e.g. slices in syrup, pulp, juice and nectar; iii) ready–to–serve beverages; and iv) dehydrated products e.g. mango fruit bar, mango cereal flakes, mango powder, strained baby foods, mango toffees etc. Canned mango slices in juice, mango concentrate, mango aroma concentrate, low viscosity and

low pulp–containing mango beverage base, aseptic bulk packing of pulp and concentrate, structured mango products etc. are relatively new product developments (Franklin, 1991). Kurdiya and Roy (1986) found that mangoes are generally canned at the "just ripe" stage as slices, cheeks or dices. Among Indian mangoes, "Alphonso" mango variety is reportedly most suitable because other varieties yield canned products with mild flavour and colour, and that addition of ascorbic acid to the canned mango slices in syrup at different levels (50–100mg/l) aids flavour retention (Kurdiya and Roy, 1986).

Mango jam and mango toffee are indicated to be sweet mango products produced and exported from India (Anonymous, 1985). Alzamura *et al*. (1993) stated that dehydrated tropical fruits are becoming popular worldwide and that a number of products based on mango have been developed. These include dehydrated mango slices, intermediate moisture mango and high moisture mango slices and puree. Britnell (1991) also wrote about structured mango products and that they can be incorporated into yoghurt, ice cream and confectioneries such as mango fruit bar, mango cereal flakes, strained baby food and mango powder (Nandanasahapathi *et al.*, 1993). Litz (2003) mentioned mango concentrate, mango aroma concentrate and alcoholic beverages as other mango products and that demand for mango concentrate in export markets has been increasing.

Ethiraj and Suresh (1992) reported that peels and stones are the main waste products of processing, and constitute 35–55% of unripe as well as ripe mangoes. Useful products can be recovered from these wastes and simultaneously avoid the disposal problem.

These wastes can be treated with pectic enzymes, their juice compressed and used in the preparation of nectar, vinegar or concentrated and used as a colouring and flavouring agent (Ethiraj and Suresh, 1992). The chemical compositions of these waste products are indicated in Appendix B7.

Krishnanand (1994) reported that mango peel can also be used for biogas production by anaerobic digestion. The results of pilot plant studies have shown that mango peel, supplemented with essential nutrients, can yield biogas at a rate as high as 0.68m^3 per kilogram volatile solids added; the gas contains 52% methane (Krishnanand, 1994).

Ethiraj and Suresh (1992) indicated that the mango seed kernel is a rich source of carbohydrates, protein, fat and tannins and that due to its blandness, plasticity and absence of toxic substances, the kernel fat (average 12%) has potential use for preparing sweetmeats. It can also be used in soap manufacturing and as a substitute for cocoa butter. No difference has been noticed in the texture, taste and flavour of toffees prepared from mango kernel oil and cocoa butter (Ethiraj and Suresh, 1992). According to them mango seed kernels also contain 47-63% starch of which 19–22% is amylase and that the starch is recommended for food use. Important chemical constituents of mango seed kernel are shown in Appendix B8.

According to Krishnanand (1994) ripe mango is especially rich in carotenes which have antioxidant properties thought to lower the risk of heart disease and stroke and contains an enzyme with stomach soothing properties similar to papain found in papayas. These

comforting enzymes act as a digestive aid (Krishnanand, 1994). The mango fruit is mostly consumed in the fresh state. However, the fruit can be frozen, dried, pickled or canned for use. The fruit is also used in the preparation of salads and in some countries, for example, India the green mango is cooked in stews and soups. Aside its food uses, mango also has some medicinal value because it is rich in astringents employed in the treatment of some diseases (Litz, 2003).

The mango fruit contains amino acids, carbohydrates, fatty acids, minerals, organic acids, proteins and vitamins (Litz, 2003). During the ripening process, the fruits are reported to be initially acidic, astringent and rich in ascorbic acid (vitamin C). Ripe mangoes contain moderate levels of vitamin C but are fairly rich in provitamin A and vitamins B_1 and B_2 (Litz, 2003). According to Litz (2003) fruit acidity is primarily due to the presence of malic and citric acids and that in addition, oxalic, malonic, succinic, pyruvic, adipic, galacturonic, glucuronic, tartaric, glycolic and mucic acids are also present. The author added that acidity is cultivar–related; during ripening acidity decreases. Following fruit set, starch accumulates in the mesocarp. Free sugars including glucose, fructose and sucrose generally increase during ripening but the sucrose content increases three–to four fold due to the hydrolysis of starch as the fruits are climacteric in nature (Castrillo *et al*., 1992).

Nutritive value of 100g edible portion of raw mango fruit has been reported to be as follows: inedible waste (34%), energy (59kcal or 253kJ), protein (0.5g), fat (0. 0g), carbohydrate (as monosaccharide) (15.3g), water (83g), Ca (10mg), iron (0.5mg), Na (7mg), Vitamin A (retinol equivalent) (200g), Thiamine (0.3mg), Riboflavin (0.04mg),

Niacin equivalent (0.4mg), and Vitamin C (30mg) (Anonymous, 1985). The United States Department of Agriculture (USDA, 2004) National Nutrient Database for Standard Reference, Release 17 also reported the chemical composition of raw mango as in Appendix B10.

2.4.2 QUALITY COMPONENTS

Wills *et al*. (1998) stated that important quality components for producers, exporters/distributors and consumers are appearance; including size, colour, shape, condition (such as freshness) and absence of defects; texture and firmness; flavour and nutritive value.

2.4.2.1 Appearance

A rapid visual assessment of the mango fruit appearance can be made on the basis of size, shape, colour, condition and or the presence of defects or blemishes and rot as indicated by Wills *et al*. (1998).

Atherton and Rudich (1986) stated that freshness, stage of senescence or ripeness, the extent of mechanical damage and pest or disease incidence detract from appearance and in most markets detract from price, even when the blemishes reduce neither keeping quality nor eating quality. Evaluation of defects is only subjective since there are no objective ways of evaluation (Atherton and Rudich, 1986).

Among these factors which influence visual appearance, Arthey (1975) had earlier reported that colour measurements in fresh and processed fruits and vegetables and other foods are without doubt the most important single quality factor that affects grower-processor relationship and consumer acceptance of products. Thus appearance is a major determinant of quality, especially because it is often the only criterion available to the buyer of the commodity (Arthey, 1975).

2.4.2.2 Firmness

According to Atherton and Rudich (1986) firmness is closely related to stage of ripeness. The authors added that sensory evaluation of fruit textural quality involving finger feel, mouth feel and slicing characteristics are all related to firmness. Beattie *et al.* (1983) indicated earlier that firm fruits (tough skin and firm flesh) are less susceptible to physical and mechanical damage, and therefore store better and enhance transportation and distribution in the marketing system. Atherton and Rudich (1986) also stated that for successful mechanization of the fruit industry, the most important characteristic is a concentrated set of firm, tough fruits. Gormley and Eghan (1982) earlier on stated that to ensure reasonable shelf-life, mango fruits should have firmness value of at least 200g/5 mm fruit compression. However, fruit firmness according to El-Sayed and Erickson (1966) has been found to be under genetic control.

2.4.2.3 Flavour

Kader *et al.* (1985) indicated that flavour is comprised of taste and aroma and that the aromas of many chemical constituents are responsible for the flavour of fruits when

tasted. Wills *et al.* (1998) stated that the taste of fruit and vegetables is usually a blend or balance of sweet and sour, often with overtones of bitterness due to tannins. The sweetness, sourness and overall flavour intensity in fruits according to De Bruyn *et al.* (1977) are influenced by sugars, acids and their interactions; and Davies and Hobson (1981) testified that fructose and citric acid are more important to sweetness and sourness than glucose and malic acid respectively. High sugars and relatively high acids give best flavour. High acids and low sugars produce tart (unpleasant sharp taste) fruit while low acids and high sugars give bland (mild in flavour, not having interesting taste) taste. Low acids and low sugars give tasteless, insipid fruits (Grierson and Kader, 1986).

2.5 MANGO FRUIT EXPORT

2.5.1 GRADES AND STANDARDS

It has been stated that the purpose of grading are to sort fruit into defined categories of uniformity (usually size, shape and absence of physical defects) and to divert out-of-grade fruit from the packline to a second grade line and/or a processing line (Anonymous, 1993). Mangoes not accepted for fresh markets are called seconds (Litz, 2003).

The OECD provides guidelines in defining international marketing requirements (Anonymous, 1993) as indicated in the appendices attached. These requirements include: minimum requirements, class standards, proposed categories for fruit sizing with maximum permissible differences allowed within each of these size groups

amongst others. Colour illustrations indicating quality standards for appearance, shape and colour, and tolerance levels for superficial skin defects have also been reported (Anonymous, 1993). Schoorl and Holt (1985) reported earlier that automatic graders separate fruit by weight, colour or shape into groupings which correspond to predetermined categories.

There are various standards that have been established for appearance and quality of fruit on the international market (Litz, 2003). Currently, the mango export market is based for the most part upon 'Haden', 'Keitt', 'Kent', 'Palmer' and 'Tommy Atkins' (Litz, 2003).

2.5.2 PRE–SHIPPING AND POST–SHIPPING STORAGE

Oosthuyse (1994 a) reiterated that deleterious effects to skin, flesh and ripening attributes limit the range of storage temperatures and that storage should be for the minimum period necessary. The author further stated that the incidence of postharvest decay on fruit that ripen after refrigerated storage is positively related to the duration of storage and the extent of ripening during storage. Disease incidence after post-storage exposure to ripening temperatures can be reduced by minimizing the shipping period and storing fruit at temperatures that inhibit softening and ground skin colour development (Oosthuyse, 1994b). Earlier report by Oosthunyse (1990) indicates that if fruit are placed in cold storage without delay after picking, storage at 8-10ºC inhibits or greatly retards ripening of Irwin, Zill, Tommmy Atkins, Kent and Keitt mangoes for up to 28 days. If chilling injury occurs disease development may be earlier and more

extensive. For fruit that have ripened, storage temperatures of lower than 8ºC can be used for up to 21 days without deterioration in quality during storage; however, the fruit will deteriorate rapidly after removal from storage (Van and Oosthuyse, 1994).

Delays in time from picking until placement of the fruit under refrigeration, effectively increases the rate of ripening at a particular temperature. This applies particularly for fruit picked at an advanced stage of maturation (Litz, 2003). If prolonged, a delay may render refrigerated storage ineffective in preventing fruit from becoming soft during transit, despite the apparent absence of softening on dispatch (Oosthuyse, 1994b). Fruit should be picked, packed and placed in cold storage within 24 hours (i.e. precooling) (Kader *et al*., 1985).

2.5.2.1 Low-Temperature Effect on Postharvest Storage

Mango fruit are tropical in origin and therefore chilling-sensitive. Prolonged storage is difficult since temperatures low enough to delay ripening injure these fruit. Some mango cultivars ('Dasheri' and 'Langra') can be safely stored at 7–8^{o}C for up to 25 days (Mann and Singh, 1976); others, however, require temperatures above 10°C (Farooqui *et al*., 1985; Fornaris–Rullan *et al*., 1989) or even 13^{o}C (Saucedo *et al*., 1977). There is much variation in susceptibility to chilling injury among cultivars (Farooqui *et al*., 1985) but, generally, green fruit should be stored at 10–15°C while ripe fruit can tolerate lower temperatures (Medlicott *et al*., 1990b). Between 12 and 13^{o}C generally is considered the optimum temperature for mango storage (Kalra and Tandon,

1983; Thomas and Oke, 1983), with temperatures around 12^{o}C being recommended to reduce the risk of chilling injury in Florida cultivars (Medlicott and Jeger, 1987).

The response to low-temperature storage depends not only on cultivar but also on fruit maturity at harvest and on the season of harvesting (Thompson, 1971; Medlicott and Jeger, 1987; Medlicott *et al*., 1988; Seymour *et al*., 1990). According to Oosthuyse (1994a) fruit harvested at an earlier stage of maturation, as indicated by the absence of mesocarp colouration, ripen more slowly at a given temperature and are more prone to chilling injury and other storage–related disorders. Such fruit may not soften at all when exposed to temperatures that are suitable for storage of more mature fruit. Even if ripening proceeds normally the quality level attained by less mature fruits is usually poor (Oosthuyse, 1994b). Several authors have reported chilling injury development in mango varieties at regimes ranging from 3–12ºC (Chaplin *et al*., 1991). Medlicott *et al*. (1990a) reported that in addition to a reduction in sensitivity to chilling injury, when fruit are ripened before storage, sensitivity to chilling injury is influenced by the stage of maturation at harvest. Fruit harvested when nearly ripe are less prone to chilling injury (Medlicott *et al*., 1990b)

Storage temperatures below 25°C affect the development of the typical aroma and flavour and the carotenoid formation in 'Alphonso' mangoes on ripening (Thomas, 1975). When 'Mamey' mangoes stored at 8–12°C were removed to ambient temperatures, the ripening process was abnormal, with poor colour and flavour development (Rolz *et al*., 1971). Storage temperature influenced the content of ascorbic

acid on ripening: 'Alphonso' mangoes stored at room temperature retained approximately 32% of the original ascorbic acid content at the eating-ripe stage, while those held for 16 days at low temperatures and subsequently ripened at room temperature showed 67–90% retention (Thomas, 1975).

2.5.2.2 Mixed Consignments

O'Hare *et al*. (1994) found that co-shipment of mangoes with papaya (*Carica papaya*) led to an increase in the incidence of ripening of mangoes, and that co-shipment with other fruit or flower types that produce high levels of ethylene can cause unanticipated triggering of ripening in mangoes. Conversely, co-shipment of mangoes with carambolas (*Averrhoa carambola*) caused ripening of the carambolas (O'Hare *et al*., 1994).

2.5.2.3 Fruit Age

Mangoes should be marketed within 28–32 days after picking and that shipping and distribution schedules determine the maximum periods between picking and marketing (Anonymous, 1994). This period could be extended by the application of optimum CA storage (McLauchlan and Barker, 1994). This is because fruit quality deteriorates with age (Litz, 2003). A typical packing and shipping schedule for mangoes consigned by sea to Europe from South Africa is shown in Appendix B9.

2.5.2.4 Networks and Co-operatives

Griffin (1995) stated that establishment of marketing co-operatives or networks can assist individual producers to achieve seasonal spread of production and fulfill buyer expectations of large supplies.

2.5.3 QUALITY ASSURANCE

According to Litz (2003) the purpose of post harvest handling is timely delivery of a product that closely matches buyer specifications and complies with mandatory regulatory requirements. Satisfying customers underpins quality assurance which aims to produce a product of the desired standard, encouraging regular, larger and more frequent purchases and brand loyalty (Litz, 2003). Bunt and Piccone (1994) reiterated that as export markets become increasingly competitive, responsive quality assurance can be the vital strategy for maintaining and expanding market niche. Mitra (1997) maintains, however, that in general terms, quality infers some degree of excellence, giving the customer satisfaction. Thus, quality assurance is a management system for controlling quality through establishing operational procedures involving the integration of the processes, services and people concerned with the product (Mitra, 1997).

Litz (2003) reiterated that the key issues or attributes of preharvest management that affect or influence postharvest development of mangoes include fruit maturity, colour (internal and external), shape, size, sweetness, position–on–tree, vitality, incidence of pests and diseases or biotic/abiotic damage, weather conditions before or at harvest,

frequency of irrigation and nutrient content. In any given tree/orchard/district/season, such attributes vary (Litz, 2003).

Lindror and Prussia (1993) indicated that ensuring a consistent supply of good quality fruit/produce is made difficult by the natural variation found in horticultural crops. The author further stated that controlling quality is often regarded simply as a job for quality control, which in many instances is an inspection–oriented procedure whereby materials and procedures are inspected entering and leaving the pack house. This kind of quality control is very narrow and only picks up errors and poor quality: it does little to rectify inconsistencies or to prevent them (Lindror and Prussia, 1993).

According to Mitra (1997) the critical control points for quality are identified throughout the postharvest chain and procedures put in place to monitor and eliminate hazards. This may be seen in the context of a total quality management philosophy whereby the company is geared toward quality at all stages of the process; the end-result being that quality is built into the system, resulting in the final check of produce prior to distribution or storage being simply one part of the system rather than the catch-all at the end of a poorly controlled chain (Mitra, 1997).

2.5.4 EFFECT OF WEATHER CONDITIONS AND IRRIGATION ON QUALITY OF MANGO

Cooke and Johnson (1994) attested that the occurrence of rainfall before harvest, high humidities and temperatures can increase diseases levels, fruit susceptibility to heat and

brush damage, and reduce storage life. Irrigation frequency can also impact significantly on postharvest diseases and disorders (Hofman and Smith, 1994).

2.5.5 EFFECT OF HARVESTING TIME, HANDLING AND DESAPPING ON QUALITY OF MANGO

According to Joyce and Patterson (1994) the water potential of fruit at harvest can affect susceptibility to handling, heat damage and product storage potential. The authors added that in hot weather, advantage can be gained from harvesting in the coolest part of the day to reduce risks associated with fruit overheating and energy requirements for postharvest cooling, and minimizes worker discomfort. Harvesting during rain can also have deleterious effects on fruit quality (Joyce and Patterson, 1994). Rough handling at harvest can cause skin damage and internal fracturing or bruising. Using hooked sticks to detach fruit (from larger/higher trees), and then picking them off the ground leads to excessive internal fracturing (Ledger, 1991) and sap–burns. Mechanical damage during harvest can also lead to the appearance of soft, darkened areas and bruises on fruit following hot water treatment.

Sap–burn is associated with certain cultivars, as such latex needs to be drained from the fruit (a process known as desapping or bleeding) in a manner which minimizes the incidence and severity of sap–burn. O'Hare (1994) reported that several systems of desapping have been assessed for reducing damage. These include desapping in a 1% solution of calcium hydroxide; washing fruit in 1% aluminium potassium sulphate; applying surface coatings to fruit prior to desapping; trimming and desapping at the

pack–house followed by inversion on a stationary rack or a roller–conveyer running below water (or water/detergent) sprays for 20 minutes and inversion in the soil (usually in the shade beneath the trees) immediately after harvest for 30 minutes.

2.5.6 EFFECT OF PHYSIOLOGICAL DISORDERS ON FRUIT QUALITY

Litz (2003) indicated that mango fruits are susceptible to several physiological disorders which become apparent during ripening and influence fruit quality. Such disorders can be considered as either induced or inherent (Litz, 2003). Some examples of induced disorders of mangoes are chilling injury after exposure to low temperature and impaired ripening of fruit after storage in atmospheres containing high levels of CO_2 (Chaplin, 1989). According to Brown *et al*. (1981) the inherent postharvest physiological disorders of mango are more difficult to study because their occurrence is often intermittent and thus unpredictable; also, the predisposing factor(s) responsible for these disorders presumably occur during the preharvest period. The authors added that a good example is the spongy stem-end disorder of 'Kensington' mangoes. Several other internal disorders of mango have been described. These include 'soft nose' in Florida mangoes (Young, 1960); black-tip (Ram, 1989) and 'internal breakdown', 'spongy tissue' or 'soft tissue' (Subramanyan *et al*., 1971) in Indian 'Alphonso' mangoes.

3.0 MATERIALS AND METHODS

Two studiess were conducted to determine the quality criteria for mango export in Ghana. They included i) field and laboratory studies to establish the criteria for harvesting mango fruits through age control and the study of fruit development and maturation and ii) laboratory studies to determine the ripening quality of mango fruits for the export and local markets.

3.1 FIELD STUDIES

Field studies were conducted to determine harvest quality attributes through age control and the study of fruit development and maturation.

3.1.1 SOURCE OF MATERIAL AND SAMPLING

Prudent Export and Import Company Ltd mango plantation, in association with fourteen other out-grower mango farms (Olympio Farms, Okly Farms, Ofei Farms, His Excellency Farms, Domalin Farms, Isaac Farms, Margaret Crab Farms, Marcu Farms, Oliva and Co. Farms, Nsia Farms, Teiku Farms, Agyemang Farms, Daachi Farms and Obeng Farms) were chosen for the field studies. All are situated in the Somanya-Dodowa mango production zone of the Dangme West District of Greater Accra Region.

Prudent Export and Import Company Ltd mango plantation was chosen for the field studies because it is situated in the mango production belt of Ghana. The farm's location has the advantage of major and minor mango seasons (April-July and December-February respectively). Besides, it is one of the six major mango nuclear

plantations for export in Ghana, covering about 100 hectares and at the peak of production. The plantation also has the top four major export mango varieties (Haden, Kent, Palmer, and Keitt) which are currently appreciated by importers (Obeng, 2007). The orchard (plantation) was designated as the 'experimental field'. Sampling was done as follows:

Number of Days from Anthesis to Harvest: For each of the four varieties, five trees were sampled at random in each of the four replications. Date of flower bud appearance was noted and sampled trees tagged. Calculating the number of days from anthesis to harvest provides one of the best and reliable indicators of maturity of mango (Iqbal, 2001). The number of days from anthesis to harvest maturity were calculated and averaged in each case for the four varieties. The figure obtained represented the number of days the mango fruit takes to reach harvest maturity from anthesis.

External Indicators of Maturation: After tagging the sampled trees at anthesis, regular visual observation (or inspection), photographing and measurement of fruit development in the field were carried out on fortnightly basis from fruit set to identify the external indicators of maturation such as size, shape, colour and leathery fruit peel/skin (appearance of white-powdery material on the surface of the fruit at maturity).

The following measurements were taken per replication:

Fruit Weight (g): Five fruits each of the four varieties were randomly picked for fruit weight assessment. Individual fruits were weighed using a balance (Mettler electronic

balance usually to two decimal places). The average weight of the five fruits represented the fruit weight of the variety assessed at a time.

Fruit Length (cm): Individual fruit length was taken of the five sampled fruits by measuring the outer curve of the fruit with a tape measure from the distal end to the point at the proximal end where the pulp is judged to terminate (Thompson and Burden, 1995). The average length of the five fruits represented the fruit length of the variety assessed at a time.

Fruit Width (cm): Individual fruit width was taken by measuring with a tape at the widest midpoint of each of the five sampled fruits (Dadzie and Orchard, 1997). The average width of the five fruits represented the fruit width of the variety assessed at a time.

Fruit Volume (cm^3): Volume of fruit was obtained by direct volume displacement or by weighing fruit under water as follows:

a. a container of water was weighed, allowing enough space for fruit submersion;
b. fruit was submerged while container was still on the scale;
c. the weight of the container plus the water plus the submerged fruit was read;
d. the difference between the two weights (in grams) was equal to the volume of the fruit in cubic centimetres (cm^3) (Dadzie and Orchard, 1997).

Fruit Density (Specific Gravity) (g/cm^3): Fruit density (specific gravity) was obtained by dividing the fruit weight in air by the fruit volume (Kushman and Pope, 1968). Individual weights were divided by individual volumes obtained earlier. The average density of the five fruits represented the fruit density (specific gravity) of the variety assessed at a time. These were done in conjunction with other visual changes in the fruit.

Fruit Indentation (cm): Individual fruit indentation depth was taken to find the depth of depression made at the point of attachment of the panicle to the mango fruit on fortnightly basis from fruit set as a measure of fruit maturation of the five sampled fruits. The average depth of the five fruits represented the fruit indentation depth of the variety assessed at a time. Fruit indentation depth also refers to fruit shoulder growth i.e. shoulder rise above the stem end, creating a pit around the pedicel.

Exudes of Latex (ml): Five fruits per tree of each of the four varieties sampled in each replication were randomly picked on fortnightly basis after fruit set to determine the quantity of latex exuded as an index pattern to distinguish between the various stages of maturation. Each fruit was harvested at the shoulder-level of the panicle and quickly turned on to a graduated vial (ml) in which the quantity/volume of the latex was measured. The average quantity/volume of latex produced by the five fruits was recorded as the amount of latex exuded by a fruit at any stage of the fruit development that was assessed.

Starch Test: Five fruits per tree each of the four varieties sampled in each replication were randomly picked for starch determination using the iodine test on fortnightly basis from fruit set to assess maturation changes. This is a simple, rapid and inexpensive method of estimating the starch content of the fruit that could serve as a useful indicator of maturity (Dadzie, 1993; Kader *et al.*, 1994).

The following procedure was used:

a) samples were cut transversely from the midpoint of the fruit approximately 2-3 cm thick.

b) one side of the cut surface of the pulp was stained for 5 seconds in potassium iodide/iodine solution.

c) the starch present in the pulp (where possible) reacted with iodine causing a dark blue colour change. Where the starch in the pulp changed to sugar (during maturation), no iodine reaction occurred and the area stayed a pale tan colour.

d) assessment of the starch pattern of each fruit was done by comparing the stained cut surface with an accompanying photograph (Dadzie and Orchard, 1997).

Any other changes observed with fruit development (e.g. shape, colour, etc.) in the field were recorded.

Temperature/Heat Units (°C): Total heat units during fruit development was calculated as the sum of daily temperature records (°C) from flower bud emergence to harvest maturity. Total heat units during fruit development is an index of fruit maturity (Kader *et al.*, 1985).

Optimum Age for Harvesting (days): Producing/bearing mango trees were randomly sampled and tagged with colour ribbons in the field at flower bud emergence. Date of flower bud opening or anthesis was noted and tagged accordingly. All sampled trees were identified by tags and different colour ribbons according to their time of flower initiation. The number of days from flower bud opening or anthesis to harvest maturity (early, mid or late harvest) represents the optimum age of the fruit for maximum shelf life.

3.2 LABORATORY STUDIES

Laboratory studies were conducted to ascertain the harvest and post-harvest quality attributes of the four main exportable varieties for the export and local markets. To reduce variation and to obtain consistent data, it was essential that all measurements were limited to or taken on freshly harvested physiologically matured fruits.

The laboratory analyses were carried out at the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR), near Legon, Accra, because it was relatively well equipped for the required studies. It is a South African National Accreditation System (SANAS) accredited testing laboratory, comparatively near the field-study area for convenience and ease of transportation.

For every harvest, fruits (packed in plastic crates) were immediately road-transported by a nissan pick-up (distance of 30km) at ambient temperature (29–35°C) from the field to the laboratory for the assessments. Major harvest and postharvest criteria that were

considered for the assessment and evaluation of the quality characteristics of the mango fruit for export included: i) fruit harvest maturity; ii) fruit ripening quality; iii) fruit shelf life; iv) fruit firmness and v) fruit flesh/pulp fibre test.

3.2.1 SOURCE OF MATERIAL

Same source as for the field studies.

3.2.2 FRUIT HARVEST MATURITY

By laboratory tests fruit maturation was assessed as a) physical fruit characteristics and b) chemical quality attributes of fruit. Thus at the stage of physiological maturity fruits of each of the four varieties were sampled and taken from the experimental field to the laboratory for assessments as follows:

Physical Fruit Characteristics: Assessment of physical fruit characteristics included assessment of changes in fruit width, length, weight, volume, density, fruit indentation, exudes of latex and starch test. They were assessed by methods/procedures outlined earlier (see 3.1.1).

Chemical Quality Attributes of Fruits: Assessment of chemical quality attributes of fruits included assessment of changes in pulp pH and total titratable acidity, total soluble solids, ascorbic acid, moisture content and dry matter content. Assessments were done weekly per each replication as follows:

Total Titratable Acidity and pH: Five fruits per tree were picked at random from each variety for this experiment. The fruits were peeled and macerated with a commercial juice extractor, filtered and then centrifuged (10,000 X g for 10 min). The supernatant juice was then titrated with 0.1N NaOH and titratable acidity was calculated and expressed as percent citric acid by the AOAC (1990) method.

pH was determined using some of the filtrate prepared during the determination of the titratable acidity. This was done using Mettler Toledo pH meter (Model 320, New York) standardised at pH 4, 7 and 10 with BDH standard buffers (Olympio and Abu, 2003). pH values give a measure of the acidity or alkalinity of a product, while titratable acidity gives a measure of the amount of acid present.

Total Soluble Solids (TSS): Measurements of the percentage of total soluble solids were performed on the supernatant juice of the same five fruits sampled for different varieties and used for the percent citric acid determination. A drop or two of the juice was placed in the prism or sample chamber of Bausch and Lomb Abbe hand refractometer (Model Carl Zeiss 9,077 Germany). Values were read and recorded in % TSS directly from the scale superimposed over the refractive index (Olympio and Abu, 2003).

Ascorbic Acid: Total ascorbic acid, an index of quality and nutritive value in fruits and vegetables (Akinbolu *et al.,* 1991), was determined by methods described by Ball (1994). They are the Titrimetric methods for vitamin C; titration with 2, 6–dichlophenol

indophenol. The method has been adopted as Final Action for the determination of ascorbic acid in vitamin preparations and juices by the Association of Official Analytical Chemists (AOAC, 1990). By the AOAC procedure, the concentration of ascorbic acid in the sample was calculated thus:

Milligram (mg) ascorbic acid per gram (g) or per ml of sample = (X–B) X (F/E) X (V/Y).

Where:

X = average titre (ml) for sample titration.

B = average titre (ml) for sample blank titration.

F = mg ascorbic acid equivalent to 1.0 ml dye solution i.e. mg ascorbic acid in aliquot of standard solution titrated divided by the average corrected titre for the standardisation titration.

E = amount (g or ml) of sample.

V = volume (ml) of initial assay solution.

Y = volume (ml) of sample aliquot titrated.

Pulp Moisture Content and Dry Matter Content: Pulp moisture content and dry matter content were assessed on five fruits per tree randomly sampled for each of the four varieties at a time as follows:

Percentage moisture content and dry matter content of the sample was calculated as follows:

Wet weight of sample (D) = B-A

Weight of dry sample (E) = C-A

Moisture content (%) = D-E X 100
D

Moisture content (%) = $\frac{100(D-E)}{D}$

Dry matter content (%) = 100-(% moisture content) (Dadzie and Orchard, 1997).

Where:

A. an empty container (e.g. foil dish) was labelled and weighed on a Mettler balance (± 0.0001) and the weight recorded (A);
B. pulp sample was placed into the container and the weight recorded (B);
C. the sample was placed in a draft air oven at 100^{o}C overnight (24hrs);
D. the sample was then transferred from the oven into a desiccator and cooled at room temperature;
E. the sample was weighed again after drying (C).

3.2.3 FRUIT SHELF LIFE

Sound freshly harvested physiologically mature mango fruits of the four varieties were stored at both ambient and cold (transit temperatures) temperatures for shelf life assessment. Tests were carried out at different times for the different varieties depending upon their physiological maturity stages and then replicated four times in accordance with the four flowering groups for each of the four varieties.

For storage tests under transit temperature (10^{o}C) conditions, corrugated fibre board carton packaged fruits (9 cartons, one carton each of counts 4 to 12) of each of the four varieties were kept in different climatic chambers for up to 21 days in order to simulate the manner of packaging and the average period that fresh mango fruit usually stays in transit during shipment.

For storage tests under ambient temperature (29-31^{o}C), fruits were randomly picked from each treatment (variety) and put into open plastic containers on a laboratory bench. A sample for each variety consisted of a mixture of three fruits each of count 4, 5, 6, 7, 8, 9, 10, 11 and 12 to justify comparison of the two different temperature regimes. Fruits were examined and rotated daily and those found to be damaged after each day's examination were discarded. The number of days to the appearance of any sign of damage on a fruit was recorded as the shelf life and the affected fruit (s) discarded from the lot up to the last fruit. The mean number of days was determined and recorded as shelf life of the fruits in the particular treatment (variety).

Definition of Damage: To determine what damage was, fruits were either defined as slightly damaged, undesirably coloured or sound.

The slightly damaged were further grouped into three, comprising: slightly physiologically damaged (wrinkles, shrinkage, softening, etc, due to wilting and ripening etc); slightly pathologically damaged (sunken spots, rotting, mycelia growth, disease symptoms etc due to bacterial and fungal infections etc); and slightly

mechanically damaged (cuts, punctures, scuffs, abrasions etc due to open wounds and, bruises due to impacts, compressions and vibrations etc).

Undesirably coloured fruits were those with poor/abnormal colour.

Sound fruits were those free from any damages.

3.2.4 FRUIT RIPENING QUALITY

Assessment of changes that occurred during ripening involved changes in peel/skin and pulp/flesh colour, pulp pH and total titratable acidity, total soluble solids content, ascorbic acid content and moisture and dry matter contents.

Sound freshly harvested physiologically mature mango fruits of the four varieties were ripened at both ambient and cold (transit temperatures) temperatures for the ripening quality assessment.

For ripening tests under transit temperature (10^{o}C) conditions, fruits were simulated for 21days and then ripened naturally at ambient temperatures to allow assessment of changes that occur during ripening.

For ripening tests under ambient conditions (29-31^{o}C), fruits were randomly picked from each treatment (variety) and put into different open plastic containers according to variety. These were then placed on a laboratory bench to ripen.

In each of the two temperature regimes, a sample for each variety consisted of a mixture of three fruits each of count 4, 5, 6, 7, 8, 9, 10, 11 and 12 to justify comparison of the two different temperature regimes.

Changes in peel and pulp colour, pulp pH and total titratable acidity, total soluble solids content, ascorbic acid content and moisture and dry matter contents during ripening were assessed by methods and procedures described earlier (see 3.2.1).

Tests were carried out at different times for the different varieties depending upon their physiological maturity stages and then replicated four times in accordance with the four flowering groups for each of the four varieties.

3.2.5 FRUIT FIRMNESS

A computerized texture analyzer (TA-XT2) was used to determine fruit firmness or 'bioyield point' of mangoes by penetration.

Twenty sound freshly harvested physiologically matured fruits of each of the four varieties were used for the tests. Two readings were taken per fruit, averaged and recorded. Tests were carried out at different times for the different varieties depending upon their physiological maturity stages and then replicated four times in accordance with the four flowering groups for each of the four varieties.

Test Set-Up: The Heavy Duty Platform was secured to the base of the machine. For each operation or test activity, the sample was positioned centrally on the blank plate of the platform and the penetration test commenced around the mid-region of the fruit.

***Observations*:** Once a trigger force of 25g has been achieved the probe proceeds to move down on to the mango fruit and an initial rapid rise in force is observed. During this stage the sample is deforming under the applied force but there is no puncturing of the tissues. This stage ends abruptly when the probe punctures through the skin and begins to penetrate into the sample flesh, which event is represented by the sudden change in slope called the 'bioyield point'. The'bioyield point' occurs when the probe begins to penetrate into the fruit, causing irreversible damage. The third phase of the puncture test, namely, the plateau of the force after the 'bioyield point' is an indication of the underlying flesh firmness of the fruit. The product of the force at the 'bioyield point' and the equivalent of the distance on the x-axis is defined as the skin integrity. The equivalent distance is known as the skin elasticity. The area under the curve after penetration is defined as the flesh integrity.

Analysis: Once tests had been performed, values of parameters for sample analysis were automatically obtained by a MACRO, program of the software of the Texture Analyzer (Szczesniak, 1995).

3.2.6 FRUIT FLESH/PULP FIBRE TEST

Five fruits each of the four varieties at both physiologically mature stage and at eating soft ripe stage (laboratory ripening) were randomly sampled from each of the four

replications for this assessment. In each case of the raw and ripened forms, each fruit was identified into front, back and middle parts for the test. Fibre test was then conducted by removing the peel/skin, followed by pulse blending (using Brilliant multi-functional blender, model no: CY-1731B) which pulped the juice from the chaff in each case of the identified part of the fruit. The same quantities were used throughout the experiment. The mixture was then sieved using muslin cloth (Nyarko, 2008) and the chaff separated from the juice. The product of this is chaff and juice. The sum of the chaff content (g) at the front, back and middle of each fruit was then calculated. The chaff content represents the fibre content. Average of the total of each group of five fruits was then recorded as the fibre content (%) per fruit for the variety tested as either raw or ripe.

3.2.7 LABORATORY TEMPERATURE AND RELATIVE HUMIDITY MONITORING

Laboratory temperature and relative humidity monitoring was done throughout the laboratory experimental period by using a climatic chamber (model no. Pinder D-7853). This chamber served a dual purpose of recording both temperature (^{o}C) and relative humidity (rh) of stored produce at a time.

3.3 DATA ANALYSES

A randomized complete block design was used. All data were analysed using the Analysis of Variance (ANOVA) technique (Snedecor and Cochran, 1980) and the

GENSTAT statistical program (2008 edition). Least Significant Difference (LSD) at 5% probability was used to determine treatment differences among varieties.

Mango fruit harvest and postharvest quality attributes were considered the most important parameters that quality criteria treatments might affect, data on these were therefore first investigated to determine if combined analyses could be conducted. Separate analyses were carried out with the data for each of the trials. The errors for these ANOVAS were tested for homogeneity of variance (Snedecor and Cochran, 1980) and found to be statistically (p=0.05) not different, indicating that the results could be anlysed together across experiments.

4.0 RESULTS

4.1 FIELD AND LABORATORY STUDIES

The results of the field and laboratory studies are presented in Tables 1–10, Figures 1–13 and Plates 1–6 under the different parameters investigated. The results cover harvest and post-harvest quality attributes of the four main export mango varieties (Haden, Kent, Palmer and Keitt). The results were obtained through age control and the study of fruit development and maturation, in order to establish quality criteria for harvesting and determine the ripening quality of mango fruits for the export and local markets.

4.1.1 DETERMINATION OF APPROPRIATE HARVEST MATURITY AT FIELD LEVEL

4.1.1.1 Age Control

The mean physiological maturity ages of fruits at early harvest intended for storage or transport to distant markets such as export markets by sea for Haden, Kent, Palmer and Keitt varietiess were 112days, 126days, 133days and 140days after fruit set, respectively. The ages for mid harvest were 119days, 133days, 140days and 147days after fruit set for Haden, Kent, Palmer and Keitt fruits, respectively. For late harvest, the ages were 126days, 140days, 147days and 154days after fruit set for Haden, Kent, Palmer and Keitt fruits, respectively.

Table 1 shows ranges of harvest periods for Haden, Kent, Palmer and Keitt mango varieties at harvest/physiological maturity.

Table 1: Harvest periods for Haden, Kent, Palmer and Keitt mango varieties at harvest/physiological maturity

Variety	Early harvest (Days from fruit set)	Mid-harvest (Days from fruit set)	Late harvest (Days from fruit set)
Haden	109-115	116-122	123-129
Kent	123-129	130-136	137-143
Palmer	130-136	137-143	144-150
Keitt	137-143	144-150	151-157

4.1.1.2 Visual Means

Visual maturity harvest indices were determined on mango fruit peel/skin colour particularly for the Haden and Palmer varieties; mango fruit pulp/flesh colour; mango fruit shape/fullness of mango fruit cheeks/outgrown shoulders/fruit indentation; mango fruit starch content; leathery fruit peel/skin; presence of ridges/grooves at the stylar scar/end of the fruit particularly for Palmer; and change in colour of fruit pedicel (Plates 1-6). Individual descriptions are shown under each plate.

Haden (Physiologically mature, 112 days from fruit set)

Haden: Ripe, 121.5 days from fruit set (Under ambient condition)

Haden: Ripe, 115.5 days from fruit set (After simulated transit condition)

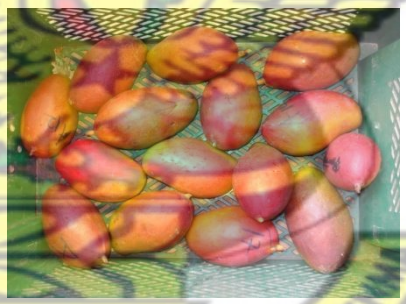
Palmer (91 days from fruit set)

Palmer (105 days from fruit set)

Palmer (119 days from fruit set)

Palmer (133 days from fruit set)

Palmer (Physiologically mature, 133 days from fruit set)



Palmer: Ripe, 143.01 days from fruit set (Under ambient condition)

Palmer: Ripe, 137 days from fruit set (After simulated transit condition)

Plate 1: Changes in mango fruit peel/skin colour at physiological and ripe stages for Haden and Palmer varieties

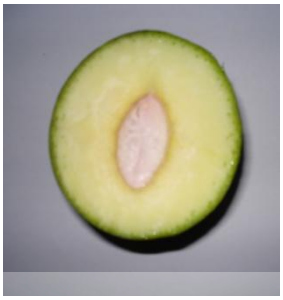
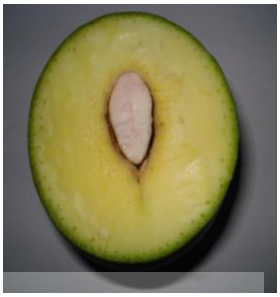
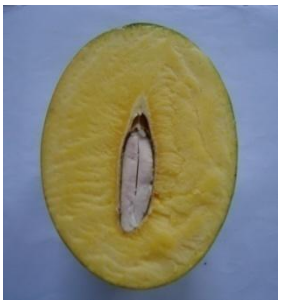
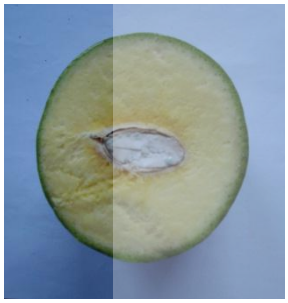
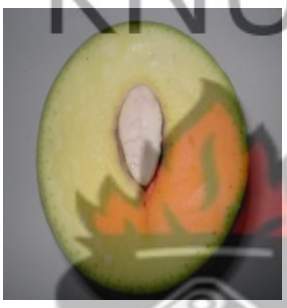
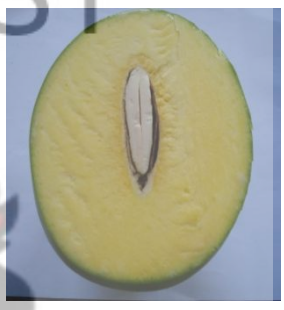
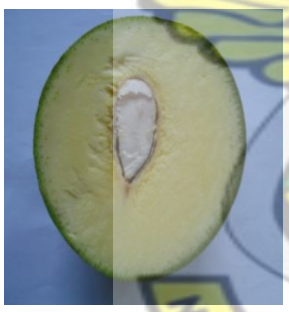
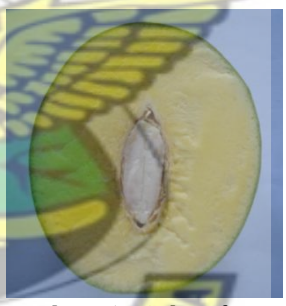
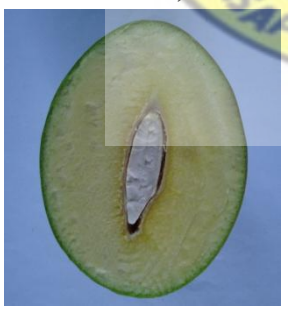
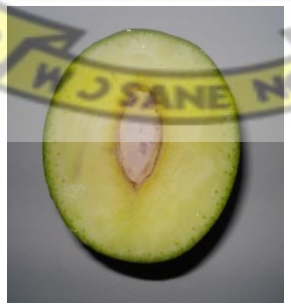
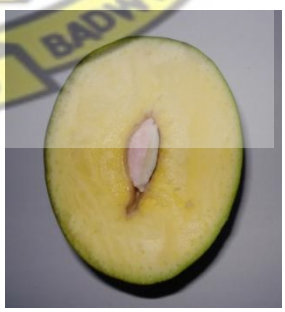
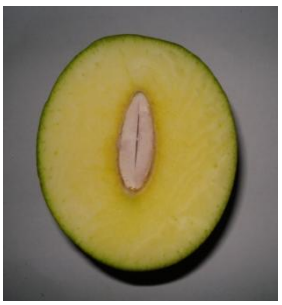
Stage 1	Stage 2	Stage 3	Stage 4
 Haden (70 days from fruit set)	 Haden (84 days from fruit set)	 Haden (98 days from fruit set)	 Haden (112 days from fruit set)
 Kent (84 days from fruit set)	 Kent (98 days from fruit set)	 Kent (112 days from fruit set)	 Kent (126 days from fruit set)
 Palmer (91 days from fruit set)	 Palmer (105 days from fruit set)	 Palmer (119 days from fruit set)	 Palmer (133 days from fruit set)
 Keitt (98 days from fruit set)	 Keitt (112 days from fruit set)	 Keitt (126 days from fruit set)	 Keitt (140 days from fruit set)

Plate 2: Mango fruit pulp/flesh colour change by stage of development for Haden, Kent, Palmer and Keitt varieties

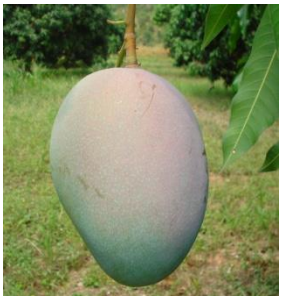
Stage 1	Stage 2	Stage 3	Stage 4
			
Haden (70 days from fruit set)	Haden (84 days from fruit set)	Haden (98 days from fruit set)	Haden (112 days from fruit set)
			
Kent (84 days from fruit set)	Kent (98 days from fruit set)	Kent (112 days from fruit set)	Kent (126 days from fruit set)
			
Palmer (91 days from fruit set)	Palmer (105 days from fruit set)	Palmer (119 days from fruit set)	Palmer (133 days from fruit set)
			
Keitt (98 days from fruit set)	Keitt (112 days from fruit set)	Keitt (126 days from fruit set)	Keitt (140 days from fruit set)

Plate 3: Mango fruit shape/indentation and pedicel colour changes by stage of development for Haden, Kent, Palmer and Keitt varieties

Stage 1	Stage 2	Stage 3	Stage 4
 Haden (70 days from fruit set)	 Haden (84 days from fruit set)	 Haden (98 days from fruit set)	 Haden (112 days from fruit set)
 Kent (84 days from fruit set)	 Kent (98 days from fruit set)	 Kent (112 days from fruit set)	 Kent (126 days from fruit set)
 Palmer (91 days from fruit set)	 Palmer (105 days from fruit set)	 Palmer (119 days from fruit set)	 Palmer (133 days from fruit set)
 Keitt (98 days from fruit set)	 Keitt (112 days from fruit set)	 Keitt (126 days from fruit set)	 Keitt (140 days from fruit set)

Plate 4: Changes in mango fruit starch content by stage of development for Haden, Kent, Palmer and Keitt varieties. Notice the degree of dark-blue colouration as maturity advances.

Common for all varieties

Plate 5: Leathery fruit peel/skin (appearance of white-powdery material on the surface of the mango fruit at maturity) occurs in all varieties

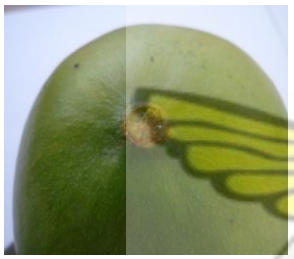
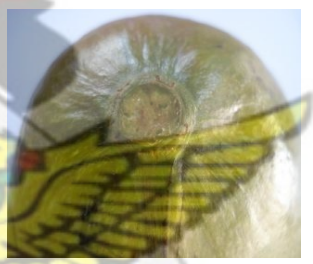
Stage 1	Stage 2	Stage 3	Stage 4
			
Palmer (91 days from fruit set)	Palmer (105 days from fruit set)	Palmer (119 days from fruit set)	Palmer (133 days from fruit set)

Plate 6: Changes in ridge/groove formation by stage of development around the stylar scar/end of Palmer mango fruit

Plate 2 indicates that Haden, Kent, Palmer and Keitt mango fruits have a distinct pale-yellow colouration on the flesh around the stone/seed at their physiological maturity stages i.e. at 112days, 126days, 133days and 140days after fruit set, respectively.

Plate 3 demonstrates mango fruit shape/fullness of cheeks/outgrown shoulders and changes in the colour of the pedicel as Haden, Kent, Palmer and Keitt mango fruits

reach physiological maturity. At physiological maturity the cheeks of the fruits were fully developed and the pedicels developed a purplish–red blush colour (Plate 3).

Plate 4 shows an assessment of development and maturation changes in Haden, Kent, Palmer and Keitt fruits using the starch iodine test. High starch content showed a higher degree of dark blue colouration. The concentration of starch continued to increase during subsequent growth and maturation of all the varieties (Plate 4). Starch concentration increased gradually up to physiological maturity (Plate 4). Where the starch in the pulp changed to sugar (during ripening), no iodine reaction occurred and the area stained a pale tan colour. The starch index pattern was used to distinguish between the various stages of maturity.

4.1.1.3 Physical Means

Physical maturity harvest indices were determined on fruit weight (g), fruit length (cm), fruit width (cm), fruit volume (cm^3), fruit density (g/cm^3), fruit indentation (outgrown shoulders) (cm) and on fresh fruit latex content (ml) (Figures 1–7).

The average weight, length, width, volume, density and indentation of each fruit of all the varieties continued to increase until physiological maturity when all readings became constant (Figures1–6).

The fruit weight, length, width and volume in the four varieties varied significantly at physiological maturity. Keitt fruit had the highest mean weight of 1104kg, while Haden

had the lowest mean weight of 640g as shown in Figure 1. Mean weight of Keitt fruit was significantly higher than the fruit weight of the other varieties. There was no significant difference in weight between fruits of Palmer and Kent but average weight of fruits of both varieties was significantly higher than that of Haden (Figure 1).

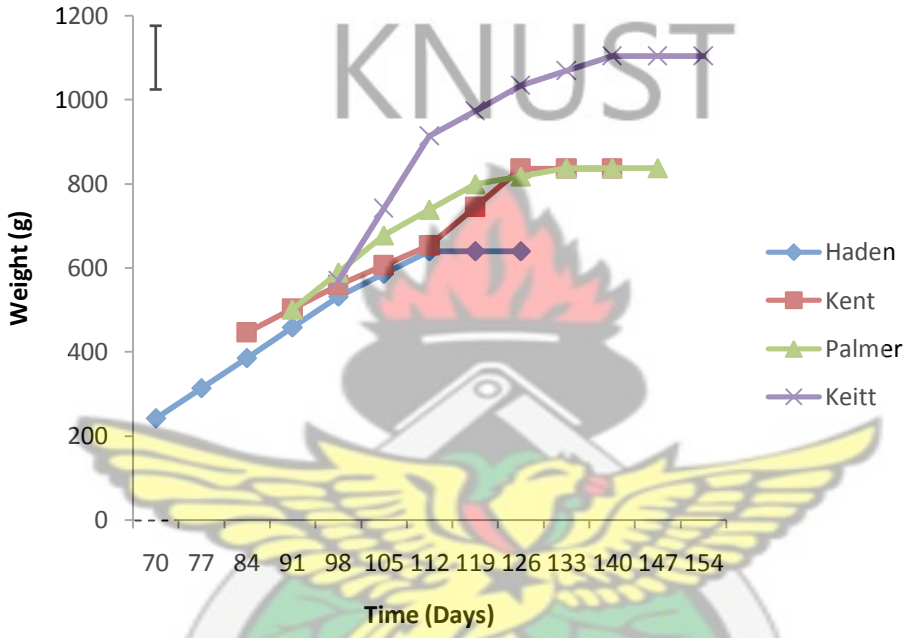


Figure 1: Changes in average weight (g) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

At physiological maturity, fruit of Palmer was longer (21.22cm) than fruits of the other varieties. Kent fruit was the shortest (16.19cm), not significantly different from fruit of Haden (16.31cm) but significantly shorter than fruit of Keitt. Fruit of Keitt was found to be moderately long (19cm) (Figure 2).

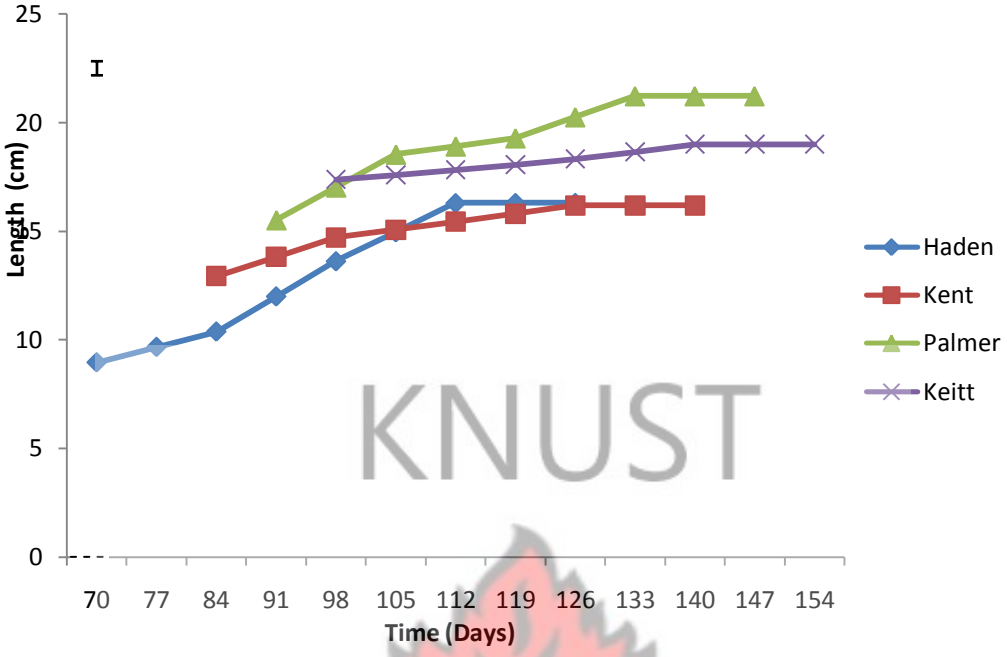


Figure 2: Changes in average length (cm) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

The fruit width of Keitt was the widest (35.91cm) and was significantly different from the others. Palmer fruit had the smallest width (30.86cm) which was significantly different from that of Kent (33.47cm) but not Haden (30.97cm) as shown in Figure 3.

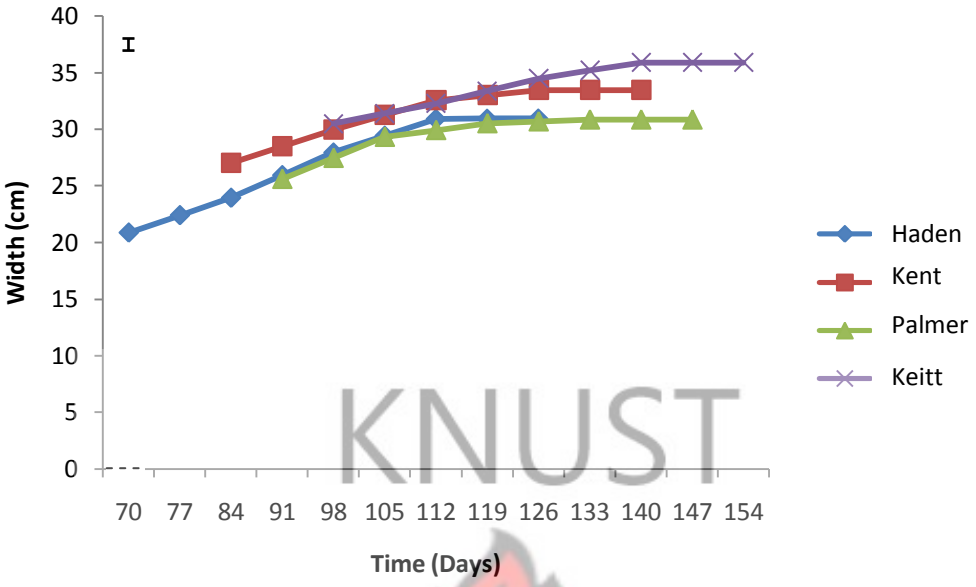


Figure 3: Changes in average width (cm) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Fruit volume was greater for Keitt (959cm^3) than the other varieties at physiological maturity. The lowest was recorded for Haden (598cm^3). Average volume of fruit for Kent (807cm^3) and Palmer (772cm^3) were not significantly different but both were significantly different from that of Haden (Figure 4).

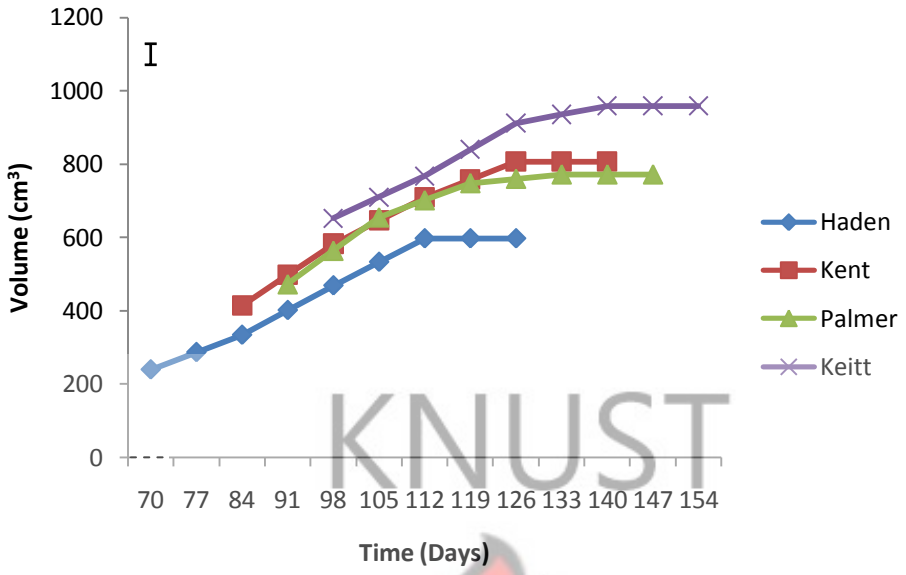


Figure 4: Changes in average volume (cm^3) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

In all the four varieties, substantive density index quantities greater than 1.0g/cm^3 occurred at physiological maturity. Fruits of all varieties also maintained constant density readings from this maturity stage (Figure 5).

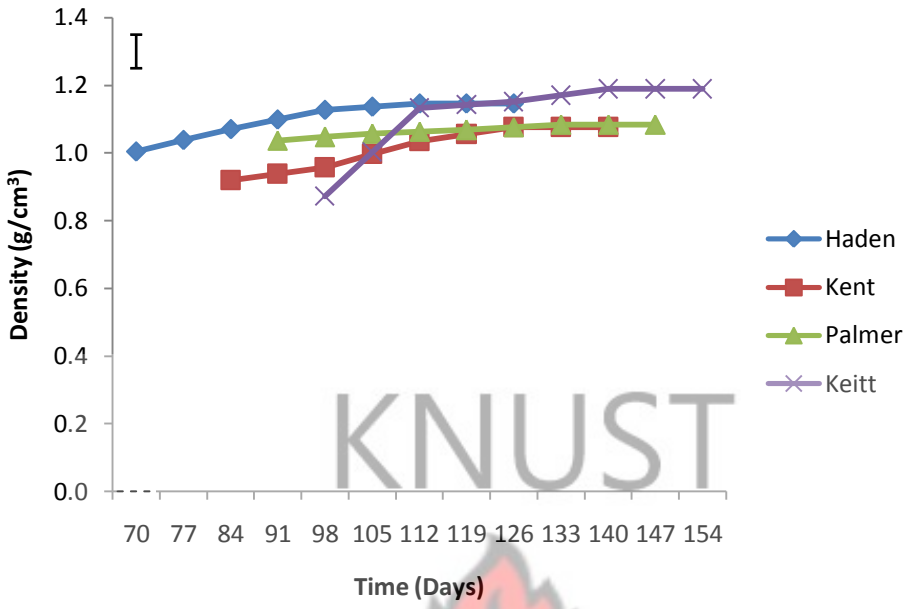


Figure 5: Changes in average density (g/cm^3) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Fruit density was highest for Keitt (1.19g/cm^3) and lowest for Kent (1.08g/cm^3) when compared at physiological maturity stage (Figure 5). The fruit density of Keitt was not significantly different from that of Haden, likewise the fruit densities of Kent and Palmer as indicated in Figure 5. Fruit density of Keitt increased drastically from 98 days after fruit set to 112 days after fruit set after which there was a gradual increment until physiological maturity (Figure 5).

Latex flow continued even after physiological maturity but at a decreasing rate (Figure 6). Initially and particularly for the first sampling, the quantity of latex emitted was significantly higher for Haden and Palmer fruits than for Kent and Keitt fruits. However, the rate of decrease of latex emission through the developmental stages to

harvest maturity was found to be significantly faster for Haden than for Palmer, Kent and Keitt fruits. At physiological maturity, Palmer fruits emitted significantly higher quantities of latex (0.43ml) than the other varieties. Haden fruits emitted the least (0.08ml). The quantity of latex emitted by Kent was significantly different from that of Haden but Keitt (Figure 6).

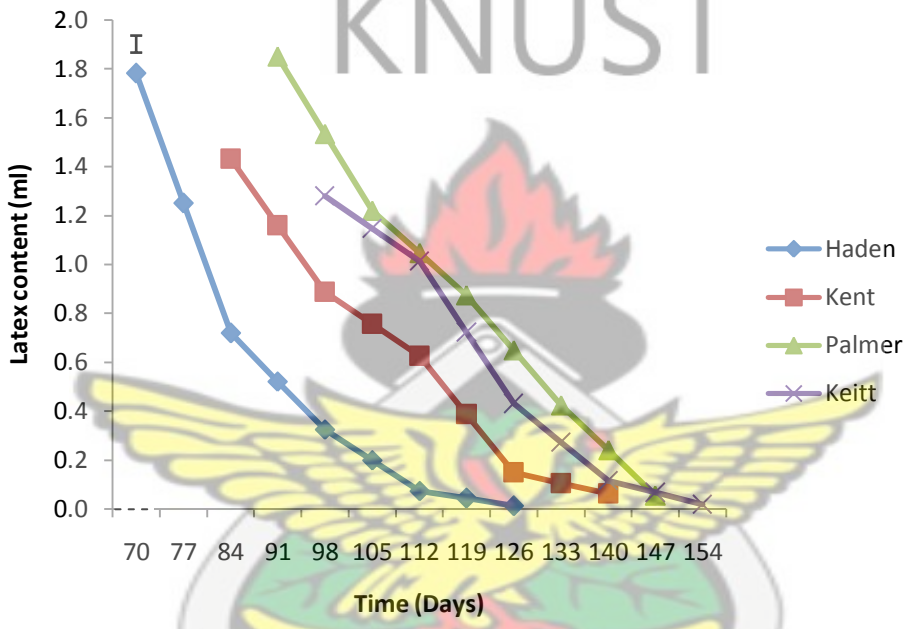


Figure 6: Changes in average latex content (ml) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Figure 7 indicates that rate of change in fruit indentation/outgrown shoulders during the developmental stages to physiological maturity was quite steady for Keitt and Kent fruits; very slow for Haden fruit and none at all in Palmer fruit (Figure 7). The fruit indentation changes along the developmental stages to physiological maturity are

manifested by ascending intensity of ridges/grooves around the stylar scar/end of the Palmer fruit as shown in Plate 6.

Keitt and Kent fruits had more indentation/outgrown shoulders (0.5cm and 0.49cm respectively) at physiological maturity. These were statistically similar, but both were significantly different from that of Haden (0.25cm). Fruits of Haden were, however, moderately indented/shouldered while Palmer fruit had no indentation/ outgrown shoulders at all (Plate 6 and Figure 7).

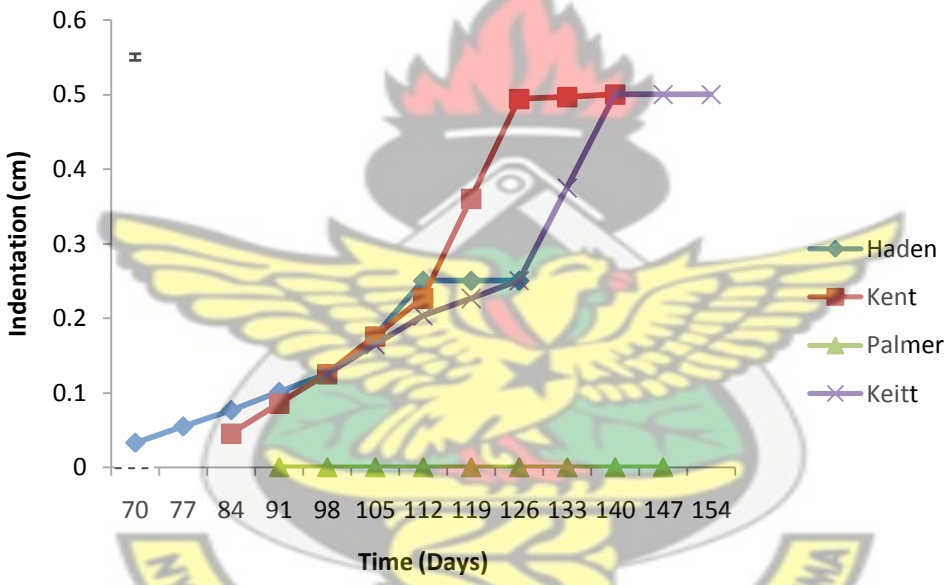


Figure 7: Changes in average indentation depth (cm) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

4.1.1.4 Seasonal Accumulated Day-Degrees (Heat Units/°C) and Daily Rainfall Records (mm)

The seasonal accumulated day-degrees (heat units/°C) and daily rainfall (mm) figures needed for optimum growth of Haden, Kent, Palmer and Keitt fruits from budding through fruit set to harvest maturity during the experimental period are shown in Table 2. For the major and minor seasons the accumulated day-degrees (°C) for Haden, Kent, Palmer and Keitt fruits were 3850.88°C, 4203.33°C, 4366.78°C and 4554.66°C; and 3305.83°C, 4007.20°C, 4207.95°C and 4409.02°C, respectively. The different accumulated heat units during the growth of Kent, Palmer and Keitt fruits were statistically similar but that of Palmer and Keitt fruits were significantly different from that of Haden fruits. Heat units accumulated for the growth of Kent fruits was not different from that of Haden fruits. This trend was the same for both seasons (Table 2).

Table 2: Accumulated daily heat units (day-degrees/°C) and daily rainfall (mm) for optimum growth of Haden, Kent, Palmer and Keitt mango fruits under Ghanaian conditions

Variety	Value label			
	Heat Units (day-degree/°C)		Rainfall (mm)	
	Major Season(mid-April to mid-August)	Minor Season(mid-Dec. to mid-March)	Major Season(mid-April to mid-August)	Minor Season(mid-Dec. to mid-March)
Haden	3850.88	3305.83	480.36	469.80
Kent	4203.33	4007.20	564.68	529.03
Palmer	4366.78	4207.95	587.24	548.31
Keitt	4554.66	4409.02	608.55	567.03
LSD (0.05)	**475.34**	**763.70**	**89.36**	**67.02**

Each value represents the mean of four independent determinations at 95% confidence level/interval of each variable.

Table 2 shows 480.36mm, 564.68mm, 587.24mm and 608.55mm; and 469.80mm, 529.03mm, 548.31mm and 567.03mm, respectively for the major and minor seasons as accumulated daily rainfall figures needed for optimum growth of Haden, Kent, Palmer and Keitt fruits respectively from budding through fruit set to physiological maturity. The trend of rainfall and the accumulated heat units was similar for all the varieties, i.e., the longer the duration of fruit development the higher the rainfall amount and accumulated heat units and vice versa (Table 2).

4.1.2 DETERMINATION OF APPROPRIATE HARVEST MATURITY IN THE LABORATORY

Laboratory studies on the identification of harvest maturity indices using changes of chemical properties during maturation included analysis of total soluble solids (TSS), titratable acidity (TA), ascorbic acid (vitamin C), pH, moisture and dry matter content of the fruit. Shelf life/storage life, ripening quality, firmness and fibre tests were also done in the laboratory.

4.1.2.1 Identification of Harvest Indices using Changes of Chemical Properties during Maturation

Figures 8-13 and Tables 3-9 show a relationship between time of harvest and chemical constituents, storage life and quality of Haden, Kent, Palmer and Keitt mango fruits at the experimental site.

Figure 8 shows changes in TSS (^{o}Brix) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. The changes in TSS (^{o}Brix) during development and maturation of Kent, Palmer and Keitt fruits were similar; but these were different from the maturation pattern of Haden fruit, that reached 8.94^{o}Brix and 12.65^{o}Brix at 112 days after fruit set (early harvest) and at 126 days after fruit set (late harvest), respectively (Figure 8). Content of TSS in the four varieties were significantly different. At physiological maturity Haden had significantly higher TSS content than Kent, Palmer and Keitt; there were no significant differences in TSS content among Kent, Palmer and Keitt; and the lowest TSS content (6.56^{o}Brix) was recorded for Keitt. The change in TSS generally showed an ascending trend during fruit development and maturation in all the trials (Figure 8).

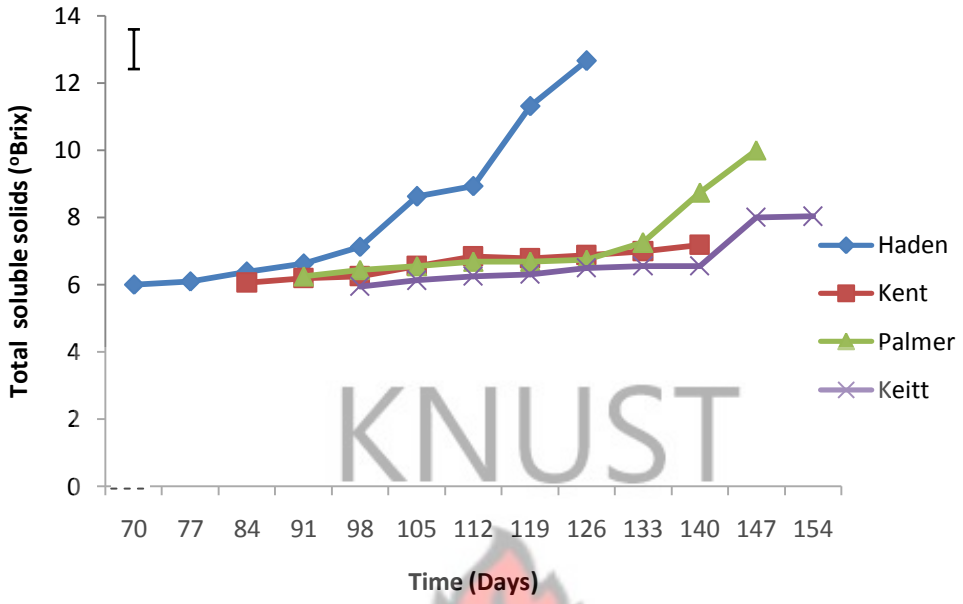


Figure 8: Changes in total soluble solids (°Brix) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Fruits of Haden, Kent, Palmer and Keitt all displayed a typical decrease in titratable acidity (TA) to 1.07, 0.81, 0.94 and 1.04% citric acid, respectively, at physiological maturity (Figure 9). Titratable acidity (% citric acid) levels in the fruit of the four varieties were significantly different. Fruits of Haden had a higher mean acidity (1.07% citric acid) than fruits of all the other varieties while Kent had the lowest mean acidity (0.81% citric acid) (Figure 9). There were no significant differences in TA content among fruits of Keitt, Palmer and Haden. Significant differences in TA content occurred between Keitt and Kent and between Haden and Kent (Figure 9).

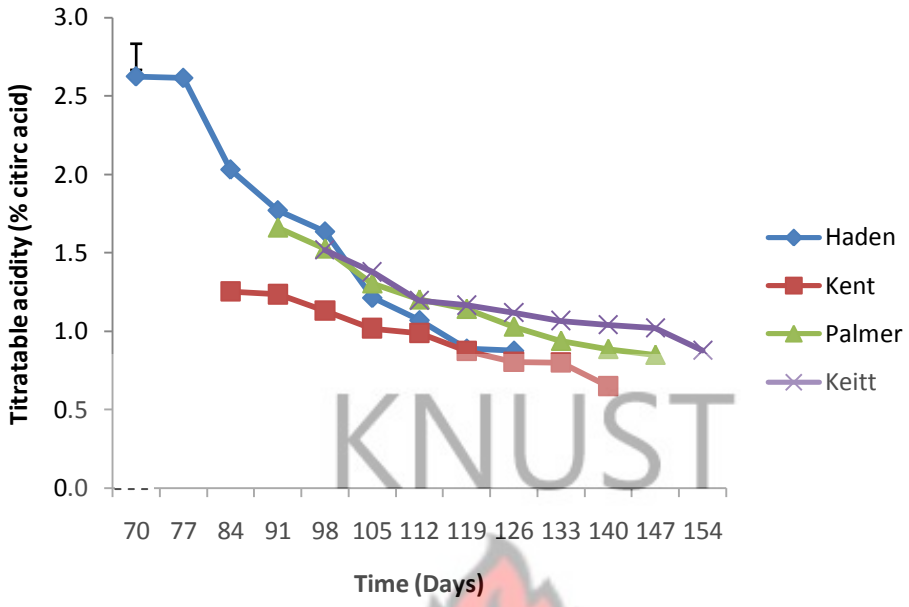


Figure 9: Changes in average titratable acidity (% citric acid) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Ascorbic acid concentration (mg/100g) in the four varieties were significantly different. Fruits of Palmer recorded the highest mean ascorbic acid concentration (35.5mg/100g) which was significantly different from all the other varieties. Fruits of Kent had the lowest mean ascorbic acid concentration (8.5mg/100g) which was statistically different from those of the other varieties. There was no significant difference in ascorbic acid content between Haden and Keitt (Figure 10). The Palmer fruits exhibited a sharp rise in ascorbic acid accumulation just before physiological maturity and thereafter increased gradually up to late harvest. The same phenomenon occurred for Haden. Generally, changes were in ascending order (Figure 10).

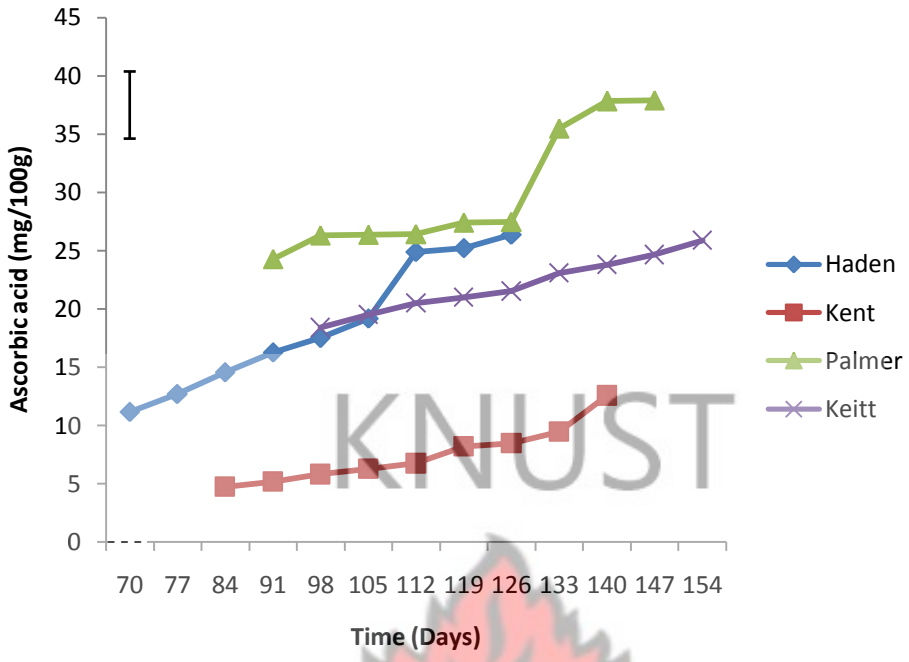


Figure 10: Changes in average ascorbic acid (mg/100g) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

In Figure 11, the typical behaviour of pH during maturation was observed for all the varieties. pH increased to 3.25, 3.50, 3.33 and 3.35 for Haden, Kent, Palmer and Keitt, respectively, at early maturity and to 3.42, 3.56, 3.44, and 3.42, respectively, at late maturity. Fruits of Kent had the highest pH value which was also different from the pH content of Haden, Palmer and Keitt. There was no significant difference in pH content among fruits of Haden, Palmer and Keitt.

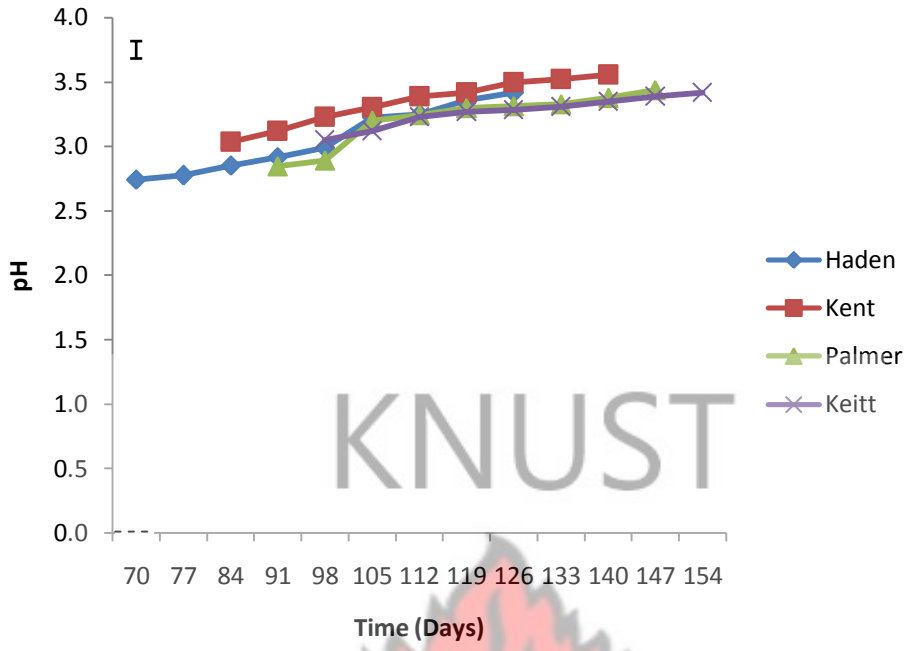


Figure 11: Changes in mean pH during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

Dry matter contents (%) in the four varieties were significantly different at $p<0.05$. In all the four varieties, dry matter and moisture contents increased and decreased respectively during fruit growth (Figures 12 and 13). Dry matter concentration in the fruits of Kent was the highest (17.77%) and also significantly different from all the others at physiological maturity. Fruits of Keitt recorded the lowest (15.74%) dry matter concentration but was neither different from that of Haden nor Palmer. Fruits of Haden and Palmer were not different in dry matter concentration (Figure 13).

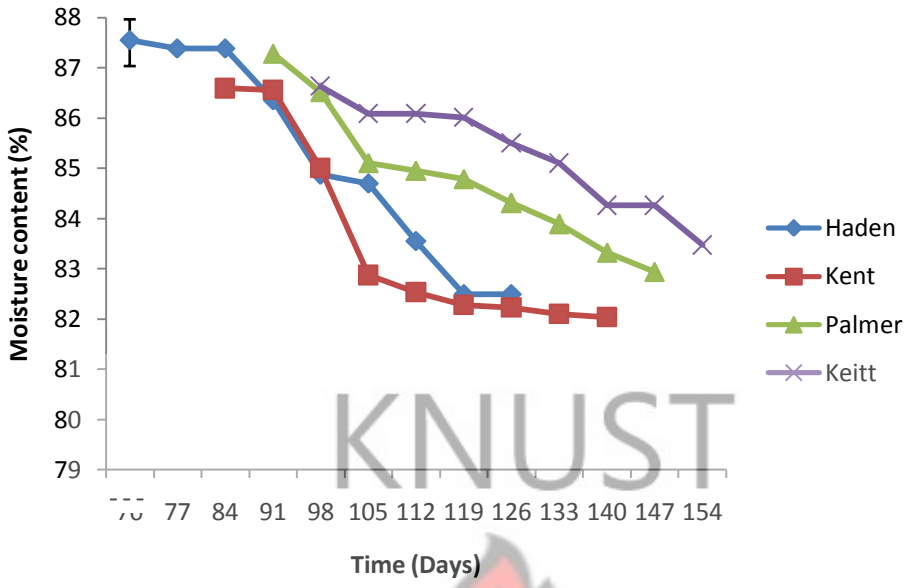


Figure 12: Changes in average moisture content (%) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

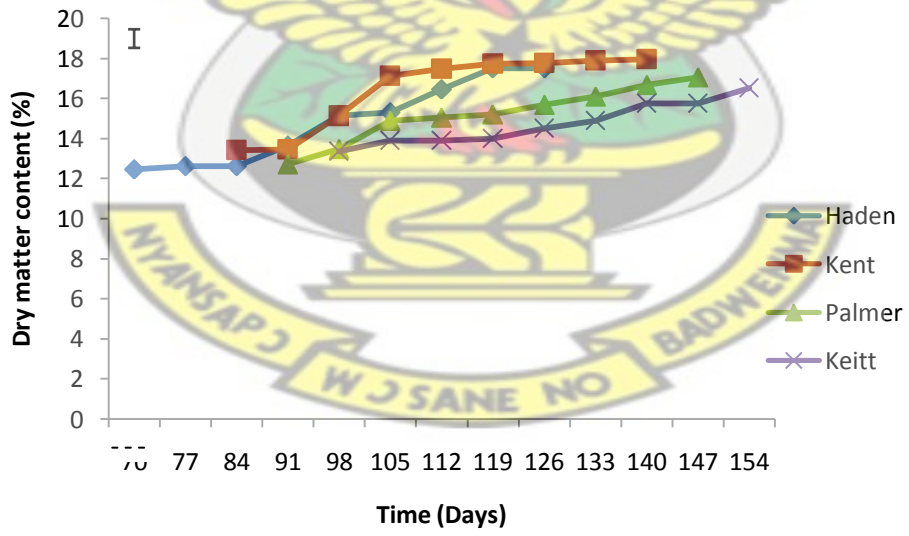


Figure 13: Changes in average dry matter content (%) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits. Bar shows standard error of differences of means. Each value represents the mean of four independent determinations at 95% confidence interval of the variable.

4.1.2.2 Chemical Constituents of Haden, Kent, Palmer and Keitt Fruits

Tables 3 to 5 show changes of chemical components in Haden, Kent, Palmer and Keitt fruits when physiologically mature (pre-climacteric) or ripe (eating soft stage). At physiological maturity Haden had the highest concentration of TA and was only significantly different from Kent which recorded the lowest. Titratable acidity concentration in Kent was similar to that of Palmer. In the case of ascorbic acid, Palmer had the highest value which was significantly different from the others. Kent recorded the lowest ascorbic acid value which was different from the others. Haden and Keitt had similar ascorbic acid concentration. Haden had the highest TSS content which was different from the others. Keitt recorded the lowest TSS content and was similar to that of Kent. In the two tables, ie, Tables 3 and 5, Kent recorded the highest pH content which was significantly different from the others. Haden recorded the least but was similar to Palmer and Keitt. Keitt had the highest moisture content and was significantly different from only Kent which recorded the least. Moisture contents were similar among Keitt, Palmer and Haden fruits. Kent accumulated the highest dry matter content and was different from the others. Keitt accumulated the least amount of dry matter but was similar to Haden and Palmer.

Table 3: Chemical constituents of Haden, Kent, Palmer and Keitt mango fruits when physiologically mature - for harvest quality

Variety	Parameter									
	TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (°Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp	Consistency of pulp	TSS/Acidity ratio
Haden	1.071	24.90	8.94	3.250	83.55	16.45	0.017	turning yellow	uniform consistent texture	8.3473
Kent	0.807	8.50	6.88	3.499	82.28	17.72	0.016	turning yellow	uniform consistent texture	8.5254
Palmer	0.940	35.50	7.25	3.328	83.89	16.11	0.017	turning yellow	uniform consistent texture	7.7128
Keitt	1.044	23.80	6.56	3.349	84.26	15.74	0.026	turning yellow	uniform consistent texture	6.2835
LSD (0.05)	**0.167**	**5.76**	**1.18**	**0.135**	**0.93**	**0.93**	**0.007**			**1.6188**

Means of four estimations expressed on fresh weight basis.

Table 4: Chemical constituents of Haden, Kent, Palmer and Keitt mango fruits when ripe (eating soft stage) - for eating/processing quality

Variety	Parameter									
	TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (^{0}Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp/flesh	Consistency of pulp	TSS/Acidity ratio
Haden	0.14	8.05	18.50	5.11	80.85	19.15	0.065	deep yellow	uniform consistent texture	132.140
Kent	0.12	3.32	17.50	4.08	80.94	19.06	0.062	deep yellow to orange yellow	uniform consistent texture	145.830
Palmer	0.31	5.52	19.10	5.00	80.25	19.75	0.066	orange-yellow	uniform consistent texture	61.610
Keitt	0.10	3.66	17.00	5.80	81.95	18.05	0.094	lemon yellow	uniform consistent texture	170.000
LSD (0.05)	**0.15**	**3.45**	**1.51**	**1.12**	**1.12**	**1.12**	**0.024**			**74.087**

Means of four estimations expressed on fresh weight basis.

Table 5: Comparative analysis of chemical constituents in Haden, Kent, Palmer and Keitt mango fruits – at harvest (physiologically mature) and ripe (eating soft stage)

Variety	Time	Parameter									
		TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (°Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp/flesh	Consistency of pulp/flesh	TSS/Acidity ratio
Haden	Initial Analysis at harvest (Physiologically Mature)	1.07	24.74	8.9	3.25	83.55	16.45	0.017	turning yellow	uniform consistent texture	8.32
	Final Analysis when ripe (eating soft stage)	0.14	8.05	18.5	5.11	80.85	19.15	0.065	deep yellow	uniform consistent texture	132.14
Kent		TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (°Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp	Consistency of pulp	TSS/Acidity ratio
	Initial Analysis at harvest (Physiologically Mature)	0.81	8.51	6.9	3.42	82.28	17.72	0.016	turning yellow	uniform consistent texture	8.52
	Final Analysis when ripe (eating soft stage)	0.12	3.32	17.5	4.08	80.94	19.06	0.062	deep yellow to orange yellow	uniform consistent texture	145.83
Palmer		TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (°Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp	Consistency of pulp	TSS/Acidity ratio
	Initial Analysis at harvest (Physiologically Mature)	0.93	35.47	7.3	3.33	83.89	16.11	0.017	turning yellow	uniform consistent texture	7.85
	Final Analysis when ripe (eating soft stage)	0.31	5.52	19.1	5.00	80.25	19.75	0.066	orange-yellow	uniform consistent texture	61.61
Keitt		TA (% citric acid)	Ascorbic Acid (mg/100g)	TSS (°Brix)	pH	Moisture (%)	DM (%)	Fibre Content (%)	Colour of Pulp	Consistency of pulp	TSS/Acidity ratio
	Initial Analysis at harvest (Physiologically Mature)	1.04	23.80	6.6	3.35	84.26	15.74	0.026	turning yellow	uniform consistent texture	6.35
	Final Analysis when ripe (eating soft stage)	0.10	3.66	17.0	5.80	81.95	18.05	0.094	lemon yellow	uniform consistent texture	170.00

Means of four estimations expressed on fresh weight basis.

At the ripe stage (eating soft stage), fruits of Palmer had the highest concentration of TA which was different from the others (Tables 4 and 5). Keitt recorded the lowest but was only significantly different from Palmer. Haden, Kent and Keitt fruits did not differ significantly in their TA concentrations. In the case of ascorbic acid, Haden showed the highest concentration and Kent the lowest. Ascorbic acid concentration was not significantly different among Kent, Palmer and Keitt fruits but ascorbic acid concentration in Kent, Palmer and Keitt were different from that of Haden (Tables 4 and 5).

Palmer had the highest TSS content on ripening and the least was recorded for Keitt. Total soluble solids concentration in Palmer was not significantly different from that of Haden but different from that of Keitt and Kent (Tables 4 and 5). In the two tables Keitt had the highest pH content at the ripe stage and was only significantly different from those of Kent which recorded the least (Tables 4 and 5). Keitt also had the highest moisture content which was significantly different from only that of Palmer fruit which contained the least on ripening. Moisture contents were similar among Keitt, Kent and Haden fruits when ripe (Tables 4 and 5). At the ripe stage Palmer recorded the highest dry matter content which was similar to that of Haden and Kent. Dry matter content for Palmer was, however, significantly different from that of Keitt which recorded the least (Tables 4 and 5).

Keitt fruit had the highest fibre content in both physiologically mature and ripe stages but with a preponderance of the latter (Tables 3-5). Again, in each case of the

physiologically mature and ripe stages, the fibre content of the Keitt fruit was significantly different from that of Haden, Kent and Palmer fruits which were similar (Tables 3-5).

Table 6: Shelf life (days) of Haden, Kent, Palmer and Keitt Mango fruits

Variety	Under Ambient Conditions			Under Transit Conditions			
	Days to ripen (eating soft stage), 29-31°C, 90 – 95% rh	Weight loss (%)	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)	Days stored under transit conditions (10°C, 85-90% rh)	Days to ripen (eating soft stage), 29-31°C, 90-95% rh	Weight loss (%)	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
Haden	9.50	6.50	3.15	21	3.50	3.31	2.91
Kent	10.52	4.96	4.09	21	4.50	2.50	3.85
Palmer	10.01	6.37	3.16	21	4.00	3.12	2.87
Keitt	11.01	4.09	4.08	21	5.00	2.34	3.92
LSD (0.05)	**1.04**	**1.85**	**0.85**		**1.03**	**0.75**	**0.92**

Means of four estimations expressed on fresh weight basis.

Table 7: Comparative analysis of shelf life (days) of Haden, Kent, Palmer and Keitt mango fruits

Variety	Parameter and Value label			
Haden	Ambient conditions	Days to ripen (eating soft stage), 29-31°C, 90 – 95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		9.50	6.50	3.15
	Transit conditions	Days to ripen (eating soft stage), 29-31°C, 90-95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh).
		3.50	3.31	2.91
Kent	Ambient conditions	Days to ripen (eating soft stage), 29-31°C, 90 – 95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		10.52	4.96	4.01
	Transit conditions	Days to ripen (eating soft stage), 29-31°C, 90-95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		4.52	2.50	3.85
Palmer	Ambient conditions	Days to ripen (eating soft stage), 29-31°C, 90 – 95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		10.01	6.37	3.16
	Transit conditions	Days to ripen (eating soft stage), 29-31°C, 90-95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		4.00	3.12	2.87
Keitt	Ambient conditions	Days to ripen (eating soft stage), 29-31°C, 90 – 95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		11.01	4.09	4.08
	Transit conditions	Days to ripen (eating soft stage), 29-31°C, 90-95% rh	% weight loss	Days to spoilage at sales/fresh market conditions (20-22°C, 85-90% rh)
		5.00	2.34	3.92

Means of four estimations expressed on fresh weight basis.

Total soluble solids/acidity ratio was highest for Keitt and lowest for Palmer at the ripe stage, but was highest for Kent and lowest for Keitt at the physiological maturity stage (Tables 3-5).

4.1.2.3 Fruit Deterioration

Fruits of Haden, Kent, Palmer and Keitt ripened (eaten soft stage) in 9.5days, 10.5days, 10.0days and 11.0days, respectively, under ambient conditions (29 to 31^{o}C and 90-95% rh) after removal of field heat or after controlling the fruit temperature at 20-25^{o}C before the initiation of the ripening process. Haden fruits ripened earlier (9.5days) and Keitt fruits much later (11.0days). Days to ripening was not significantly different among Haden, Kent and Palmer fruits but was statistically different between Keitt and Haden (Tables 6 and 7).

After exposure to transit conditions for 21days, fruits of Haden, Kent, Palmer, and Keitt ripened (eating soft stage) in 3.5days, 4.5days, 4.0days and 5.0days, respectively. Average weight loss was highest (6.50%) for Haden and lowest (4.09%) for Keitt during ripening under ambient conditions. The same occurred during ripening after exposure to transit conditions. Fruits also took more days after ripening under ambient conditions to develop any objectionable or unacceptable characteristics when compared to fruits under simulated transit conditions before ripening. Under ambient as well as transit conditions spoilage was observed much earlier in Haden (3.15days for ambient and 2.91days for transit) and Palmer (3.16days for ambient and 2.87days for transit) fruits than in Kent (4.09days for ambient and 3.85days for transit) and Keitt (4.08days for ambient and 3.92days for transit) fruits as in Tables 6 and 7.

Table 8: Firmness Index (N) of Haden, Kent, Palmer and Keitt mango fruits when physiologically mature (hard green stage)

Variety	Bioyield Point (N)	Fruit Flesh Firmness (N)
Haden	93.12	145.30
Kent	104.18	177.98
Palmer	117.81	149.87
Keitt	122.91	194.98
LSD (0.05)	**21.45**	**37.51**

Means of four estimations expressed on fresh weight basis.

Table 9: Comparative analysis of Firmness Index (N) of Haden, Kent, Palmer and Keitt mango fruits when physiologically mature (hard green stage)

Variety	Parameter	Value
Haden	Bioyield Point	93.12
	Fruit Flesh Firmness	145.30
Kent	Bioyield Point	104.18
	Fruit Flesh Firmness	177.98
Palmer	Bioyield Point	177.81
	Fruit Flesh Firmness	149.87
Keitt	Bioyield Point	122.91
	Fruit Flesh Firmness	194.98

Means of four estimations expressed on fresh weight basis.

Both flesh/pulp firmness and bioyield point measurements were made on mango fruits harvested at physiological maturity or mature hard green stage (pre-climacteric stage)

Table 10: Typical picking and shipping schedule for mango fruits consigned by sea and air to the EU from Ghana

Operation	Days Required	
	Sea freight	Air freight
Picking and Packaging	1	1
Pre-cooling and accumulation of load	1	1
Transport to port, port handling and accumulation of load	1	1
Voyage time	14-21	1/4
Discharge handling	1	1
Transport and distribution	2	1
Total	**20-27**	**5 1/4**

Tables 8 and 9 show fruit bioyield point (when the probe punctures through the mango fruit skin causing irreversible damage) and fruit flesh firmness (the plateau of the force which occurs after the bioyield point and is an indication of the underlying flesh firmness of the fruit) index values (N) for Haden, Kent, Palmer and Keitt. When bioyield point and fruit flesh firmness index values of the four varieties were compared, values of fruit flesh firmness were higher than values of bioyield point in all the varieties (Tables 8 and 9). For fruit flesh firmness, Keitt recorded the highest (194.98N) and Haden the lowest (145.30N). Keitt and Kent fruits were significantly not different as well as Haden and Palmer fruits in their firmness values. Keitt recorded the highest force (122.91N) for the bioyield point and this was significantly higher than the effect of Haden only. Treatment effect of Palmer was also significantly higher than that of the Haden variety. However, difference between Kent and Haden were similar (Tables 8 and 9).

Table 10 shows a typical picking and shipping schedule for mango fruits consigned by sea and air to the EU from Ghana. The sea freight takes much longer time (20-27days), almost three to four times, than air freight (about 6 days).

5.0 DISCUSSION

The results of the field and laboratory studies have been discussed under identification of harvest indices using changes of physicochemical properties during maturation.

5.1 FIELD AND LABORATORY STUDIES

Field and laboratory studies on the four different varieties had different commencement days after fruit set (70days for Haden, 84days for Kent, 91days for Palmer and 98days for Keitt). This is in accordance with the assertion by Kader *et al*. (1985), that the basic requirement for prediction of maturity is for a measurement that can be made prior to, but which is highly correlated with the date of maturation. According to the authors, the simplest prediction system uses measurements which relate to development of the fruit in a regular way through the latter part of the growing season. Determination of the different commencement days therefore depended on their various physiological maturation periods after fruit set, such as for Haden, 112days; Kent, 126days; Palmer, 133days and Keitt, 140days. When the relationship between changes in the index quantity and quality and storage life of the commodity has been determined, an index value can be assigned for the minimal acceptable maturity (Kader *et al*., 1985).

5.1.1 IDENTIFICATION OF HARVEST INDICES USING CHANGES OF PHYSICOCHEMICAL PROPERTIES DURING MATURATION

Several mango growers rely on the changes of peel from green to yellow colour as a sign of maturity. This is, however, not applicable to mangoes that are harvested in the hard green stage such as in Haden, Kent, Palmer and Keitt mango varieties. Moreover,

this will involve a total of 4 to 6 harvests per tree of fruit from one bloom. Aside from being laborious and costly, fruits so harvested ripen within a few days and cannot be shipped or stored for long periods (Ruehle and Ledin, 1955).

It was observed during the study that different peel/skin colourations of the varieties were not consistent in changes and thus cannot be used as an adequate maturity index. On the other hand, in most mango cultivars including Haden, Kent, Palmer, and Keitt, flesh/pulp colour changes (Plate 2) are some–what uniform when fruit advances in maturity. Unfortunately, this is a destructive index, but more consistent and more utilized than skin colour change. Lakshminarayana (1975) indicated that mango fruit peel/skin colour does not show a consistent trend during maturation. The author also stated that mango fruit flesh/pulp colour changes from white to bright yellow as maturity advanced. Bhatnagar and Subramanyam (1973) earlier on reported that for "Alphonso" and "Pairi" cultivars, it usually takes 110 to 125days after fruit set for the flesh colour to change from white to pale-yellow which indicates harvest maturity. Yahia (1999) also indicated that flesh colour is commonly used as a maturity index in several mango growing regions.

Caldeira (1970) indicated that the concentration of tannin decreased with maturity and that it is probably as a result of polymerization of tannin. The author added that visually, this can be correlated with the disappearance of latex. In this case, with respect to latex content, an index value can be assigned for the minimal acceptable harvest maturity for Haden, Kent, Palmer and Keitt varieties as 0.075ml, 0.150ml, 0.425ml and

0.116ml respectively (Figure 6) since these results tallied with other acceptable harvest maturity index values such as in Figures 1-5 and in Figure 7.

In mango fruit, however, latex flow does not stop entirely at physiological maturity but reduces in flow rate and quantity (Figure 6). Tree ripe fruits, however, exhibit complete disappearance of latex, though not desirable since such fruits are spoiled by birds and other rodents and also do not keep long in storage and in transit. This notwithstanding, Pantastico (1975) reported that in West Pakistan, the general criterion for the time of harvesting mango fruit is when a few ripe fruits begin to fall naturally from the tree known as 'takpa'. The whole crop on that tree is considered to have developed enough for picking and that it is generally believed that fruits picked from the tree at 'takpa' stage and ripened in storage acquire better flavour, quality and colour (Pantastico, 1975).

Nunez-Elisea (1984) reiterated that a characteristic seldom mentioned when describing mango fruits is the amount of latex secreted by the peduncle at harvest. The author added that the mango latex is corrosive and so damages the fruit surface and causes human skin irritation when in contact. It was further stated that mango fruits that secrete a very small amount of latex after harvest, allow for easier fruit handling. Thus for safety of fruit surface and human skin, and for easier handling due to latex secretion Haden and Keitt fruits may be favoured (Figure 6).

In relation to other indices the indentation index maturity values established for Haden, Kent and Keitt were 0.25cm, 0.49cm and 0.50cm, respectively (Figure 7) since the fruit of all the three varieties maintained constant indentation values at this stage of their developments. Palmer is an exception in this context, but rather its harvest maturity is determined by the intensity of depressions or ridges/grooves around the stylar scar/end of the fruit as demonstrated in Plate 6. Iqbal (2001), Yahia (1999) and Medlicott (1990) reported that fully mature mango fruits show indentation (out-grown shoulders), formation of depressions with ridges/grooves at the stem-end, firm and green. According to the authors this criterion is used in several regions but does not apply to all the cultivars and must be considered with other factors. Hulme (1971) suggested that the best stage for export occurs when the shoulders have outgrown from the stem-end. By analogy with apples, this stage, being just before the climacteric rise in respiration, would appear to be a suitable stage of maturity for maximum transport and storage (Hulme, 1971). However, Singh (1960) earlier on pointed out that stem-end and shoulder relationship does not hold true for all varieties of mango. This confirms the findings here-in on Palmer fruit which does not exhibit outgrown shoulders as a harvest maturity index in mangoes (Figure 7).

Significant increases in dry matter and starch contents during maturation were found (Plate 4 and Figure 13) in all the varieties. A limitation, however, occurred i.e. the differences between colours in the range of high starch content (mature green stage) are not very distinct (Plate 4). This finding is confirmed by Dadzie and Orchard (1997) in bananas. Popenoe *et al*. (1958) suggested that for Haden and Zill mangoes grown in

Florida, the point of maximum starch content was a good index of full maturity for harvesting. Anon (1972) and Bhatnagar and Subrananyam (1973) confirmed this for some Indian varieties.

For all the four varieties the cheeks of the fruits were fully developed (out-grown shoulders) and the pedicel-ends developed purple-red blush colours at 112days, 126days, 133days and 140days after fruit set for Haden, Kent, Palmer, and Keitt varieties, respectively (Plate 3). This also paralleled the change in flesh colour from white to pale-yellow (Plate 2), a flesh/pulp colour that demonstrates stage of physiological maturity in all the varieties (Bhatnagar and Subramanyam, 1973; Anon, 1965) and the appearance of white powdery material (Yahia, 1999) on the surface of the mature fruit (Plate 5). Out-grown shoulders, flesh colour and the appearance of the white powdery material are some of the maturity indices that could be used to determine the harvesting stage. Similar observations were reported by Johnson *et al*. (1997) and Kruger (1998). Hofman and Ledger (2006) reported that in South Africa, flesh colour is favoured for assessing mango fruit maturity, while in Australia, skin colour, dry matter and accumulated heat units are considered as well.

The accumulated day-degrees (^{o}C) needed for optimum growth of fruits from flower bud initiation through fruit set to harvest maturity during the experimental period (Table 2) indicates that a range of 3850.9-4203.3^{o}C (heat units) is conducive for optimum growth of Haden and Kent fruits while a range of 4203.3-4554.7^{o}C is conducive for the growth of Kent, Palmer and Keitt mango fruits for the major season. Thus, Kent fruits

can grow normally at all the two ranges. For the minor season, a range of 3305.8-4007.2^{o}C is conducive for Haden and Kent mango fruits while a range of 4007.2-4409.0^{o}C is conducive for Kent, Palmer and Keitt mango fruits. Kent fruits can grow normally at both ranges to. Pantastico (1975), Yahia (1999) and Litz (2003) indicated that temperature is a very important factor that influences fruit maturity and quality and that temperature can influence, not only the suitability of the growing region for mango cultivation, but also for the harvest period and the quality of fruit. According to Yahia (1999) the minimum temperature (base temperature) at which mango will not develop normally is 17.9^{o}C. Heat units which are calculated from the sum of the temperature units (degree days) in excess of the base temperature over the growing season, has been calculated in some countries for mango (Yahia, 1999). Whiley *et al*. (1988, 1989 and 1991) described the vegetative growth and flowering responses of several monoembryonic and polyembryonic cultivars to four temperature regimes ranging from vegetatively inductive (30^{o}C day/25^{o}C night) to floral inductive (15^{o}C day/10^{o}C night).

The seasonal accumulated rainfall ranges needed for optimum growth of fruits from budding through fruit set to harvest maturity during the experimental period (Table 2) indicate that a range of 480.36-564.68mm is conducive for the growth of Haden and Kent fruits while a range of 564.68-608.55mm is conducive for the growth of Kent, Palmer and Keitt mango fruits for the major season. Thus, Kent fruits can perform normally at all the two heat unit ranges. For the minor season, a range of 469.80-529.03mm is conducive for Haden and Kent mango fruits while a range of 529.03-567.25mm is conducive for Kent, Palmer and Keitt mango fruits. Kent fruits can grow

normally at both heat unit ranges to. According to Yahia (1999) the amount of and distribution of rainfall not only determine the suitability of the region for mango growing, but also influence the maturation and quality of the fruit. Mango growth is generally successful when the annual rainfall ranges between 75 and 350mm without water-logging and rains do not fall during flowering, fruit set and fruit development (Yahia, 1999). Differences in rainfall as well as in temperature readings occurred among the two seasons during the experimental period but were not significantly different (Table 2). The differences were most probably attributable to the climatic location of the study area as shown in Appendices D1 and D2. Thus, in fixing the maturity index values for mangoes, temperature, rainfall, days from anthesis to harvest and morphological changes may be considered.

The peel/skin colour, pulp/flesh colour, shape/indentation/fullness of cheeks/out-grown shoulders of fruit, starch concentration, leathery fruit peel/appearance of white powdery material on the surface of the fruit, formation of depressions or ridges/grooves at the fruit stem-end and colour of pedicel may be established as criteria for harvest maturity. Maturity standard for individual mango varieties under specific agro-climatic conditions can then be fixed for local consumption as well as for export purposes.

The physiological maturity dates for Haden (112days), Kent (126days), Palmer (133days) and Keitt (140days) as obtained by computing the number of days from full bloom/fruit set to early harvest show that Keitt and Palmer are late maturing varieties; Kent, a medium maturing variety and Haden, an early maturing variety. All the four

varieties also come into production or are in crop during both the minor and major seasons in the Somanya-Dodowa mango production zone irrespective of the differences in their maturity periods. The two production seasons have been made possible in this zone most probably because of the nearness of the study area to the sea and for the fact that this production zone is situated along the Akwapim and Shai hills where the mean annual temperature range and mean annual rainfall range are about the same for both minor and major seasons as indicated in Appendices D1 and D2. The two mango seasons in the study area could also be associated to the marked dry spells that occur between July and August and between December and January for the minor and major seasons respectively. These dry spells are normally accompanied by low night temperatures suggested to be conducive for flowering in mangoes (Litz, 2003).

Fruits of all the four varieties maintained a constant weight, length, width, volume, density and indentation at maturity (Figures 1–5; 7). Similar observation has been reported by other workers including Pantastico (1975) and Watada *et al*. (1984). Yahia (1999) stated that physicochemical composition of mango is not only an important factor in the selection of suitable cultivars for different purposes, but its trends can also serve as a guide to indicate appropriate harvest time for mango. These trends include stabilization of fruit weight, length, width, volume, density, indentation, latex content and starch concentration (Yahia, 1999).

All the varieties used in the study had the appropriate size (weight) of the export fruit quality as defined by the Codex Standards for mangoes indicated in Appendix A. The

diameter of fruits is an excellent criterion for industrial isolation of pulp for processing (Pantastico, 1975), thus suggesting that Keitt is a suitable mango variety for processing since it is bulky (widest width of 35.91cm and highest mean weight of 1104g) (Figures 1 and 3). The growth rate of Haden, Kent, Palmer and Keitt mango fruits in the present study appear to take the form of a simple sigmoid pattern (Figures 1–5; 7). Similar observation has also been made by Hulme (1971) and Pantastico (1975).

Ghana's mangoes (both whole fresh fruits and processed forms) are largely exported by both air and sea freights; where air freights take at most 6 hours and for sea freights a range of 14-21days (MTSS, 2004; Twum, 2008; MIR, 2008) to various destinations (Table 10). Thus, the appropriate harvest stage with particular reference to time (time with accompanying maturity characteristics) considers both air and sea freights. To simulate sea freight, Haden, Kent, Palmer, and Keitt mango varieties were harvested at 112days, 126days, 133days and 140days after fruit set respectively, i.e. at early maturity. For air freight, Haden, Kent, Pamer, and Keitt mango varieties were harvested at 126days, 140days, 147days and 154days after fruit set respectively, i.e. at late maturity. Yahia (1999) observed that fruit, especially for export, should be harvested earlier and that the time for harvesting should be established on the basis of the type of market, distance from the orchard or the packing house and the type of transport to be used. Fruit has to be harvested at the ideal stage in order to develop the most adequate organoleptic quality and the longest postharvest life (Yahia, 1999).

All harvest dates have appropriate accompanying characteristics as indicated in Plates 1-6 and Figures 1-13. Fruits intended for the European market should be harvested right after full maturity (physiological maturity) i.e. early harvest if they are to be transported by sea, and can be harvested later i.e. mid or late harvest if the fruit is to be transported by air (Table 10). The latter can also be applied for fruit intended for local market, processing or intended to be consumed very close to the orchard. Fruit to be sold in distant markets inside the country which needs to be kept for a few days or weeks before being sold should be harvested shortly after full maturity (physiological maturity). Where customers are accustomed to ripe fruits, and where the distance is short, fruit can be harvested between full maturity and early stages of ripeness. Fruit should always be harvested after full maturity and before full ripeness, but should never be harvested over-ripe for any market.

At physiological maturity (preclimacteric)/early maturity and up to two weeks after/mid maturity, Haden showed a significantly high level of TSS (8.94^{o}Brix and 12.65^{o}Brix, respectively) when the four varieties were compared, indicating that the Haden fruit may be softer than Kent fruit (6.88^{o}Brix and 7.19^{o}Brix, respectively), Palmer fruit (7.25^{o}Brix and 10^{o}Brix, respectively) and Keitt fruit (6.56^{o}Brix and 8.03^{o}Brix, respectively) (Figure 8) and therefore much more suitable for the fresh market. However, Doreyappa and Ramanjaneya (1994) reported a higher level of TSS (18.9^{o}Brix) and an acidity of 0.22% in Haden indicating that different growing conditions affect the physico-chemical attributes of the fruit.

As maturity advanced in all the varieties, TSS continued to increase while TA decreased (Figures 8 and 9, respectively). Similar changes were also observed by Kliewer (1965) in grapes. The variability of TSS of different varieties might be attributed to the alteration occurring in cell wall structure during maturation processes. Moreover various hydrolytic enzymes also affect complex carbohydrates changing them into smaller compounds (Kays, 1991; Kittur *et al.*, 2001) thus reflecting the conversion of starch into sugars. At advanced maturity, organic acids form salts which contribute to the increase of TSS (Kliewer, 1971). This may also explain the higher concentrations of TSS at the ripe stage than the physiological maturity stage (Tables 3-5). The total soluble solids content of fruit is important both from the stand point of product consistency and processing, as well as the quality of the fresh produce (Gould, 1983). Opena (1983) indicated that high value of total soluble solids is desirable because it relates to the yield of processed products. A sharp increase in TSS/acidity ratio was observed at ripening (Tables 3-5). For most fruits, a higher TSS/acidity ratio indicates better eating quality (Singleton and Gortner, 1965).

The variability in pH (Figure 11) among the four varieties corresponded to the changes in the acidity (Figure 9) of the respective varieties. Variation in acidity among various varieties may be attributed to the extent of degradation of citric acid as a function of the activity of citric acid glyoxylase during maturation/ripening (Doreyappy-Gowda and Huddar, 2001; Rathore *et al.*, 2007). Another study by Kudachikar *et al.* (2001) also confirmed the changes in pH and acidity in mangoes during maturation/ripening processes. The authors ascribed such changes to the stage of maturity of mangoes. In

most of the varieties the results show a rise and fall, but generally a decreasing trend in acidity during maturation similar to that obtained for other fruits such as the apple (Hulme, 1971). This pattern of acid change was also observed by Singh *et al.* (1937) and Mukherjee (1953). The mean acidity at maturity was similarly higher for Haden and Keitt varieties (Figure 9) with a slight preponderance of the latter, indicating that the Keitt variety is suitable for processing since acids are not only important as major taste components, but also play important roles in the satisfactory processing of products (Doreyappa and Ramanjaneya, 1994).

Mangoes are a particularly rich source of vitamin C (ascorbic acid) (Pantastico, 1975). The present study showed that in all the varieties ascorbic acid concentration increased throughout development and maturation (Figure 10). When mangoes were ripened a decreasing ascorbic acid concentration trend was observed (Table 4). The decrease in ascorbic acid concentration during ripening could be attributed to its susceptibility to oxidative destruction (Aina, 1990) as impacted by the ripening environment.

The ascorbic acid content is considerably greater in the green mature fruit (Tables 3 and 5) than in ripe fruit (Tables 4 and 5), although the ripe mango is an excellent source of the vitamin (Hulme, 1971), particularly the Palmer variety (Figure 10). Mattoo and Modi (1969) working with the Alphonso variety found 250mg/100g fresh pulp in the unripe fruit, 90mg in the partially ripe fruit and 165mg in the ripe fruit. Soule and Hatton (1955) found 79mg/100g ascorbic acid in unripe fruit and 25mg in ripe Haden

mangoes, indicating that different growing conditions affect the physicochemical attributes of the fruit.

According to Krochta *et al.* (1975) the retention of ascorbic acid is an index of quality and nutritive value in fruit and vegetable processing and the associated rapid loss cannot be over emphasized. Salunkhe *et al.* (1991) indicated that loss of ascorbic acid can occur during storage in the raw state and that losses are accelerated by high temperatures and high rates of wilting. They further stated that bruising and mechanical damage greatly increase the rate of loss of ascorbic acid because it is highly susceptible to oxidation, either directly or through an enzyme (ascorbic acid oxidase) which is widely distributed in plant tissues. Hence, the need for proper handling and restoration of the mango fruit.

The pattern of chemical changes was strikingly similar in all the varieties. Thus, the increase in TSS and TSS/acid ratio and the decreasing trend in TA could be used as another easily estimatable criterion for fixing the maturity standard of mango. While TSS and pH values showed an increasing trend, ascorbic acid and TA showed a decreasing trend as maturation/ripening progressed (Tables 3 and 4). A considerable decrease in the acidity of mango was observed during ripening with a pH shift from 3.25, 3.499, 3.328 and 3.349 to 5.11, 4.08, 5.00 and 5.80 for Haden, Kent, Palmer and Keitt mango fruits, respectively (Tables 3-5), indicating that the fruit is mildly acidic like most other mango varieties (Hulme, 1971; Pantastico, 1975; Yahia, 1999; Litz,

2003). Yahia (1999) observed that in several mango cultivars, changes in maturity indices are either irregular or too small.

The physiological loss in weight while in storage (Tables 6 and 7) is linked to the fact that the mango skin bears stomata and transpiration continues after the fruit has been harvested. The considerable variation among treatments could be attributed to their responses to different temperature, relative humidity (Simmonds, 1959), atmospheric composition (Adel, 1993) and the degree of maturation/ripeness (Doreyappy-Gowda and Huddar, 2001; Kudachikar *et al*., 2001; Rathore *et al*., 2007).

An increase in temperature increases the loss of the water, which means a loss in weight of the produce (Harris, 1988). Simmonds (1959) earlier on reported a rise in water loss at the maturation phase and after, the change that is related to degenerative changes of the skin. This observation corresponds with the results of the present study (Figure 12). The slight but insignificant reduction in moisture content during maturation (Figure 12) and ripening (Tables 3-5), has been explained in terms of a maximum rise in water loss in the maturation stage due to degenerative changes of the skin (Simmonds, 1959), resulting from both respiration and transpiration sources (Aina, 1990).

At ripening (eating soft stage), moisture levels recorded for Haden, Kent, Palmer and Keitt mango fruits stood at 80.85%, 80.94%, 80.25% and 81.95% respectively while at the physiologically mature stage (early harvest) the levels were 83.55%, 82.28%, 83.89% and 84.26% respectively (Figure 12; Tables 3-5) account for their high

perishability. Meanwhile a USDA (2004) source indicated 81.71% as general moisture content for mango fruit at physiological maturity. This disparity in moisture content may be attributed to varietal differences, environmental differences as well as differences in production conditions. However, a reduced water content and related increase in soluble solids concentration is desirable in processing mango fruits, where paste production is the objective (Kordylas, 1991). The Palmer fruit which had the lowest moisture content (80.25%) and highest TSS (19.1$0^{o}$Brix) at the ripe stage (Table 4) is thus recommended here. At physiological maturity the Kent fruit was, however, significantly lower in moisture content (Figure 12) when compared to fruits of the other varieties.

Fruits harvested at the advanced stage of maturity were high in soluble solids, dry matter and starch contents than those harvested earlier (Figure 8; Figure 13; Plate 4; Tables 3-5). Similar results have been reported by Saranwong *et al*. (2004). Selection of soluble solids, dry matter and starch as harvesting indices is thus appropriate since starch is the source of sugar production at the ripe stage.

Accumulating a sufficient amount of starch would allow the ripe fruit to be able to synthesize a large amount of sugar. This is supported by significant activities of starch break-down and sugar synthesis during ripening (Tandon and Kalra, 1983; Ueda *et al*., 2000). The increase in dry matter suggests accumulation of organic substances needed for completing the ripening process (Saranwong *et al*., 2004).

Mangoes grown in the various seasons did not primarily display any significant variation in any of the physicochemical attributes tested when seasonal averages were compared, indicating that the season of production has least or no influence on most of the physicochemical attributes of mangoes grown in Ghana. A reputable producer as well as an exporter commented during the study, and I quote ‘’definite distinction between the major and minor seasons in this zone is virtually lost’’.

In each case of the physiologically mature and ripe stages, the fibre content of the Keitt fruit was significantly higher than that of Haden, Kent and Palmer fruits (Tables 3-5). Haden, Kent and Palmer fruits were similar in their fibre contents (Tables 3-5). By the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference, Release 17, on mango fibre content, all the present exportable mango varieties contain a much desirably far less fibre when compared with the standard (3.7g fibre/average size mango fruit) (Figure 1; Tables 3-5). They are virtually fibreless and thus internationally acceptable, which imply good market for Ghana. This characteristic is also a requirement for the fresh market.

The weight loss of mango fruits increased with time of storage, regardless of the storage temperature, and the rate of weight loss was comparable for the four varieties (Tables 6 and 7). After 9.5days, 10.5days, 10.0days and 11.0days in storage for ripening for Haden, Kent, Palmer and Keitt mango fruits respectively, their weight losses were higher at 20 to 22^{o}C and 90-95% rh, when compared with the same varieties that ripened in 3.5days, 4.5days, 4.0days and 5.0days respectively after they were stored to

simulate transit conditions which took 21days (Tables 6, 7 and 10). The results obtained for the weight loss are in agreement with the values previously reported by other authors (Krishnamurthy, 1988; Reddy and Raju 1988; Mahayothee *et al*., 2002). The values of weight loss obtained in this present study do not seem to be crucial in terms of development of shrivelling in Haden, Kent, Palmer and Keitt mangoes (Tables 6 and 7) when compared with the findings of Reddy and Raju (1988) and Cecilia *et al.* (2007).

Shrivelling of the mango fruit skin did not increase above an objectionable rating during storage, regardless of the storage temperature. Although not objectionable, the highest shrivelling rates were observed in Haden and Palmer varieties with a slight preponderance of the former (Tables 6 and 7). Changes in mango fruit texture (softening, shrivelling, shrinking, wrinkling, etc.) during ripening have been previously attributed to the degradation of pectic compounds by pectic enzymes, which activity significantly increases as the fruit ripens (Tridjaja and Mahendra, 2002).

Increased softness was the quality factor that determined the maximum shelf life of the fruit after they were transferred from the ripening chamber to sale/fresh market storage conditions (13-15^{o}C; 85 to 90% rh) (Krishnamurthy, 1988; Reddy and Raju, 1988; Mitra, 1997; Yahia, 1999; Mahayothee *et al.*, 2002; Litz, 2003; Cecilia *et al*., 2007) as indicated in Tables 6 and 7. Although softness was the first quality factor to reach the limiting quality rate, colour changes and decay should not be disregarded as they also contributed to the loss of quality in the fruit stored. For fruit ripened from direct physiological harvest, softening was considered to be the major quality limiting factor

for Haden, Kent, Palmer and Keitt fruits as it reduced their shelf lives to 3.2days, 4.1days, 3.2days and 4.1days, respectively (Tables 6 and 7). Softening of the fruit was likewise the major quality limiting factor for the fruits of these same four mango varieties stored at the sale/fresh market storage conditions after ripening, prior to simulation at transit conditions, and reduced the shelf life of the fruits to 2.9days, 3.9days, 2.9days and 3.9days, respectively (Tables 6 and 7).

Shrivelling does not seem to be a great concern if mango fruits are stored under appropriate relative humidity conditions (90 to 95% rh). Signs of decay in Haden and Palmer fruits became visible/evident after three days at 13 to 15^{o}C, and for Kent and Keitt varieties, after 4 days at 13 to15^{o}C (Tables 6 and 7). These findings are in line with that of Cecilia *et al*. (2007) who reported that signs of decay in "Tommy Atkins" and "Palmer" mangoes became evident after 12days at 12^{o}C, after 4 to 5days at 15^{o}C and after 3 to 4days at 20^{o}C. They also reported that softening of the fruit was the major quality limiting factor for "Tommy Atkins" and "Palmer" mangoes stored at 15^{o}C, and reduced the shelf life of the fruits to 3days.

Fruit pre-exposed to transit conditions (10^{o}C; 85 to 90% rh) before ripening (20 to 22^{o}C; 90 to 95% rh), and stored at sales/fresh market conditions (13 to 15^{o}C and 85-90% rh) did not suffer any chilling injury. Although storage of mango fruits at 10-12^{o}C is recommended to avoid the risk of chilling injury (Mitra, 1997; Yahia, 1999; Litz, 2003), it reduced the shelf life of Haden, Kent, Palmer and Keitt fruits to a maximum of 2.9days, 3.9days, 2.9days and 3.9days respectively when stored at sales/fresh market

conditions. In relation to this, Cecilia *et al*. (2007) again reported that storage at 12^{o}C reduced the shelf life of "Tommy Atkins" and "Palmer" fruits at medium-ripe stage to a maximum of 6 to 8days.

In comparison therefore, the shelf life of Haden, Kent, Palmer and Keitt fruits established from the quality evaluations in the present study was 9.5days, 10.5days, 10.0days and 11.0days respectively at 20 to 22^{o}C, 90-95% rh, and 3.2days, 4.1days, 3.2days and 4.1days respectively at 13 to 15^{o}C, 85-910% rh; and for those that were stored to simulate transit conditions before ripening, was 3.5days, 4.5days, 4.0days and 5.0days respectively at 20 to 22^{o}C, 90-95% rh, and 2.9days, 3.9days, 2.9days and 3.9days respectively at 13 to 15^{o}C, 85-90% rh depending on the variety (Tables 6 and 7). These analyses show that Kent and Keitt fruits store better than Haden and Palmer fruits under both ambient and transit conditions (Tables 6 and 7) and are therefore recommendable for sea freight or for longer distances where relatively much time is spent before delivery. This finding is reflected in the conduct of firmness test made on the same four mango varieties where Kent and Keitt fruits were significantly firmer than Haden and Palmer fruits on comparison (Tables 8 and 9). The differences in the fruit shelf life of the four mango varieties might be associated with differences in the maturity days of the different varieties at the time of harvest and with cultivar variations.

In comparison flesh/pulp firmness was slightly higher than that at bioyield point as indicated in Tables 8 and 9. Dadzie and Orchard (1997) indicated that the texture or

firmness of the pulp of fruits is an important post harvest attribute in the assessment of the post harvest characteristics at harvest. According to the authors flesh/pulp firmness could be used as a maturity/ripening index and that it could also facilitate comparison of the state of softening of the different cultivars under study. Assessment of firmness is important in the evaluation of fruit's susceptibility to physical or mechanical damage or post harvest handling (Kramer, 1973).

6.0 CONCLUSIONS AND RECOMMENDATIONS

Quality criteria investigated for harvesting export mango fruits from Ghana were on age control, visual aids, physical and chemical methods.

Several physiological maturity indices for export purposes have commercial application only for a specific type of harvest (early, mid or late harvest) and for specific cultivars. Physiological maturity ages (intended for storage or transport, example, by sea to distant markets) were established as 109-115days, 123-129days, 130-136days and 137-143 days after fruit set for Haden, Kent, Palmer and Keitt fruits, respectively for early harvest. The established time for mid harvest were 116-122days, 130-136days, 137-143days and 144-150days after fruit set for Haden, Kent, Palmer and Keitt, respectively. For late harvest, it was 123-129days, 137-143days, 144-150days and 151-157days after fruit set for Haden, Kent, Palmer and Keitt, respectively.

The time for harvesting should be established on the basis of the type of market, distance from the orchard or the packing house and the type of transport to be used. The appropriate harvest stage with particular reference to time (time with accompanying maturity characteristics) considers both air and sea freights. To simulate sea freight, Haden, Kent, Palmer, and Keitt mango fruits were harvested at 112days, 126days, 133days and 140days after fruit set, respectively, i.e., at early maturity. For air freight, they were harvested at 126days, 140days, 147days and 154days after fruit set, respectively, i.e., at mid and late maturity stages. Harvests at 126days, 140days, 147days and 154days after fruit set for Haden, Kent, Palmer, and Keitt, respectively can

also be applied for fruits intended for local market, processing or intended to be consumed very close to the orchard. Fruits to be sold in distant markets inside the country which need to be maintained for a few days or weeks before they are sold should be harvested at 119days, 133days, 140days and 147days after fruit set for Haden, Kent, Palmer and Keitt, respectively, i.e., shortly after full maturity. Where customers are accustomed to ripe fruits, and where the distance is short, fruits can be harvested between 119 and 126days for Haden, 133 and 140days for Kent, 140 and 147days for Palmer and 147 and 154days for Keitt; i.e., between full maturity and early stages of ripeness. Fruits have to be harvested at the ideal stage in order to develop the most adequate organoleptic quality and the longest postharvest life. Thus they should always be harvested after full maturity and before full ripeness, but should never be harvested over-ripe for any market.

Visual methods such as changes in fruit peel/skin colour are applicable only to Haden and Palmer. Haden and Palmer show changes in fruit peel/skin colour from green to pale green during development to physiological maturity (export stage) but turn yellow and pink respectively on ripening. Changes in colour on the flesh around the stone/seed, fruit shape/indentation, development of a purplish–red blush colour of the pedicel, starch iodine test and the leathery fruit peel, i.e., appearance of white powdery material on the surface of fruit at physiological maturity were, however, applicable to all the varieties. At physiological maturity all the varieties had a generally yellow colouration on the flesh around the stone/seed; fruit cheeks/shoulders (showing fruit shape/indentation) of all the varieties were fully developed and the pedicels developed a

purplish–red blush colour; starch concentration in all the varieties attained a high starch content which showed a higher degree of dark blue colouration upon iodine test; and all the varieties showed a leathery fruit peel, i.e., the appearance of a white powdery material on the surface of the fruit. Often visual methods become arbitrary and subjective, so that the methods cannot be defined accurately enough to enable a shipping organization, a processor or any other beneficiary to set definite standards. Standards must be in numbers not in words. The approach then is to combine several methods of assessing maturity in order to establish appropriate quality criteria for export.

For Haden, Kent, Palmer and Keitt mango fruits, harvests were made at physiological maturity when each variety maintained a constant weight (640g, 836g, 837g and 1104g for Haden, Kent, Palmer and Keitt, respectively), length (16.30cm, 16.19cm, 21.22cm and 19.00cm for Haden, Kent, Palmer and Keitt, respectively), width (30.94cm, 33.47cm, 30.86cm and 35.90cm for Haden, Kent, Palmer and Keitt, respectively), volume (598cm^3, 807cm^3, 772cm^3 and 959cm^3 for Haden, Kent, Palmer and Keitt, respectively), density (1.147g\cm^3, 1.076g\cm^3, 1.084g\cm^3 and 1.189g\cm^3 for Haden, Kent, Palmer and Keitt, respectively) and indentation (0.25cm, 0.49cm, and 0.50cm for Haden, Kent, and Keitt, respectively). Palmer did not show indentation at maturity; rather, this is represented by the intensity of ridges/grooves around the stylar scar/end of its fruit. For latex content the index values for Haden, Kent, Palmer and Keitt at physiological maturity were 0.075ml, 0.150ml, 0.425ml and 0.116ml, respectively since these results tallied with the other harvest maturity index values. Thus, for fixing

maturity indices as quality criteria for mango fruits, days from fruit set to harvest, indentation/shape, latex content and morphological changes are important.

Physiological maturity index values established for Haden, Kent, Palmer and Keitt were 8.94°Brix, 6.88°Brix, 7.25°Brix and 6.56°Brix, respectively, for soluble solids; 1.07% citric acid, 0.81% citric acid, 0.94% citric acid and 1.04% citric acid, respectively, for titratable acidity; 24.9mg/100g, 8.5mg/100g, 35.5mg/100g and 23.8mg/100g, respectively, for ascorbic acid; 3.25, 3.50, 3.33 and 3.49, respectively, for pH; 83.55%, 82.23%, 83.89% and 84.26%, respectively, for moisture content; 16.45%, 17.77%, 16.11% and 15.74%, respectively, for dry matter content; 0.017%, 0.016%, 0.017% and 0.026%, respectively, for fibre content; 145.30N, 177.98N, 149.87N and 194.98N, respectively, for fruit flesh firmness; and 8.35, 8.53, 7.71 and 6.28, respectively, for total soluble solids/acidity ratio.

The pattern of chemical changes was strikingly similar in all the varieties. Thus, the increase in TSS and TSS/acid ratio and the decreasing trend in TA could be used as another easily estimating criterion for fixing the maturity standard of mango. While TSS and pH values showed an increasing trend, ascorbic acid and TA showed a decreasing trend as maturation/ripening progressed. Also selection of soluble solids, dry matter and starch as harvesting indices is appropriate since starch is the source of sugar production at the mature stage. All determinations were made in relation to the age control criterion because of its precision in measuring or determining harvest maturity

stage. It was recognised that the method is laborious and time-consuming because of the need to obtain baseline data.

Ripe (eating soft stage) index values established for Haden, Kent, Palmer and Keitt were 18.5°Brix, 17.5°Brix, 19.5°Brix and 17.0°Brix, respectively, for total soluble solids; 0.14% citric acid, 0.12% citric acid, 0.31% citric acid and 0.10% citric acid, respectively, for titratable acidity; 8.05mg/100g, 3.32mg/100g, 5.52mg/100g and 3.66mg/100g, respectively, for ascorbic acid; 5.11, 4.08, 5.00 and 5.80, respectively, for pH; 80.85%, 80.94%, 80.25% and 81.95%, respectively, for moisture content; 19.15%, 19.06%, 19.75% and 18.05%, respectively, for dry matter content; 0.065%, 0.062%, 0.066% and 0.094%, respectively, for fibre content; and 132.14, 145.83, 61.61 and 170.00, respectively, for TSS/acidity ratio. Fruits of Haden, Kent, Palmer and Keitt ripened (eaten soft stage) in 9.50days, 10.52days, 10.01days and 11.01days, respectively, under ambient conditions (20 to 22°C, 90-95% rh). When transit conditions (10°C, 85-90% rh) were simulated for 21 days, fruits ripened (eating soft stage) in 3.5days, 4.5days, 4.0days and 5.0days, respectively. Haden, Kent, Palmer and Keitt fruits developed objectionable or unacceptable characteristics after ripening under ambient conditions and stored at sales/fresh market conditions (13-15°C, 85-90% rh) in 3.15days, 4.09days, 3.16days and 4.08days respectively. When transit conditions (10°C, 85-90% rh) were simulated for 21days and fruits were subsequently ripened and stored at sales/fresh market conditions (13-15°C, 85-90% rh) spoilage time reduced to 2.91days, 3.85days, 2.87days and 3.92days for Haden, Kent, Palmer and Keitt fruits, respectively. Thus proper age control and identification of key indices of maturity for

mango to determine ripening quality for export and local markets is essential. This will ensure maximum shelf life and best eating quality to the consumer and at the same time will not risk an abnormal ripening.

A multi-disciplinary approach with emphasis on cultivar/variety, location, season, chemical composition, region or other ecological variables such as temperature and rainfall and even nutrition is thus needed, but it should also be noted that a more holistic view requires more time and different techniques and methods for assessment. It should therefore be apparent that a single harvest maturity index figure would not always reflect the harvest index in all giving situations.

The following are recommended:

1. Several methods of assessing maturity should be combined in order to establish appropriate quality criteria for export, since a single harvest maturity index figure would not always reflect the harvest index in all giving situations.
2. Other methods outside this study such as sinks and floats, growth of seed hairs, development of lenticels, development of abscission layer and others should be investigated under the same conditions to complement the study to make better decisions. These should be investigated and selected according to variety and growing region.
3. Future research should consider easy–to–apply harvest indices and non–destructive methods that correlate positively to enable a computerised system of checking fruit maturity.

4. The Ghana Standards Board in collaboration with other institutions, agencies, regulatory bodies, development programs and projects should ensure that the Ghana standards for mango is properly used by the stakeholders in the industry.
5. The Ministry of Food and Agriculture in collaboration with Ghana Standards Board and other institutions, agencies, regulatory bodies, development programs and projects should promote Good Agricultural Practices (GAP) in mango farms and also support the farmers financially. This is in consideration of the changing trends of the sector and the opportunities for employment and income generation in the country.
6. Cultivars should be grown separately in the field to facilitate cultural practices and harvesting.

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APPENDICES

APPENDIX A. PROVISIONS CONCERNING SIZING

Size is determined by the weight of the fruit, in accordance with the following table:

Size Code	**Weight** (in grams)
A	200 - 350
B	351 - 550
C	551 - 800

The maximum permissible difference between fruit in the same package belonging to one of the above mentioned size groups shall be 75, 100 and 125g respectively. The minimum weight of mangoes must not be less than 200g.

For all classes, 10% by number or weight of mangoes in each package are permitted to be outside (above or below) the group size range by 50% of the maximum permissible difference for the group. In the smallest size range, mangoes must not be less than 180g and for those in the largest size range a maximum of 925g applies, as follows:

Size code	**Normal size range**	**Permissible size range (< 10% of fruit/package exceeding the normal size range)**	**Max. permissible difference between fruit in each package**
A	200 – 350	180 – 425	112.5
B	351 – 550	251 – 650	150
C	551 – 800	426 – 925	187.5

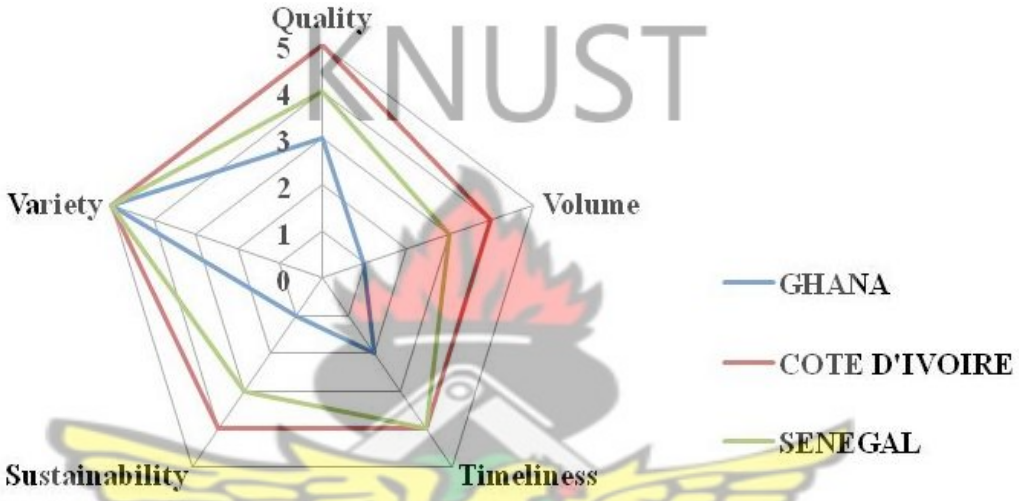
SOURCE: EUSMG, 2001

APPENDIX B. BUYER BENCHMARKING FOR GHANA, COTE D'IVOIRE AND SENEGAL

KEY

0 - 5 = favourable

5 - 0 = unfavourable.



SOURCE: Ava *et al*., 2008

Appendix C1. Changes in average weight during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	242	313.45	385	458	531	585.5	640	640	640				
Kent			446.7	502.9	559	606	653	744.5	836	836	836		
Palmer				500.5	589.25	678	738.5	799	818	837	837	837	
Keitt					569.4	741.2	913	973.5	1034	1069	1104	1104	1104

Appendix C2. Changes in average length during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	9	9.67	10.38	12	13.62	14.96	16.3	16.305	16.31				
Kent			12.94	13.83	14.72	15.08	15.44	15.815	16.19	16.19	16.19		
Palmer				15.51	17.02	18.53	18.91	19.28	20.25	21.22	21.22	21.2	
Keitt					17.38	17.6	17.81	18.06	18.31	18.655	19	19	19

Appendix C3. Changes in average width during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	21	22.405	23.95	25.96	27.96	29.45	30.94	30.955	30.97				
Kent			27.03	28.51	29.98	31.29	32.59	33.03	33.47	33.47	33.47		
Palmer				25.62	27.475	29.33	29.93	30.53	30.695	30.86	30.86	30.9	
Keitt					30.5	31.39	32.28	33.39	34.5	35.205	35.91	35.9	35.9

Appendix C4. Changes in average volume during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	241	287.75	335	402.4	469.7	533.9	598	598	598				
Kent			415	499	583	646.2	709.4	758.2	807	807	807		
Palmer				473	564	655	701.6	748.2	760.1	772	772	772	
Keitt					653.1	710.6	768	840.3	912.6	935.8	959	959	959

Appendix C5. Changes in average density during development and maturation of Haden, Kent, Palmer and Keitt mango fruits.

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	1	1.038	1.071	1.1	1.128	1.138	1.147	1.147	1.147				
Kent			0.919	0.939	0.958	0.997	1.035	1.0555	1.076	1.076	1.076		
Palmer				1.036	1.047	1.058	1.063	1.068	1.076	1.084	1.084	1.08	
Keitt					0.872	1.003	1.133	1.142	1.151	1.17	1.189	1.19	1.19

Appendix C6. Changes in average latex content during development and maturation of Haden, Kent, Palmer and Keitt mango fruits.

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	1.8	1.25	0.719	0.522	0.325	0.2	0.075	0.0438	0.0125				
Kent			1.431	1.16	0.888	0.757	0.625	0.3875	0.15	0.1063	0.063		
Palmer				1.85	1.5345	1.219	1.047	0.875	0.65	0.425	0.241	0.06	
Keitt					1.281	1.147	1.013	0.722	0.431	0.2735	0.116	0.07	0.02

Appendix C7. Changes in average indentation depth during development and maturation of Haden, Kent, Palmer and Keitt mango fruits.

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	0	0.0544	0.076	0.101	0.125	0.175	0.25	0.25	0.25				
Kent			0.045	0.085	0.125	0.176	0.227	0.3602	0.4937	0.4968	0.5		
Palmer				0	0	0	0	0	0	0	0	0	
Keitt					0.125	0.164	0.203	0.2266	0.25	0.375	0.5	0.5	0.5

Appendix C8. Changes in soluble solids (^{o}Brix) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	6	6.1	6.4	6.625	7.125	8.62	8.94	11.31	12.65				
Kent			6.06	6.188	6.25	6.562	6.844	6.78	6.88	7	7.19		
Palmer				6.25	6.438	6.562	6.688	6.688	6.75	7.25	8.75	10	
Keitt					5.938	6.125	6.25	6.312	6.5	6.56	6.56	8	8.03

Appendix C9. Changes in average titratable acidity (% citric acid) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

Variety	Days after fruit set												
	70	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	2.6	2.614	2.031	1.771	1.636	1.214	1.071	0.89	0.877				
Kent			1.254	1.236	1.132	1.02	0.991	0.876	0.807	0.803	0.652		
Palmer				1.663	1.529	1.307	1.204	1.144	1.031	0.94	0.888	0.85	
Keitt					1.519	1.379	1.199	1.167	1.119	1.069	1.044	1.02	0.88

Appendix C10. Changes in average ascorbic acid (mg/100g) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

Variety	Days after fruit set												
	70	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	11	12.71	14.57	16.3	17.51	19.2	24.9	25.22	26.38				
Kent			4.74	5.2	5.82	6.3	6.75	8.2	8.5	9.46	12.57		
Palmer				24.29	26.31	26.37	26.43	27.43	27.5	35.5	37.83	37.9	
Keitt					18.39	19.5	20.5	21	21.52	23.1	23.8	24.7	25.9

Appendix C11. Changes in average pH during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	2.7	2.775	2.853	2.917	2.991	3.226	3.25	3.356	3.418				
Kent			3.036	3.122	3.231	3.305	3.388	3.418	3.499	3.523	3.559		
Palmer				2.846	2.892	3.197	3.246	3.299	3.313	3.328	3.38	3.44	
Keitt					3.052	3.122	3.229	3.269	3.284	3.31	3.349	3.39	3.42

Appendix C12. Changes in average moisture content (%) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

	Days after fruit set												
Variety	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	88	87.39	87.39	86.35	84.87	84.7	83.55	82.49	82.49				
Kent			86.59	86.56	85	82.87	82.53	82.28	82.23	82.1	82.04		
Palmer				87.28	86.52	85.11	84.95	84.79	84.31	83.89	83.32	82.9	
Keitt					86.64	86.09	86.09	86.01	85.5	85.1	84.26	84.3	83.5

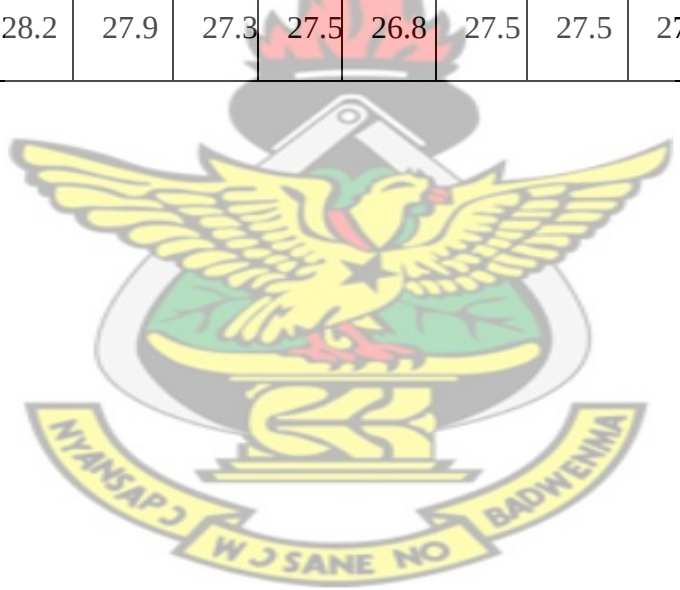
Appendix C13. Changes in average dry matter content (%) during development and maturation of Haden, Kent, Palmer and Keitt mango fruits

Variety	Days after fruit set												
	70	**77**	**84**	**91**	**98**	**105**	**112**	**119**	**126**	**133**	**140**	**147**	**154**
Haden	12	12.61	12.61	13.65	15.13	15.3	16.45	17.51	17.51				
Kent			13.41	13.44	15.13	17.13	17.47	17.72	17.77	17.9	17.96		
Palmer				12.71	13.48	14.89	15.05	15.21	15.69	16.11	16.68	17.1	
Keitt					13.36	13.91	13.91	13.99	14.5	14.9	15.74	15.7	16.5

Appendix D1. Mpehuasem Average Daily Temperature (°C)

Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2007	01	28.0	25.9	24.8	25.7	25.3	25.1	25.4	28.0	28.8	28.0	29.0	27.7	25.8	26.3	26.8	26.0	25.8
2007	02	30.3	30.2	29.8	29.9	29.9	29.6	29.8	29.8	30.3	28.0	30.0	29.0	30.1	30.6	28.9	29.5	29.6
2007	03	29.7	29.8	29.8	29.9	30.1	30.1	30.1	29.6	28.6	29.3	30.0	29.0	30.5	30.1	29.8	26.1	28.0
2007	04	29.6	28.1	29.0	29.3	27.8	27.6	29.1	27.0	28.6	29.3	29.2	29.4	30.0	29.6	29.2	27.4	28.7
2007	05	29.1	29.7	30.0	29.3	29.0	29.5	29.3	29.3	29.3	30.1	28.3	28.3	28.2	28.1	28.6	28.0	29.1
2007	06	28.5	27.4	25.0	27.2	26.5	29.0	24.9	26.3	26.8	27.3	25.5	26.4	26.8	25.6	27.0	26.7	26.1
2007	07	26.3	25.8	25.8	26.6	24.4	25.4	25.3	25.1	25.6	26.3	25.6	26.4	26.8	26.6	27.1	26.8	25.6
2007	08	25.8	25.6	25.6	25.3	24.7	25.3	25.8	25.6	25.8	26.3	25.5	25.9	25.5	25.8	26.0	25.3	26.1
2007	09	23.6	24.7	25.5	25.1	23.9	25.0	26.1	27.0	25.8	26.4	26.5	25.8	26.3	27.3	26.8	26.5	26.7
2007	10	28.3	27.5	27.5	27.2	27.5	26.3	25.8	26.4	25.1	27.0	27.6	27.5	28.0	26.3	27.1	27.5	27.3
2007	11	28.1	27.5	26.5	27.8	27.3	28.0	28.2	27.9	28.1	27.0	27.6	27.9	28.1	28.1	28.4	27.6	27.3
2007	12	28.8	29.0	27.9	28.0	27.0	28.5	27.0	28.2	27.5	28.3	28.1	27.8	27.9	28.6	28.7	28.9	28.5
2008	01	28.8	28.2	28.9	28.3	27.8	28.7	27.9	27.1	25.5	26.5	25.3	28.1	29.0	28.3	28.7	28.6	28.3
2008	02	25.5	28.2	28.4	29.1	29.2	29.6	29.3	29.3	28.3	29.2	29.6	29.8	30.4	29.7	29.2	29.7	30.3
2008	03	29.2	30.0	30.2	30.0	29.9	29.7	28.8	28.8	29.5	27.0	28.8	28.5	28.1	28.9	29.5	29.6	28.9
2008	04	27.0	28.9	27.4	28.8	28.3	27.8	28.9	28.6	29.1	29.3	28.5	28.5	28.9	29.0	28.9	29.4	28.8
2008	05	29.1	29.0	26.3	27.9	28.8	27.4	27.5	28.8	28.0	29.0	28.7	27.3	28.8	27.2	28.7	27.8	27.5
2008	06	28.0	28.3	25.4	28.1	28.4	26.5	26.3	27.9	27.5	27.1	27.7	28.0	25.4	25.0	26.3	26.0	24.0
2008	07	27.0	27.9	26.9	27.2	26.7	26.2	25.8	25.9	26.3	26.0	26.1	26.8	27.0	26.4	26.1	26.3	26.9
2008	08	25.2	26.3	25.7	26.3	26.5	26.0	26.9	25.7	26.3	25.6	26.4	26.5	26.3	26.1	25.3	25.3	25.8
2008	09	26.3	25.4	25.8	25.6	26.0	26.3	27.4	27.2	27.5	27.1	26.4	26.5	26.5	26.0	26.6	26.5	27.1
2008	10	27.5	27.1	27.8	27.8	27.7	27.8	27.3	27.2	28.0	27.3	27.5	27.1	28.1	27.5	28.1	27.3	28.1
2008	11	27.8	28.3	28.2	28.1	28.3	28.3	28.5	29.0	28.1	28.2	27.5	28.1	27.9	27.6	28.5	28.5	29.0
2008	12	28.5	29.0	28.4	28.2	27.8	25.9	26.9	27.6	28.0	28.3	28.5	28.3	28.4	28.6	28.4	28.8	28.2
2009	01	29.2	28.3	27.9	28.3	29.2	28.6	29.1	28.8	27.8	28.0	28.1	29.2	29.0	29.8	29.7	28.3	28.8

2009	02	27.8	28.6	27.8	29.0	29.2	29.1	29.6	29.1	29.0	29.3	29.5	29.2	29.4	29.0	28.1	28.2	29.0
2009	03	29.4	28.4	28.8	29.6	30.1	29.9	29.0	30.3	27.8	29.3	29.5	29.0	28.8	28.7	29.1	27.6	28.5
2009	04	29.0	29.5	29.1	29.7	28.0	29.6	29.8	27.0	28.8	29.5	29.2	29.5	28.3	27.0	28.9	25.0	27.8
2009	05	29.5	28.1	26.2	28.3	26.8	28.0	28.3	27.1	27.6	26.3	27.3	28.8	29.1	29.3	29.0	29.0	29.3
2009	06	29.0	29.3	29.5	28.5	28.6	27.0	28.3	28.8	28.8	28.5	27.0	26.8	26.3	26.5	27.6	25.4	26.1
2009	07	26.4	27.0	27.1	27.5	26.9	26.8	26.8	25.1	25.3	24.9	25.0	25.0	25.5	25.8	26.0	26.3	25.0
2009	08	25.8	25.0	25.0	25.2	25.0	25.5	25.6	26.0	26.1	26.3	26.1	25.8	24.8	26.0	26.0	25.6	26.3
2009	09	26.7	26.6	26.9	26.6	27.0	27.1	27.3	27.4	26.6	26.3	26.8	27.0	27.6	27.1	25.6	25.8	26.7
2009	10	27.6	27.6	28.0	28.2	27.9	27.3	27.5	26.8	27.5	27.5	27.5	27.4	27.1	26.9	27.0	27.2	27.3



Mpehuasem Average Daily Temperature (°C)

Year	Month	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2007	01	26.7	26.3	26.8	27.5	27.9	28.8	29.4	29.0	29.9	29.3	30.0	29.8	29.7	30.1
2007	02	29.8	29.5	28.9	29.6	28.1	28.6	29.5	28.5	29.8	28.5	29.5			
2007	03	29.4	29.6	29.5	30.2	30.0	29.8	28.8	29.1	28.4	27.5	28.6	29.8	30.0	28.5
2007	04	29.4	29.2	29.5	29.8	29.6	28.9	28.5	29.1	29.0	29.3	30.0	29.5	29.4	
2007	05	29.3	29.5	29.6	27.6	27.9	28.3	28.0	28.3	28.5	28.5	27.0	26.6	26.0	27.7
2007	06	26.6	27.2	27.0	26.5	27.2	26.1	26.4	26.7	27.0	26.6	26.8	26.1	26.6	
2007	07	25.5	26.3	26.8	25.1	25.9	26.8	26.8	26.3	25.1	25.5	26.0	25.8	25.4	25.8
2007	08	25.8	26.4	25.7	24.5	25.0	26.0	26.0	26.0	26.7	26.7	25.7	26.8	27.3	26.3
2007	09	27.5	27.2	27.0	26.3	26.8	27.3	26.8	27.0	27.5	27.3	27.7	27.8	27.8	
2007	10	27.5	26.8	27.1	27.7	27.7	28.3	26.2	27.7	27.9	27.5	26.8	27.7	27.3	27.6
2007	11	28.1	28.6	28.5	26.8	27.6	27.5	28.0	28.0	28.7	28.4	28.1	28.7	28.8	
2007	12	28.3	28.5	29.1	28.6	27.9	28.3	27.3	28.3	27.9	28.6	28.5	28.8	29.1	28.3
2008	01	28.1	26.3	26.9	25.4	24.5	24.8	23.8	24.5	24.8	25.8	24.3	25.9	25.3	25.9
2008	02	31.3	29.7	29.8	30.3	30.5	30.5	29.9	29.7	30.0	29.5	29.0	29.8		
2008	03	29.1	28.1	29.1	29.6	29.8	30.0	30.0	30.0	29.3	29.4	29.3	30.0	29.4	27.9
2008	04	27.2	28.6	28.5	29.7	29.8	27.6	29.0	26.3	27.9	28.6	27.6	28.0	28.5	
2008	05	29.2	27.3	27.8	29.0	27.8	28.8	26.1	26.5	27.8	28.1	26.1	26.8	26.6	27.8
2008	06	25.9	26.8	27.3	27.5	27.2	27.3	26.2	26.8	27.0	27.4	27.0	26.5	26.3	
2008	07	26.3	26.7	26.6	27.1	25.2	25.8	26.0	26.3	26.9	25.6	26.2	26.3	26.2	24.8
2008	08	25.5	26.0	26.1	26.8	26.1	26.5	27.0	26.7	26.3	27.3	25.5	24.8	26.2	25.9
2008	09	26.7	25.4	26.8	27.5	27.1	27.0	27.1	27.8	27.3	26.8	26.5	27.5	27.8	
2008	10	27.7	28.1	28.6	27.6	26.6	27.4	28.0	28.4	28.7	28.3	28.0	28.1	27.7	28.6
2008	11	28.8	27.6	28.1	28.4	28.8	28.6	28.7	29.0	28.7	28.8	29.3	29.3	28.4	
2008	12	29.3	28.9	29.3	29.1	29.4	29.6	28.3	28.2	27.8	27.8	28.3	29.0	29.0	29.8
2009	01	29.1	28.9	28.0	24.6	24.4	23.8	23.5	26.1	26.3	28.1	28.6	28.7	28.9	27.0

2009	02	28.0	29.5	29.3	29.0	29.4	29.5	29.5	29.5	28.7	29.0	29.4			
2009	03	29.2	28.8	29.5	28.4	29.1	29.8	29.7	29.7	30.0	30.2	30.0	29.2	29.5	27.6
2009	04	28.3	26.5	28.8	29.7	27.6	28.9	29.6	28.3	28.6	27.4	28.5	29.2	29.8	
2009	05	29.8	30.0	28.6	28.5	29.1	30.0	30.0	29.1	28.8	29.5	29.3	29.1	26.2	27.8
2009	06	27.6	28.0	26.0	26.3	26.8	27.8	26.5	25.8	26.3	25.5	24.8	24.8	26.0	
2009	07	25.8	26.3	26.8	26.0	26.5	26.4	26.6	25.5	25.3	24.3	24.3	25.0	25.2	24.8
2009	08	25.5	26.1	25.5	26.0	26.3	25.9	26.3	24.4	25.3	26.2	26.0	25.5	25.8	26.1
2009	09	26.8	27.3	27.0	26.8	26.6	27.4	27.0	25.9	26.8	27.4	27.3	27.6	27.5	
2009	10	27.8	27.7	27.5	27.8	27.5	27.7	28.3	28.8	28.0	28.3	28.5	27.5	27.5	28.3

Appendix D2. Mpehuasem daily rainfall (mm)

Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2007	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0
2007	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.4	1.1	0.0
2007	04	50.9	0.0	0.0	6.3	29.6	0.0	35.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.3	28.0	0.0	3.3	0.0	0.0	0.0	0.0
2007	06	0.0	42.6	25.3	0.0	0.0	0.0	9.6	0.0	0.0	3.2	0.0	0.0	22.0	0.4	0.0	0.0	0.0
2007	07	0.0	0.0	0.0	85.6	2.2	3.9	27.2	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	19.1	21.5
2007	08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0
2007	09	4.3	1.6	0.0	1.2	6.9	0.0	0.0	0.0	0.0	0.0	5.5	11.2	0.0	0.0	0.0	0.0	0.0
2007	10	0.0	0.0	0.0	0.0	38.0	4.6	8.3	3.8	0.4	0.0	0.0	0.0	15.1	0.0	0.0	0.0	0.0
2007	11	6.2	0.0	0.0	5.8	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	1.0	0.0	1.9	0.0	0.0
2007	12	0.0	0.0	0.0	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0
2008	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	03	0.0	0.0	0.0	0.0	0.0	11.8	0.0	0.0	14.8	0.0	0.0	7.9	0.0	0.0	0.0	0.0	0.0
2008	04	0.0	2.1	0.0	0.0	30.6	0.0	0.0	0.0	0.0	25.3	0.0	0.0	0.0	0.0	0.0	0.0	3.7
2008	05	0.0	61.7	0.0	0.0	16.2	15.7	0.0	8.2	0.0	0.0	4.1	0.0	48.0	0.0	0.0	6.7	0.0
2008	06	0.0	0.0	2.9	0.0	0.0	11.6	0.0	0.0	0.6	5.9	0.0	1.7	15.2	0.8	26.9	9.8	2.0
2008	07	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	08	2.4	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.2
2008	09	0.0	1.3	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1
2008	10	0.0	0.0	0.0	0.0	0.0	25.3	0.0	0.0	0.0	0.2	1.2	0.0	0.0	0.0	0.0	16.2	0.0
2008	11	0.0	0.0	34.5	2.6	0.0	0.0	0.0	0.0	0.0	59.7	0.0	0.0	12.5	0.0	0.0	0.0	0.0
2008	12	0.0	0.0	0.0	0.0	137.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	02	0.0	0.0	0.0	0.0		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0	

2009	03	0.0	3.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	59.3	0.0	17.0	0.4	0.0
2009	05	0.0	9.2	0.0	2.5	0.0	0.0	30.0	0.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	06	0.0	0.0	3.5	0.0	1.1	1.9	0.0	0.0	0.0	6.9	18.9	0.7	39.6	0.0	11.8	0.0	0.0
2009	07	0.3	0.0	0.0	0.0	0.0	0.5	63.0	14.0	10.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.8	0.6	0.0	0.0	0.0	0.9
2009	09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	10	0.0	0.0	0.0	0.0	0.5	0.0	2.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						1.6												0.0

MPEHUASEM DAILY RAINFALL (mm)

Year	Month	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2007	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	02	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
2007	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.7	0.0	0.0	0.0	0.0	0.0
2007	04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2007	05	0.0	0.0	0.0	42.6	0.0	0.0	0.0	0.0	0.0	6.5	0.0	37.1	0.0	0.0
2007	06	0.0	0.0	23.2	1.0	0.0	0.0	8.3	0.0	0.0	0.0	2.0	1.6	0.0	
2007	07	3.6	0.0	26.8	0.0	0.0	0.0	0.0	2.4	6.8	1.3	0.0	0.0	0.0	0.0
2007	08	0.0	0.0	0.0	2.7	0.0	0.0	0.3	1.0	0.0	0.0	0.0	0.0	16.7	45.5
2007	09	0.0	0.0	63.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2007	10	0.0	0.0	0.0	0.0	0.0	23.2	0.1	0.0	0.0	7.6	0.0	0.0	0.0	0.0
2007	11	0.0	0.0	26.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2007	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
2008	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.4	31.9
2008	04	6.4	0.0	0.0	0.0	4.1	0.0	17.8	0.0	0.0	24.1	0.0	3.1	0.0	
2008	05	117.3	0.0	0.0	17.6	0.0	0.0	11.6	0.0	0.0	1.0	26.8	2.6	0.0	0.0
2008	06	0.0	0.0	0.0	0.0	1.0	9.8	0.1	1.4	0.5	0.0	9.6	1.4	0.2	
2008	07	0.0	0.0	0.0	0.0	23.2	0.0	0.0	0.0	10.2	0.3	0.0	0.0	36.2	28.9
2008	08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	50.6	1.0	0.0	0.0
2008	09	3.7	2.2	8.8	0.0	0.8	0.5	0.0	0.0	0.1	0.0	1.4	0.0	0.0	
2008	10	0.0	0.0	0.0	42.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0
2008	11	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	
2008	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	0.0

2009	02	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.8	0.0	0.0	0.0			
2009	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.1	0.0
2009	04	13.9	0.0	0.0	18.2	0.0	0.0	6.0	0.0	12.0	0.0	0.0	0.0	0.0	
2009	05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	1.2	0.0
2009	06	0.0	4.1	0.0	0.0	0.0	14.2	5.2	5.5	2.0	4.1	42.2	1.4	2.3	
2009	07	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.0	0.0	0.0
2009	08	0.0	0.0	0.0	3.9	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0
2009	09	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.3	0.0	0.0	0.3	0.0	0.0	
2009	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	19.0	0.4	0.0	0.0