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Effects of different storage temperature conditions on ripening quality and shelf life of mango (*Mangifera indica*) fruits in Ghana

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ABSTRACT

Purpose: Physiologically matured fruits of Haden, Kent, Palmer, and Keitt mango varieties were used for experiment. The fruits were held at ambient (29-31 °C) and simulated-transit temperature (10-13 °C) conditions. Quality which includes fruit firmness, weight, and spoilage, were assessed and used to determine shelf life of stored fruits. **Research Method**: A Completely Randomized Design with four replications was used. For each of the four varieties, five mango trees were sampled at random in each of the four replications of a mango plantation when fruits were physiologically matured. **Findings**: For the ambient and simulated-transit temperature conditions, Kent (4.09 days and 3.85 days, respectively) and Keitt (4.08 days and 3.92 days, respectively) fruits stored longer. Haden fruits ripened significantly earlier (9.50 days and 3.5 days, respectively) than Keitt fruits (11.01 days and 5 days, respectively). Ripening time was statistically not different among Haden, Kent, and Palmer fruits. Softness, colour, and decay were limiting quality factors for all mango fruits stored at both conditions. Higher shriveling rates were observed in Haden and Palmer fruits with a slight preponderance of the former, for both conditions. Average weight loss was highest (6.50 % and 3.31 %, respectively) for Haden and lowest (4.09 % and 2.34 %, respectively) for Keitt, but generally lower in fruits stored under transit conditions. **Research limitations**: No limitations to report. **Originality/Value**: A single quality attribute cannot be used to express loss of quality of mango fruit over the normal physiological range of mango fruit growth and development.

INTRODUCTION

The Ghanaian mango industry relies heavily on the Florida cultivars (Haden, Kent, Palmer, and Keitt) for fresh and processed mangoes traded locally and for export (FAGE/USAID/TIPCEE, 2007; Abu et al., 2011). There are several other cultivars that are also recognized commercially but are mainly consumed locally. Haden, Kent, Palmer, and Keitt mango cultivars all perform well under the climatic conditions in Ghana. Ghana's mangoes are now largely exported by both air and sea freights. Though air-freight is more expensive, it gets fruits to their destination markets faster and therefore more likely to be in good quality. However, to be competitive on the international market considering the high air freight charges (between $ 0.70/kg and $ 1.15/kg; Takyi, 2007), Ghana must consider using sea freight for mango export and thus benefit from cheaper freight rates and the opportunities to move bigger volumes to the market.

Domestic and international trade of fresh mango fruit 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). Mangoes must be consumed soon after harvest. In many producing countries, there is an annual glut followed by scarcity. For all of these reasons, mangoes are still considered as luxurious, expensive items in the markets in many industrialised countries (Litz, 2003).

Most of the postharvest technologies for mango fruits have been developed for controlling diseases and insects and for protection against injury during packaging and transport (Tridjaja & Mahendra, 2002). Kitigawa (1994) earlier on reported that mango fruits have poor storage qualities and storage methods have been characterized by variable results and the occurrence of physiological disorders, but technologies for longer term storage such as controlled or modified atmospheres have not been applied successfully to the fruit. Fruit stored under modified atmospheres often show undesirable characteristics, i.e. poor color and eating quality, and the presence of undesirable flavors. But some studies have shown clear evidence that mango ripening can be delayed satisfactorily (Schouten, 2005). Clearly, other alternatives are, therefore, required to delay ripening and subsequent softening.

Temperature is the most important environmental factor that influences the deterioration rate of harvested fruits and vegetables. According to Kader and Mitcham (2008), for each increase of 10 ^{o}C above optimum, the rate of deterioration increases by two- to three-fold and that exposure to undesirable temperatures results in many physiological disorders. Temperature also influences how ethylene, reduced oxygen, and elevated carbon dioxide as well as spore germination and growth rate of pathogens affect the commodity (Kader & Mitcham, 2008).

All the same, any precautionary measures (highly recommended) toward quality maintenance may be inadequate and even fruitless if the quality factors (in relation to storage life and ripening quality of these fruits at ambient and transit temperatures) that limit mango marketability are unknown. In this regard, the prerequisite of remedial development is to assess the ripening condition and trend of mango fruit storage to enhance knowledge on quality factors that limit mango marketability. Thus, the objective of the study was to determine the sensitivity of Haden, Kent, Palmer, and Keitt mango fruits to ambient and transit temperature storage conditions, and consequently, the development of physiological disorders.

MATERIALS AND METHODS

Experimental site and plant materials

Laboratory studies were conducted to determine the sensitivity of the fruits of four mango varieties (Haden, Kent, Palmer, and Keitt) to ambient and transit temperature storage conditions and the consequent development of physiological disorders involved in quality deterioration. The study was carried out at the bio-chemistry laboratory of Food Research Institute, Legon, Accra. The experimental period consisted of two major (April to July) and two minor (December to February) seasons. The experiment was conducted following completely randomized design with four replications.

Sampling

For each of the four varieties, five mango trees were sampled at random in each of the four replications of a mango plantation (Prudent Export and Import Company Ltd mango plantation at Ayenya, situated in the Somanya-Dodowa mango production zone of the Dangme West District of Greater Accra Region) when fruits were physiologically matured at 112, 126, 133, and 140 days after fruit-set for Haden, Kent, Palmer, and Keitt, respectively (Abu, 2010).

Shelf life at transit temperature conditions

For shelf life tests under transit temperature (10-13 ^{o}C) conditions, corrugated fiber board carton packaged fruits (9 cartons; one carton each of counts 4 to 12) of each of the four varieties were first 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 fruits usually stay in transit during shipment, i.e, from Ghana to Europe (Abu, 2010). After the simulation period fruits were transferred to the ripening chamber (similar to ambient conditions) for ripening to be effected.

Shelf life at ambient temperature conditions

For shelf life tests under ambient temperature (29-31 ^{o}C) conditions, fruits were randomly picked from each variety and put into open plastic containers on a laboratory bench in different rooms of the laboratory. A sample for each variety consisted of 9 cartons; one carton each of counts 4 to 12 to justify comparison under 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. These was averaged out and recorded as shelf life of the fruits in the particular variety (Abu, 2010).

Ripening, weight loss, and spoilage test

Days taken to ripen (eat-ripeness stage) at ambient condition (29-31 ^{o}C, 90-95% RH), weight loss (%) during ripening, and days taken to spoil after ripening i.e. at sales/fresh market conditions (20-22 ^{o}C, 85-90% RH) regarding fruits due for assessment under ambient conditions were determined. These same parameters were determined for fruits due for assessment under transit conditions, but only after the fruits were simulated for transit temperature (10-13 ^{o}C) conditions for twenty-one (21) days (Abu, 2010).

Days taken to ripen from physiological maturity:

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 which could serve as a useful indicator of maturity/ripening (Dadzie & Orchard, 1997), on fortnightly basis.

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 color change. Where the starch in the pulp changed to sugar (during maturation/ripening), no iodine reaction occurred and the area stained a pale tan color.
d) Assessment of the starch pattern of each fruit was done by comparing the stained cut surface with a mango maturation/ripening chart (Dadzie & Orchard, 1997).

Weight loss (%) when ripe:

This was computed considering difference in weight before and after ripening.

Days taken to spoil/damage factors after ripening:

This was computed as outlined and defined under "Visual determination of fruit quality", below.

Fruit firmness

A computerized texture analyzer (TA-XT2) was used to determine fruit firmness (the plateau of the force which occurs after the bio-yield point which is an indication of the underlying flesh firmness of the fruit) and 'bio-yield point' (when the probe punctures through the skin of the mango fruit causing irreversible damage) of the mangoes by penetration. Fruit firmness and 'bio-yield point' are indicators of mango fruit skin and the underlying flesh firmness of the fruit, respectively.

Here, twenty sound freshly harvested physiologically matured fruits of each of the four varieties were used for the tests. Two readings were taken per fruit and averaged for recording using the computerized texture analyzer. Once tests have been performed, values of parameters for sample analysis were automatically obtained by a MACRO, program of the software of the Texture Analyzer (Rosenthal, 2010). The average measurement of the twenty fruits represented the value of the particular fruit quality attribute parameter of the variety assessed at a time. Tests were carried out at different times for the different varieties depending upon their physiological maturity stages.

Visual determination of fruit quality

A typical picking and shipping schedule for mango fruits consigned by sea and by air to the EU from Ghana (Abu, 2010), was also consulted in relation to sea and air freight. Visual determinations were made in relation to the development of physiological disorders such as fruit softening, changes in fruit colour, development of decay, and shriveling, by regular visual observation/inspection. This was done as follows:

Sound freshly harvested physiologically mature mango fruits of the four varieties were stored at both ambient and transit temperature conditions for the shelf life assessment. Tests were carried out at different times for the different varieties depending upon their physiological maturity stages.

For storage tests under transit temperature (10 ^{o}C) conditions, corrugated fibre board carton packaged fruits (nine 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 °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 each fruit took to show any sign of damage was recorded as the shelf life and the affected fruit(s) discarded from the lot up to the last fruit. These was averaged out 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 colored, or sound.

The slightly damaged were further grouped into three, comprising: slightly physiologically damaged (wrinkles, shrinkage, and softening due to wilting and ripening); slightly pathologically damaged (sunken spots, rotting, mycelia growth, and disease symptoms due to bacterial and fungal infections); and slightly mechanically damaged (cuts, punctures, scuffs, and abrasions due to open wounds and, bruises due to impacts, compressions, and vibrations).

Undesirably colored fruits were those with poor/abnormal color.

Sound fruits were those free from any damages.

Statistical analysis

All data were analyzed using the Analysis of Variance (ANOVA) technique (Snedecor & Cochran, 1980) with the GENSTAT statistical program. Least Significant Difference (LSD) at 5% probability was used to determine treatment differences among varieties. Separate analyses were carried out with the data for each of the seasonal trials. The errors for these ANOVAS were tested for homogeneity of variances (Snedecor & Cochran, 1980) and found to be statistically not different at $p>0.05$, so the results for the seasonal experiments were pooled for analysis.

RESULTS

Ripening quality at ambient and transit temperatures

Fruit of Haden, Kent, Palmer, and Keitt ripened (eat-ripeness stage) in 9.5, 10.5, 10.0, and 11.0 days, respectively, under ambient conditions (29 to 31 °C and 90-95% RH) after removal of field heat i.e. by controlling the fruit temperature at 20-25 °C before the initiation of the ripening process. Days to ripening was not significantly different among Haden, Kent, and Palmer fruits but was statistically different ($p<0.05$) between Keitt and Haden (Table 1).

After exposure to transit conditions for 21 days, and then ripened under ambient conditions (29 to 31 °C and 90-95% RH), fruits of Haden, Kent, Palmer, and Keitt ripened (eat-ripeness stage) in 3.5, 4.5, 4.0, and 5.0 days, respectively; indicating the same trend in ripening time as it were for ambient conditions, but much faster.

Shelf life

Generally, under ambient conditions, there was a slow development of unpleasant fruit characteristics (fruit softening, changes in fruit color, development of decay, and shriveling) as compared to transit conditions. Under ambient and transit conditions, spoilage was observed much earlier in Haden (3.15 days for ambient and 2.91 days for transit) and Palmer (3.16 days for ambient and 2.87 days for transit) fruits than in Kent (4.09 days for ambient and 3.85 days for transit) and Keitt (4.08 days for ambient and 3.92 days for transit) fruits as in Table 1. This resulted to limiting the shelf lives of the fruits to 3.15, 4.09, 3.16, and 4.08

days for Haden, Kent, Palmer, and Keitt respectively (Table 1; days to spoilage) under ambient conditions; and to 2.91, 3.85, 2.87, and 3.92 days for Haden, Kent, Palmer, and Keitt respectively (Table 1; days to spoilage) under transit conditions.

Signs of decay in Haden and Palmer fruits became visible after 3 days at 20-22 ^{o}C, and for Kent and Keitt varieties, after 4 days at 20-22 ^{o}C (Table 1). Fruit pre-exposed to transit conditions (10-13 ^{o}C; 85 to 90% RH), ripened (29-31 ^{o}C; 90 to 95% RH), and stored at sales/fresh market conditions (20-22 ^{o}C and 85-90% RH) did not suffer any chilling injury.

Table 1. Days to ripen, weight loss, days to spoilage, and shelf life (days) of Haden, Kent, Palmer, and Keitt Mango fruits

Variety	Variables and temperature conditions						
	Ambient conditions			Transit conditions			
	Days to ripen (eat-ripeness stage; 29-31 ^{o}C, 90–95 % RH) from physiological maturity	Weight loss (%) when ripe	Days to spoilage (under sales/fresh market conditions; 20-22 ^{o}C, 85-90 % RH) after ripening	Days stored under transit conditions (10-13 ^{o}C, 85-90 % RH) at physiological maturity.	Days to ripen (eat-ripeness stage; 29-31 ^{o}C, 90-95 % RH) from physiological maturity	Weight loss (%) when ripe	Days to spoilage (under sales/fresh market conditions; 20-22 ^{o}C, 85-90 % RH) after ripening
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 2. Fruit bio-yield point and firmness index (N) of Haden, Kent, Palmer, and Keitt mango fruits when physiologically matured

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 3. Typical picking and shipping schedule for mango fruits consigned by sea and by air to the European Union from Ghana

Operation	Time (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

Weight loss

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.

Fruit bio-yield point and fruit firmness

Fruit bio-yield point and fruit flesh firmness index values (N) at physiological maturity are presented in Table 2. Values of fruit flesh firmness were higher than values of bio-yield point in all the varieties (Table 2). Significant difference ($p<0.05$) in fruit flesh firmness occurred only between Keitt (highest - 194.98 N) and Haden (lowest - 145.30 N). Keitt and Kent fruits were significantly not different ($p>0.05$) in their flesh firmness; this was the same for Haden and Palmer fruits. Significant difference ($p<0.05$) in force for the bio-yield point occurred between Keitt (highest - 122.91 N) and Haden (lowest - 93.12 N). Bio-yield point test for Palmer recorded a significantly higher force when compared with that of Haden. However, differences in force for the bio-yield point were not significant ($p>0.05$) between Kent and Haden (Table 2).

Typical picking and shipping schedule

A typical picking and shipping schedule for mango fruits consigned by sea and by air to the European Union from Ghana is presented in Table 3.

DISCUSSIONS

Ripening quality of fruits at ambient and transit temperatures

Days to ripening were significantly different between Keitt and Haden fruits but similar for three varieties (Haden, Kent, and Palmer). The differences in ripening time among the different varieties could be attributable to their gene constitutions (Rathore et al., 2007) whiles the significant difference in ripening time between Keitt and Haden fruits could be due to the comparatively vast difference in their physiological maturity periods (Abu, 2010). An earlier report by Lakshminarayana (1980) indicated that in a climacteric fruit, such as mango, the fruit is not considered to be of desired eating quality at the time it initially becomes mature, but requires a ripening period (typically 8 to 10 days at about 25 ^{o}C) before it achieves the taste and texture desired at the time of consumption.

The trend for ripening under transit conditions was similar to that of ambient temperature conditions but occurred rather earlier. This has been explained in terms of the degenerative changes in the chemical constituents as well as of the skin (Rodeiro et al., 2006), resulting from both respiration and transpiration sources (Rocha Ribeiro et al., 2007) as maturation progressed in transit.

Shelf life

Under ambient temperature conditions fruits took longer time to lose their quality characteristics as compared to fruits under transit conditions. Under both conditions the results suggest that Haden and Palmer were fast to deteriorate than Kent and Keitt. Softening or changes in mango fruit texture during ripening have been previously attributed to the degradation of pectic compounds by pectic enzymes, which activity significantly increases as the fruit ripens (Barreto et al., 2008). Shriveling of the mango fruit skin did not increase above an objectionable rating during storage, regardless of the storage temperature.

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 or fresh market storage conditions (20-22 °C, 85-90% RH) (Krishnamurthy, 1988; Reddy & Raju, 1988; Mitra, 1997; Yahia, 1999; Mahayothee et al., 2002; Litz, 2003; Cecilia et al., 2007). Although softness was the first quality factor to reach the limiting quality rate, color 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 3.15, 4.09, 3.16, and 4.08 days respectively. Softening of the fruit was likewise the major quality limiting factor for the fruits of the mango varieties stored at the sale or fresh market storage conditions after ripening (prior to simulation at transit conditions) and reduced the shelf lives of the fruits to 2.91, 3.85, 2.87, and 3.92 days, respectively.

Weight loss

At ambient and transit temperatures, weight loss was highest (6.50%) in Haden and lowest (4.09%) in Keitt and the observed values corroborate with the values previously reported by other authors (Krishnamurthy, 1988; Reddy & Raju 1988; Mahayothee et al., 2002; Schouten, 2005). Cecilia et al. (2007) reported 3.9% and 3.7% weight losses in "Tommy Atkins" and "Palmer" respectively, stored at 20 °C for 5 days. The authors also reported that the maximum weight loss value obtained for "Tommy Atkins" mango stored for 18 days at 12 °C (7.8%) corresponded to a shriveling rate of only 4.7, which is well below the maximum acceptable rate before the visual quality of the fruit becomes objectionable. Cecilia et al. (2007), however, indicated that the maximum weight loss obtained for "Palmer" mango (6.5%) after 14 days at 12 °C corresponded to a shriveling rate of 3.5, which was close to the maximum acceptable before the fruit become unacceptable for sale. It was therefore concluded that a weight loss between 9 and 7% may be suggested as a maximum acceptable before "Tommy Atkins" or "Palmer" mangoes become unacceptable for sale (Cecilia et al., 2007). The values of weight loss obtained in this study do not seem to be crucial in terms of development of shriveling in Haden, Kent, Palmer, and Keitt mangoes when compared with the findings of Reddy and Raju (1988), and with the findings and conclusion of Cecilia et al. (2007).

Fresh fruits are living tissues and are subject to continuous change after harvest. Thus the weight losses and other objectionable characteristics the fruits developed during storage is a response to; the loss of stored food reserves in the commodity during respiration which translated to loss of salable dry weight and hastening of senescence as the reserves which provide energy for maintaining the living status of the commodity are exhausted; transpiration or water loss since it results in not only direct quantitative losses (loss of salable weight), but also causes losses in appearance (due to wilting and shriveling), textural quality (softening, juiciness, flaccidity, limpness, and loss of crispness), and nutritional quality; compositional changes (loss of chlorophyll, development of carotenoids, development and changes in anthocyanins, changes in carbohydrates, and changes in organic acids) which may continue after harvest and could be desirable or undesirable; ethylene production or ethylene effects that could be desirable or undesirable; and atmospheric composition that can either delay or accelerate deterioration of fresh horticultural crops (Kader et al., 1985; Kader, 2008; Kader & Mitcham, 2008). Deterioration set in much earlier in the early maturing varieties (Haden and Palmer) most probably because they are longer rapidly respiring commodities (Abu, 2010).

Fruit firmness, picking, and shipping schedule

Dadzie and Orchard (1997) indicated that the texture or firmness of the pulp of fruits is an important postharvest attribute that could be used as a maturity or ripening index which could also facilitate comparison of the state of softening of fruits and vegetables. According to Abu (2010), assessment of firmness is important in the evaluation of fruit's susceptibility to physical or mechanical damage during postharvest handling. In this study softening has been found to be the major quality limiting factor for Haden, Kent, Palmer, and Keitt mango fruits during storage, as it reduced their shelf lives to 3.15, 4.09, 3.16, and 4.08 days respectively. These analyses show that Kent and Keitt fruits store better than Haden and Palmer fruits under both ambient and transit conditions and are therefore recommendable for sea freight or for longer distances where relatively much time is spent before delivery, while Haden and Palmer fruits are recommendable for air freight. The sea freight operations take much longer time (20-27 days), almost three to four times that of air freight (about 6 days).

CONCLUSION

Generally, ripening and subsequent deterioration occurred earlier in fruits that were simulated for transit conditions. Days to ripening were significantly different between Keitt and Haden fruits but similar for Haden, Kent, and Palmer fruits. The trend for ripening under transit conditions was similar to that of ambient temperature conditions but occurred rather earlier.

Under ambient temperature conditions fruits took longer time to lose their quality characteristics as compared to fruits under transit conditions. Under both conditions, deterioration set in much earlier in the early maturing varieties (Haden and Palmer) than the late maturing varieties (Kent and Keitt); weight loss was highest in Haden and lowest in Keitt; and softening was found to be the major quality limiting factor for all the varieties under study during storage. These analyses show that Kent and Keitt fruits store better than Haden and Palmer fruits under both ambient and transit conditions and are therefore recommendable for sea freight or for longer distances where relatively much time is spent before delivery, while Haden and Palmer fruits are recommendable for air freight. The attributes obtained from the quality evaluations for the different temperature regimes showed that a single quality attribute cannot be used to express loss of quality of mango fruit over the normal physiological range of mango fruit growth and development.

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Conflict of interest
The authors have no conflict of interest to report.

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