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EFFECTS OF DIFFERENT TEMPERATURE TREATMENT ON QUALITY AND SHELF-LIFE OF SOLO PAPAYA (*Carica papaya* L.) FRUITS

BY

SAMUEL KOFI NGNAMBALA

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EFFECTS OF DIFFERENT TEMPERATURE TREATMENT ON QUALITY AND SHELF-LIFE OF SOLO PAPAYA (*Carica papaya* L.) FRUITS

A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc. POSTHARVEST TECHNOLOGY) DEGREE.

BY

SAMUEL KOFI NGNAMBALA

APRIL, 2013

DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this project is the result of my own research and it has not been not been submitted either in part or whole for any other degree elsewhere.

Signature……..... .....……

SAMUEL KOFI NGNAMBALA DATE

(STUDENT)

Signature…….. .....……

DR. FRANCIS APPIAH DATE

(SUPERVISOR)

Signature…….. .....……

MR. P. Y. ADJEI DATE

(SUPERVISOR)

Signature…….. .....……

DR. BEN K. BANFUL DATE

(HEAD OF DEPARTMENT)

DEDICATIONS

I dedicate this piece of work to my wife Lucy Abena Nyaaba and children Janet, Caroline and Kelvin.

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ABSTRACT

An experiment was conducted to assess the effects of heat treatment on the quality and shelf-life of solo papaya fruits. The experiment was conducted at the laboratory of the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi in August, 2011.Mature green fruits were obtained from papaya farms in Darbaa in the Atwima Nwabiagya District in the Ashanti Region. A Completely Randomised Design with three replications was used for the study. Three different treatments namely (i) T_{40} - fruits exposed to 40^{o}C for 20 minutes, (ii) T_{50} - fruits exposed to 50^{o}C for 20 minutes and a control (no exposure to high temperature) and stored under ambient condition. From the results, T_{40} recorded the highest cumulative weight loss of 11.72%10 days in storage. Significant differences in total soluble solid ($P<0.05$) were observed among the treatments with $T_{40}$and T_{50}having total soluble solids (TSS)of 8.5^{o}Brix at colour stage 5 respectively. Significant differences in total titratable acidity (TTA) were recorded among the treatments with T_{40} and T_{50} fruits recording the highest TTA of 0.73at colour stage 2 respectively. Treatment T_{50} fruits recorded the longest shelf life of 8 days, followed by those of T_{40} (7 days) and control (6 days). The study has shown that heat treating Solo Papaya fruits at 50^{o}C for 20 minutes is sufficient to delay ripening and extend shelf-life. This would allow sufficient time for transportation and marketing.

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CHAPTER ONE

1.0 INTRODUCTION

Papaya also known as pawpaw is a native of tropical America and is now grown in most tropical countries.It is a popular breakfast food and serves to make fruit salad and all kinds of dessert. The fruit contains a high amount of vitamins A and C and is also considered as a laxative. It belongs to the family Caricaceae. Several species of the genus Carica are cultivated. *Carica candamarcensis*, *Carica erythrocarpa, Caricaquercifoli* arethe only useful species cultivated extensively in different parts of the tropics (Samson, 1982).

Thereare a number of named varieties which are difficult to maintain. Some varieties which are commonly grown include, Bluester, Sunrise Graham, Betty, Fairchid, Kissimmee and Hortus Gold (Abutiate, 1995). The ripe fruit is consumed fresh for its taste ,for vitamin and mineral content and for its digestive properties. It can also be prepared in fruit salads, jams, purees, juices and is incorporated into various preparations .The seeds sap and flowers have vermifuge properties. Infusions of the flower are febrifuge and expectorant. The roots can be prepared as a vegetable as a substitute for other vegetables. The young leaves are eaten as a vegetable in certain dishes in Asia and the green fruit is grated in salads .For its pharmaceutical use, papain and papain – containing substances have been used in treatment of various ailments affecting the human body.

The papaya plant, as grown from seeds may have one of several flower formations. There is the pure male (staminate) plant with all its flowers of this form, and the pure female (pistillate) plant with all its flowers of this one kind. There is also the plant with complete or bisexual (Hermaphrodite) flowers, which is the most desirable form for fruiting.

Pawpaw can be cultivated by direct seeding or nursing and transplanting when the seedlings are due. The seeds can be nursed in a seed bed where uniform and vigorous seedlings are produced or in container nursery such as in polythene bags. Nursing seeds and transplanting option is the best as the nature of the seedlings are observed before transplanting.

Pawpaw has significant potentials as a fruit crop. During ripening, loss of firmness is extremely rapid, and thistrait may be the biggest obstacle to the development of a broader market as handling without injury is difficult. Cold storage of pawpaw seems limited to 4 weeks at 4 degrees Celsius (Archbold and Pomper, 2003).Cold (storage for longer period than 4 weeks causes the development of chiling injury symptoms such as black discoloration, rapid loss of firmness, impaired respiration, tissue acidification and a decrease in antioxidant content (Archbold and Pomper,2003). In the more cold storage may also be limited to few people, households and for other commercial purposes. In most cases, papaya fruits are sold on the market under the sun for days. The fruits, if not all sold, are stored at room temperature and sold thereafter.

Cold storage is the most common technique used to extend the shelf life of pawpaw fruits. It has been shown that above freezing, every ten degree Celsius decrease in storage temperature shows fruit deterioration and overall quality loss by at least two fold. Fruit cooling decreases respiration rate and fruit softening, minimizes water loss, inhibits ethylene synthesis and retard pathogen development and fruit decay (Lurie, 2003; Johnston *et al*, 2002). Most temperate fruits are best stored near zero degrees Celsius. However, peaches stored longer than eight weeks between minus one and one degree Celsius, often develop chilling injury symptoms such as internal browning and woolly texture (Crisoto *et al*.,1995). On the other hand, tropical and subtropical fruits should be stored between six and thirteen degrees Celsius depending on species and cultivars. For this latter group, storage temperatures below the optimal range can cause chilling injury (Lurie, 2003). Cold injury development depends on the length of exposure, to temperature, cultivar, Pre harvest cultural practices and ripening stage of fruit. Pawpaw fruit can be stored for one month at 4 degree Celsius with little loss in quality (Archbold *et al*., 2003). Cold storage delayed the ripening process of both ripe and unripe fruit and significantly delayed the loss of firmness. However, upon removal from cold storage, firmness declined rapidly accompanied by a rise in ethylene production and respiration. Observations also indicated that longer storage periods results in external discoloration of the fruit. When fruits are exposed to low temperature, they exhibit a decreased sugar and phenolic metabolism (Merodio and De La Plaza, 1997). Unstructured analysis indicated that starch degradation, membrane structure and cell disassembly were dramatically impaired (Merodio and De La Plaza, 1997).

As a result of the problems associated with cold storage, it has become necessary to find other ways of extending the shelf life of pawpaw fruit. Exposing the pawpaw fruit to high temperature is another way of retarding the ripening process thereby extending the shelf life. However, the effect of the high temperatures on the quality of the fruits needs to be investigated hence the present study.

The objective of this study was to assess the effects of heat treatment on the quality and shelf-life of solo papaya fruits.

The specific objectives were therefore, to determine

- The characteristic colour stages for the Solo papaya variety grown in Ghana.
- The effect of the heat treatment on the quality of the solo papaya fruits.
- The effects of heat treatment on shelf life of the solo papaya variety.
- Relations between the chemical properties of Solo papaya fruits.

Based on the objectives the following research questions were asked:

1. Can pre-ripening heat treatment be used to delay ripening in Solo papaya in order to allow for sufficient time for transportation, export or sales?
2. What are the characteristic colour stages for Solo papaya fruits grown in Ghana?
3. What are the chemical properties accompanying each colour stage of the Solo papaya fruits?
4. How does heat treatment affect the chemical properties of Solo papaya fruits during ripening?

5. Are there significant correlations between the chemical attributes of the Solo papaya fruits?

CHAPTER TWO

LITERATURE REVIEW

2.1 TAXONOMY, ORIGIN AND DISTRIBUTION

Cultivated papaya, *Carica papaya* L., sometimes known as pawpaw (or papaw), is a fast-growing tree-like herbaceous plant in the family Caricaceae. Red and pink-fleshed cultivars are often known as 'papaya' to distinguish them from the yellow-fleshed fruits, known as 'paw paw', but both of these common names refer to the same plant species. Irrespective of its flesh colour, *Carica papaya* is generally known as 'papaya' in other countries. In some areas, an unrelated plant, *Asiminia triloba* (Annonaceae), native to north America, is also called paw paw (Nakasone and Paull, 1998).

Until recently, the Caricaceae was thought to comprise 31 species in three genera (namely Carica, Jacaratia and Jarilla) from tropical America and one genus, Cylicomorpha, from equatorial Africa (Nakasone and Paull, 1998). However, a recent taxonomic revision proposed that some species formerly assigned to Carica were more appropriately classified in the genus Vasconcella (Badillo, 2002). Accordingly, the family's classification has been revised to comprise Cylicomorpha and five South and Central American genera (Carica, Jacaratia, Jarilla, Horovitzia and Vasconcella) (Badillo, 1971), with *Carica papaya* the only species within the genus Carica (Badillo, 2002).

Although opinions differ on the origin of *Carica papaya* in tropical America (Garrett, 1995), it is likely that *C. papaya* originates from the lowlands of eastern Central

America, from Mexico to Panama (Nakasone & Paull, 1998). Its seeds were distributed to the Carribean and south-east Asia during Spanish exploration in the 16th Century, from where it spread rapidly to India, the Pacific and Africa (Villegas, 1997).Papaya is now grown in all tropical countries and many sub-tropical regions of the world. It was introduced as a horticultural crop for fruit production (Garrett, 1995)

2.1.2 Morphology of Papaya

Carica papaya is a soft-wooded perennial plant that lives for about 5-10 years, although commercial plantations are usually replanted sooner (Chay-Prove *et al*. 2000). Papayas normally grow as single-stemmed trees with a crown of large palmate leaves emerging from the apex of the trunk, but trees may become multi-stemmed when damaged (Villegas, 1997). The soft, hollow, cylindrical trunk ranges from 30 cm diameter at the base to about 5 cm diameter at the crown. Under optimal conditions, trees can reach 8-10 metres in height but in cultivation, they are usually destroyed when they reach heights that make harvesting of fruit difficult (Villegas, 1997).

Papaya flowers are born on inflorescences which appear in the axils of the leaves. Female flowers are held close against the stem as single flowers or in clusters of 2-3 (Chay-Prove *et al*. 2000). Male flowers are smaller and more numerous and are born on 60-90 cm long pendulous inflorescences (Nakasone & Paul,l 1998). Bisexual flowers are intermediate between the two unisexual forms (Nakasone & Paull, 1998). The functional gender of flowers can be altered or reversed, depending on environmental conditions, particularly temperature.

Fruits are ready to harvest five to six months after flowering, which occurs five to eight months after seed germination (Chay-Prove *et al*. 2000). The fruits range in size from 7-30 cm long and vary in mass from about 250 to 3000 g (OECD, 2003). Fruit from female trees are spherical whereas the shape of fruit from bisexual trees is affected by environmental factors, particularly temperature, that modify floral morphology during early development of the inflorescence (Nakasone & Paull, 1998).

Ripe papaya fruits have smooth, thin yellow-orange coloured skin. Depending on the cultivar, flesh thickness varies from 1.5 to 4 cm (Nakasone & Paull, 1998) and flesh colour may be pale yellowish to red (Villegas ,1997; Nakasone & Paull ,1998). Mature fruits contain numerous grey-black spherical seeds 5 mm in diameter (Villegas ,1997).

2.1.3 Cultivation of Papaya

Commercial plantings of *C. papaya* occur throughout the tropical and sub-tropical regions of the world accounting for more than 95% of production world-wide (Garrett, 1995). In the absence of irrigation, fruit production is optimal in areas with a minimum monthly rainfall of about 100 mm, minimum relative humidity of 66% (Nakasone & Paull 1998) and where temperatures range between 21 and 33º C (Villegas, 1997; Nakasone & Paull, 1998; OECD, 2003). Temperatures below 12-14º C strongly retard fruit maturation and adversely affect fruit production (Nakasone & Paull, 1998). Papaya is extremely sensitive to frost, which can kill the plant.

2.1.4 Cultivars of Papaya

There are several varieties of papaya developed for different markets or consumers.

i. ***Kapoho Solo*** is a pear shaped, high sugar papaya with a greenish-yellow skin that turns yellow as the fruit ripens. The deep-yellow flesh has a pleasant peach-melon taste.

ii. ***Rainbow*** is genetically engineered papaya resistant to the ringspot virus disease. The fruit has greenish-yellow skin that turns yellow as the fruit ripens with golden-yellow flesh. Initial consumer testing has confirmed the extreme popularity of this golden yellow flesh variety.

iii. ***Sunrise/ SunUp***is popular by its nickname "strawberry" papaya. Sunrise has a freckled greenish-yellow skin that turns yellow as the fruit ripens. It has a juicy, dramatic red-orange colour flesh. SunUp is a genetically engineered papaya of the red-flesh variety that is resistant to the ringspot virus disease.

iv. ***Kamlya / Lala Gold*** is a rounder, larger fruit than the other varieties. It has a thin, greenish-yellow skin with thick orange flesh. It is ripe when it yields to finger pressure and not on skin colour. It is grown for the local market. Lala Gold is the genetically engineered papaya of the Kamlya variety that is resistant to the ringspot virus disease.

2.1.5 Uses of Papaya

Economically, *Carica papaya* is the most important species within the Caricaceae, being cultivated widely for consumption as a fresh fruit and for use in drinks, jams, candies and as dried and crystallised fruit (Villegas, 1997). Green fruit and the leaves and flowers may also be used as a cooked vegetable (Watson, 1997). Nutritionally, papaya

is a good source of calcium and an excellent source of vitamins A and C (Nakasone & Paull, 1998). The vitamin A and C content of one medium papaya fruit approaches or exceeds USDA minimum daily requirements for adults (OECD, 2003). The fruit of some species of Vasconcella may be used as a food source, particularly in some regions of South and Central America, but such usage is relatively limited.

Papaya also has several industrial uses. Biochemically, its leaves and fruit are complex, producing several proteins and alkaloids with important pharmaceutical and industrial applications (El Moussaoui *et al*., 2001). Of these, however, papain, is a particularly important proteolytic enzyme that is produced in the milky latex of green, unripe papaya fruits. The latex is harvested by scarifying the green skin to induce latex flow, which is allowed to dry before collection for processing (Nakasone and Paull, 1998). Evolutionarily, papain may be associated with protection from frugivorous predators and herbivores (El Moussaoui *et al*., 2001). Commercially, however, papain has varied industrial uses in the beverage, food and pharmaceutical industries including the production of chewing gums, in chill-proofing beer, tenderising meat, drug preparations for various digestive ailments and the treatment of gangrenous wounds. Papain has also been used in the textiles industry, for degumming silk and for softening wool (Villegas, 1997) and in the cosmetics industry, in soaps and shampoo.

2.2 POST HARVEST QUALITY OF FRUIT

Harvested fruit are still living organs; hence, even though they are detached from the plant, they continue to exchange gas with and loose water to the environment. Since the

connection with the mother plant has been cut, the respiratory substrate and water losses that occur cause permanent changes in fruit composition (Burdon, 1997).

Many pre-harvest and post-harvest factors such as genetics, cultural practices, maturity at harvest and post-harvest handling techniques influence composition and quality of fruit by the time it reaches the consumer. However, in contrast to pre-harvest factors, post-harvest treatments cannot improve fruit quality above that of a fruit ripened on the plant, but rather only slow down the deterioration rate (Burdon, 1997; Kader, 2002). This is true of both climacteric and non-climacteric fruits. Generally, the higher the respiration rate of a fruit, the shorter the post-harvest shelf life (Kader, 2002). Once harvested, keeping fruit within their optimal range of temperature and relative humidity are the most important factors in maintaining fruit quality and minimizing postharvest loss (Kader, 2002; Crisosto *et al.*, 1995).

2.3 MATURITY INDEX FOR FRUIT

Maturity at harvest is the factor that mostly influence final fruit quality and fruit storage life. Fruit harvested immature are more subject to shriveling, mechanical damage and, when they do ripen, normally have inferior quality than fruit harvested mature or ripe (Crisosto *et al*., 1995; Kader, 2002).

On the other hand, overripe fruit has a very short shelf life and become too soft and mealy shortly after harvest. Generally fruitpicked too early or too late are more likely to develop physiological disorders and have shorter storage life than fruit harvested mature.

‘Mature’ and ‘ripe’ are two distinct terms that refer to different stages of fruitdevelopment (Reid, 2002).

To plant physiologists, ’maturity’ identifies the fruit stage which will ensure proper ripening after harvest. Most postharvest technologists will define ‘mature’ as a sufficient stage of development that will develop at least the minimum acceptable quality after harvesting and postharvest handling. In contrast, horticultural maturity has been defined as the stage of development at which a plant or plant part possesses the prerequisites for consumption. Based on the characteristics of the product, be it a sprout, vegetative tissue, flower or fruit, a given commodity may be horticulturally mature at any stage of development. Due to the fact that the stage of fruit ripening and the time of harvest determine the quality of the marketed fruit, many maturity indices have been developed with the purpose of predicting or identifying the best time of harvest.

Despite the fact that fruit that ripen on the tree have the best quality, many fruit are harvested at a physiologically mature but not fully ripe stage to allow long distance distribution. These fruits are firm and can sustain handling with a minimum of damage. Thus, most commonly-used maturity indices are those that compromise between marketing needs and optimum consumer quality (Burdon, 1997; Kader, 2002).

In fruit production, physical features such as size, abscission force, colour, texture, titratable acidity and changes in total soluble solids and physiological features such as respiration and ethylene production have been useful tools for maturity index development (Reid, 2002; Thompson, 2003a). In the pawpaw-related cherimoya,

changes in skin color, total soluble solids content, protein content, looseness of seeds, surfacetraits are characteristics commonly used for planning the fruit harvest schedule (Merodio and De La Plaza, 1997).

Like many fruits, papaya undergoes a variety of physical and chemical changes during ripening. As reported by McGrath and Karahadian (1994a), these events and their relationship with aroma development could be useful tools for defining appropriate pawpaw maturity index. However, the lack of a distinctive colour change hinders visual detection of ripening, and harvest requires touching fruit to detect softening and/or pedicel abscission.

2.4 POST-HARVEST QUALITIES AT HARVEST

2.4.1 Peel and Pulp Colour

The colour of fruits probably contributes more to theassessment of quality by the consumer than any other single factor. Therefore, peel andpulp colour are important post-harvestselection criteria. The colour of the fruit could give an indication of state of deterioration, disease infestation, maturity and/or contamination. The market quality andconsumer acceptability are significantlyinfluenced by the colour of the fruit. The peel colour is often the major post-harvestcriterion used by researchers, growers and consumers to determine whether the fruit isripe or unripe (Medlicott *et al*., 1992). In some countries, (e.g. Ghana, Nigeria,Honduras, etc), consumers have developed distinct correlations between colour and theoverall quality of specific products. Colour is critical as the first visual assessment of the quality of fruit. Consumers associate the colour of the peel with specific tastes or uses andthey will usually buy a particular fruit if the

colour is suited to the requiredpurpose or desire. In some West African countries, if the pulp colour of papaya is white, consumers feel that, the fruit is immature and if the pulpcolour is orange/yellow it indicates that the fruit is mature. Therefore, assessment ofpeel and pulp colour is important in the post-harvest screening of new hybrids.

2.4.2 Total Soluble Solids (TSS)

Fruits contain many compounds which are soluble in water; e.g. sugars, acids, vitamin C, amino acids and some pectins. These soluble compounds form the soluble solids content of the fruit. In most ripe fruits sugar forms the main component of soluble solids. Total soluble solids is an important postharvest quality attribute in the screening of new hybrids of fruits. Since the amount of TSS or sugar in fruits usually increases as they mature and ripen, the soluble solids content of the fruit can be a useful index of maturity or stage of ripeness. The refractometer is the instrument used to measure the total soluble solid content of fruits.

2.4.3 pH and Total Titratable Acidity (TTA)

pH values give a measure of the acidity or alkalinity of a product, while titratableacidity gives a measure of the amount of acid present.Assessment of pH and titratable acidity of fruits areused primarily to estimate consumption quality and hidden attributes. They couldbe considered as indicators of fruit maturity or ripeness. Acids make an importantcontribution to the post-harvest quality of the fruit, as taste is mainly a balancebetween the sugar and acid contents, hence post-harvest assessment of acidity isimportant in the evaluation of the taste of the fruit.

2.4.4 Moisture and Dry Matter Content

Moisture and dry matter content (%) are important post-harvest quality criteria since they provide a measure of the water content. They also provide plant breeders with information in determining whether increased yield is due to higher water content or due to genuine increase in harvested weight. Assessment of dry matter content is essential because, the high rate of respiration accompanied by water loss that occurs in plantain and banana during ripening, particularly at the climacteric stage causes a net reduction in the proportion of the fruit dry matter. Evaluation of the dry matter content could provide useful information on the differences in the moisture content between hybrids and their parents.

2.4.5 Shelf life studies

Shelf-life is simply the time period that a fruit can be expected to maintain a predetermined level of quality under specified storage conditions. In other words, the period (in days) between initiation or commencement of ripening (i.e. end of greenlife) and end of saleable life or edible life (of the fruit) on the shelf. It is essential that new banana, cooking banana and plantain are screened for their shelf-life potential, since it would provide useful information about the storage and marketing potential of the new hybrids. By knowing the shelf-life, it would also enable proper and adequate storage, handling and marketing techniques to be devised.

2.5 POSTHARVEST STORAGE AND FRUIT QUALITY

2.5.1 Cold Storage Treatment

Cold storage is the most common technique used to extend the shelf life of fruit. It has been shown that, above freezing, every 10 °C decrease in storage temperature slows fruit deterioration and overall quality loss by at least 2-fold. Fruit cooling decreases respiration rate and fruit softening, minimizes water loss, inhibits ethylene synthesis, and retards pathogen development and fruit decay (Lurie, 2003; Johnston *et al*., 2002).Temperate climate crops such as pome fruit, kiwifruit and stone fruit are best stored near 0 °C. However peaches stored longer than 8 weeks between -1 and 1 °C often develop chilling injury symptoms such as internal browning and wooly texture (Thompson, 2003b). On the other hand, tropical and subtropical fruits should be stored between 6 and 13 °C depending on species and cultivar. For this latter group, storage temperatures below the optimal range can cause chilling injury(Lurie, 2003; Crisosto *et al*., 1995).

Pawpaw fruit can be stored for one month at 4°C with little loss in quality, longer storage time can cause loss of firmness, reduced respiration and ethylene production, and black discoloration. Cold storage delays the ripening process of both ripe and unripe fruit and significantly delays the loss of firmness. However, upon removal from cold storage, firmness decline rapidly accompanied by a rise in ethylene maximum than fruit ripened after harvest (Archbold *et al*., 2003). Longer storage periods resulted in external and internal black discoloration of fruits possibly due to symptoms of cold injury (Koslanund, 2003).

Despite the fact that low temperature storage is the most effective postharvest approach for prolonging fruit and vegetable shelf life, the negative impact of low temperatures and cold stress have been studied in many crops. External symptoms such as skin discoloration and desiccation, internal breakdown, uneven ripening, development of large sunken areas, poor flavour and poor colour developmentare attributed to cold injury (Al-Haq and Sugiyama, 2004; Perez-Tello *et al*., 2001). Also, cold stored fruits had lower ethylene production, less softening and a higher pulp concentration of sucrose and citric acid when compared to fruit stored at higher temperatures (Alique *et al*., 1994; Maldonado *et al*., 2004).

2.5.2 Postharvest Heat Treatments

Postharvest heat treatments have attracted recent research interest as a promising new technique to maintain fruit quality during storage; which might be an alternative to or reduce the need for chemical disinfestation of fruit and could modify its response to other stresses (Hong *et al*., 2007). In particular, biotechnologists have shown increasing interest in the use of postharvest heat shock to alleviate chilling injury in various crops. On the other hand, heat treatments also inhibit biochemical pathways involved in ripening and other biological processes in a number of fruits and vegetables. Factors that influence temperature responses include species, variety, cultivation methods, fruit size, morphology, physiological maturity, final temperature and duration of exposure at various temperatures and type of treatment (Fallik, 2004;Ferguson *et al*., 2000; Paull and Chen, 2000). Exposure of fruit to temperatures of 40-42°C can induce resistance to chilling injury, delay the ripening process, and modify its quality (Ferguson *et al*., 2000, Lurie, 1998)

Despite the decrease in fruit quality observed after cold storage, consumers still prefer fresh products over the canned or frozen alternatives. For this reason prolonging fruit shelf life and decreasing fruit perishability have been the aim of many studies (Paull and Chen, 2000; Ruoyi *et al.,* 2005). In the previous decades, various approaches such as heat treatments, controlled atmosphere storage, and modified atmosphere storage treatment have been evaluated with interesting results (Burmeister *et al.,* 1997; Paull and Chen, 2000;., Polenta *et al*2006; Ruoyi *et al.,* 2005; Whitaker *et al.,* 1997). Among these options heat treatment seems one of the more promising approaches for delaying fruit ripening, prolonging cold storage and reducing cold storage injury symptoms (Erkan *et al*., 2005; Lurie, 1998).

Heat treatments such as hot water baths or high temperature air chambers have become commonly-applied fungal and insect control techniques (Erkan *et al.,* 2005; Lurie, 1998). During research to develop heat treatments for postharvest pest control, it was observed that fruit tolerance to low temperature increased, cold storage injury symptoms decreased, and fruit quality was maintained for longer periods (Paull and Chen, 2000; Erkan *et al*., 2005; Lurie, 1998).

Unfortunately, despite the benefits observed for many species, general guidelines are difficult to draw since different species, different cultivars, and fruit at different ripening stages respond differently to similar temperature/time combinations (Paull and Chen, 2000).

Heat treatments can be applied using hot water, vapour heat or forced hot air. Hot water dips (50–70 °C for 10–60 s) have been effective for fungal pathogen control and insect disinfestation. They can be safely applied directly at the storage/packaging area, and they are commonly applied in the commercial postharvest warehouse (Rodov *et al*., 1995; Erkan *et al*., 2005). On the other hand, vapour heat treatment (38–46 °C for 12–96h) is a quarantine treatment normally applied to fruits and vegetables with the aim of eliminating insect eggs and larvae. In the past the heat was transferred to the fruit using water condensation techniques. However, commercial facilities currently warm commodities to 40–50 °C by forcing vapour heat (95% RH or above) or moist air (58–90% RH) on the commodities placed in the heating chamber (Lurie, 1998; Thompson, 1996).

Similar to the vapour heat treatment, exposure to hot air decreased fungal infection and was effective as a quarantine treatment. Hot air treatments can be considered long term treatments. Excessively high temperature can cause peel browning, pitting, yellowing, abnormal softening, flesh darkening, increased decay and abnormal starch metabolism (Lurie, 1998). As a general guideline, the maximum temperature tolerance for plants can be located in the 42–60 °C range based on the original evolutionary habitat of the species (Paull and Chen, 2000).

Preliminary observations about the beneficial effect of heat treatment in slowing pawpaw ripening were reported by Koslanund (2003). Pawpaw exposed to 42, 46 or 50°C for 15, 30 and 60 min prior to the beginning of bench ripening presented decreased

ethylene production, a lower respiration rate and slower loss of firmness when compared to untreated fruit.

CHAPTER THREE

MATERIALS AND METHODS

3.1 LOCATION OF EXPERIMENT

The laboratory work was conducted at the laboratory of the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi. The experiment was carried out in August, 2011.

3.2 SOURCE OF PAPAYA FRUITS

Mature green fruits of the Solo papaya variety were harvested from papaya farms in Darbaa in the Atwima Nwabiagya District in the Ashanti Region.The harvested fruits were transported for 2hours to the laboratory.

3.3 PREPARATION OF FRUITS

Papaya fruits showing a slight overall loss of green color with some signs of yellow colour at the blossom end were selected for the laboratory work. Mature fruits uniform in shape and size without any deformity and apparently showing no sign of disease were selected. The fruits were washed under running water then placed on a clean bench and allowed to dry.

3.4 EXPERIMENTAL DESIGN

A Completely Randomised Design (CRD) with three replications was used for the experiment. The number of fruits per treatment was 27 and a total of 81fruits were used for the experiment.

3.5 TREATMENTS

The papaya fruits were subjected to three different treatments.

- T_{40} - fruits were exposed to a temperature of 40^{o}C for 20 minutes
- T_{50} - fruits were exposed to a temperature of 50^{o}C for 20 minutes
- Control- fruits were kept under ambient condition.

3.6 APPLICATION OF HEAT TREATMENTS

Two hot air-ovens were heated to a temperature of 40^{o}C for treatment $T_{40}$and 50^{o}C for treatments T_{50}. The ovens were initially heated for about 30 minutes at their respective temperatures (40^{o}C and 50^{o}C). The fruits selected for the heat applications were arranged on plastic trays. The trays with the fruits were gently placed inside the heated oven chamber for 20 minutes after which the fruits were removed out and allowed to cool. The fruits were all kept under ambient conditions (T=28±3^{o}C, RH=85%).Daily observations were made and data taken on weight loss, colour changes / skin colour, total soluble solids (TSS), pH and total titratable acidity.

3.7 PARAMETERS STUDIED

3.7.1 Cumulative Weight Loss (%)

The loss in fruits weight was determined daily using a balance (Model: ZPS Series). The initial weight of fruits was recorded and subsequent weight recorded at each observation. The percentage weight losses was calculated using the formula

Weight loss (%) = $\frac{W1 - W2}{W1} \times 100$

Where W1 = initial weight, and W2 = final weight.

Cumulative percentage weight loss was determined by adding the daily weight loss recorded together.

3.7.2Colour Scoring of Solo Papaya Variety

Colour stages of the fruits were determined based on visual skin colour assessment. The colour stages developed for the Maradol papaya fruit was adopted for the Solo variety because they have similar ripening characteristics.

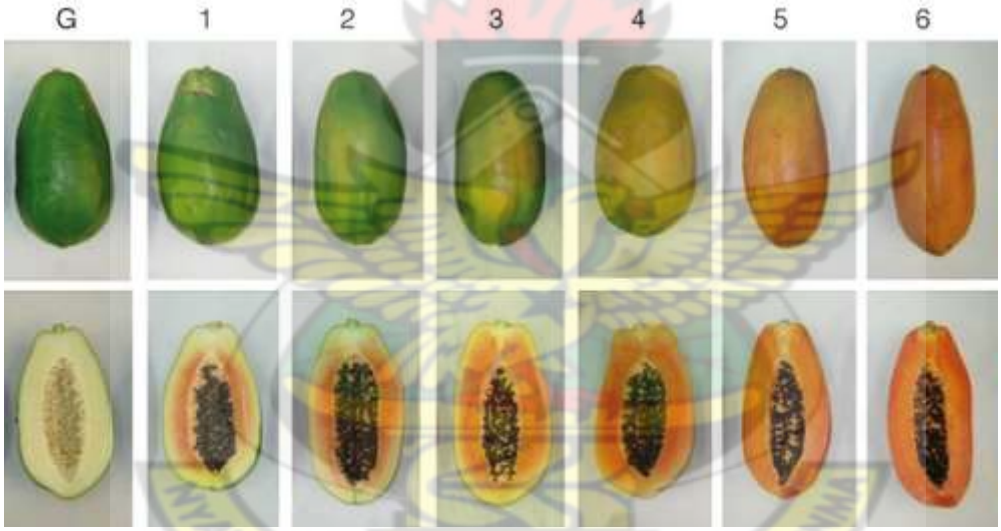

Plate 3.1: Maradol papaya fruit at each colour stage.

Key: G - green skin without yellow stripe; 1- green skin with light yellow stripe; 2 - green skin with well-defined yellow stripe; 3 - one or more orange-colored stripes in skin; 4 - clearly orange-colored skin with some light green areas; 5 - characteristic orange-colored skin; 6 - fruit color similar to stage 5, but more intense (Felipe *et al*., 2009).

3.7.3Total Soluble Solids (TSS)

The fruit was peeled and 30g of the pulp was weighed using a balance (Model: ZPS Series). The weighed sample was blended with 90ml distilled water using a blender(Binatone Model: BLG-402) fitted with a filter. The filtrate was then emptied into a 200ml beaker. A single drop of the filtrate was placed on the prism of a hand-held refractometer (DIGIT-080). Total soluble solids of the fruits were expressed in ^{o}Brix (AOAC, 1990).

3.7.4 pH

The fruit was peeled and 30g of the pulp was weighed using a balance (Model: ZPS Series). The weighed sample was blended with 90ml distilled water using a blender (Binatone Model: BLG-402) fitted with a filter. The filtrate was then emptied into a 200ml beaker. A small amount of the filtrate was poured into an empty beaker and the electrode of the pH meter (Combo pH & EC meter – HI 98129) wasplaced in the filtrate. The pH value of the filtrate was read and recorded after the reading has stabilized (AOAC, 1990).

3.7.5 Total Titratable Acidity (TTA)

The fruit was peeled and 30g of the pulp was weighed using a balance (Model: ZPS Series). The weighed sample was blended with 90ml distilled water using a blender (Binatone Model: BLG-402) fitted with a filter. The filtrate was then emptied into a 200ml beaker. 25 ml of the filtrate was pipetted into 200ml conical flask and 25ml of distilled water was added. Four drops of phenolphthalein indicator was added and titrated against 0.1N Sodium hydroxide (NaOH) until a colour change was observed

(AOAC, 1990). The volume of NaOH used was read and recorded TTA was calculated using the formular

$$\%\ acid = \frac{N \times V_1 \times Eq\ .wt}{v_2 \times 10}$$

N = normality of the titrant

V_1 = volume of the titrant

Eq.wt = equivalent weight of predominant acid

V_2 = volume of sample

3.7.6 Shelf Life Studies

Shelf life studies were conducted on the Solo papaya varietyfor a period of 10 days. During this period, moisture loss and fruit quality were monitored. Shelf life studies were terminated when the fruits started showing some signs of rots.

3.8 DATA ANALYSIS

The data collected were subjected to Analysis of Variance (ANOVA) using Statistix 9 statistical software. Difference between treatments means were separated using the least significance difference test at 5% (P=0.05).

CHAPTER FOUR

RESULTS

4.1CUMMULATIVE WEIGHT LOSS (%) OF PAPAYA FRUIT

Figure 4.1 shows the effect of heat treatment on cumulative weight loss (%) of Solo papaya. There was a gradual increase in weight loss observed among the treatments over the storage period. At day 10 of the storage period, the highest cumulative weight loss of 11.72% was recorded by T_{40} and the lowest of 9.47% by T_{50}. However, no significant differences were observed among the treatments during the storage period ($P>0.05$).

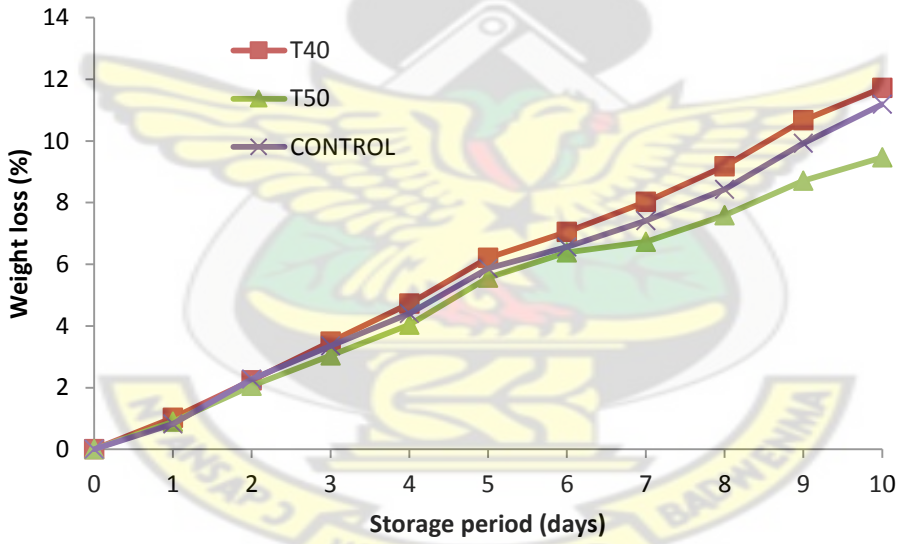

Figure 4.1: Effect of heat treatment on cumulative weight loss (%) of Solo papaya

4.2 COLOUR STAGESFOR SOLO PAPAYA FRUIT

Table 4.1: Characteristic colour stages and corresponding chemical attribute of the fruit kept under ambient conditions.

Indices	Colour stage						
	G	1	2	3	4	5	6
Peel colour							
Pulp colour							
Time*	0 day	1 day	2 days	3 days	5 days	8 days	9 days
pH	6.08	6.15	6.13	5.97	5.87	5.93	5.79
TSS	5.4	6	5.63	5.48	7.35	7.95	7.2
TTA	1.95	1.8	1.88	1.73	1.5	2.4	1.73

* Time taken for a fruit to reach a particular colour stage

The external and internal characteristics of the untreated fruits at the different colour stages of ripening are presented in Table 4.1. Indices such as the peel or skin colour, pulp colour, time taken to reach a particular colour stage, pH, TSS and TTA at the various colour stages were assessed.

Visual assessment of the fruits at the various colour stages and their descriptions are presented in Table 4.2.

Table 4.2: Visual characteristics of Solo papaya fruit

Colour stage	Description
Green fruit	Green skin without yellow stripe; pulp very hard and pale orangein colour; seeds well-formed and contains large amounts of latex.
1	Green skin with a light yellow stripe; pulp exhibits some areas with orange colour, very hard and contains large amounts of latex.
2	Green skin with well-defined yellow stripe; pulp is orangein colour near seed cavity, although still hard and with large amounts of latex.
3	One or more yellow-coloured stripes in skin; pulp orange in colour, except near skin, still hard but contains less latex.
4	Skin clearly yellowcolour with some light green areas; pulp intense orange, pulp softer than in stage 3, but still a bit hard for consumption, low latex content.
5	Skin displays yellow colour characteristic of Solo variety; pulp firmness appropriate for consumption, latex no longer present.
6	Conditions similar to stage 5, but with more intense yellow colour in skin and softer pulp still adequate for consumption, presence of rots

4.3 TOTAL SOLUBLE SOLIDS (TSS) OF PAPAYA FRUIT

Figure 4.2 shows the effect of heat treatment on total soluble solids of the papaya fruits. There was a gradual increase in total soluble solids from the green fruit stage to colour stage 4 for the control and colour stage 5 for T_{40} and T_{50} respectively, then a decline to colour stage 6. The highest total soluble solids of 8.5 ^{o}Brix was recorded by treatment T_{40} and T_{50} at colour stage 5. Significant differences were observed among the treatments at colour stage 5 and 6 ($P<0.05$). However, no significant differences were observed among the treatments at colour stage 1, 2, 3, 4 and the green stage ($P>0.05$).

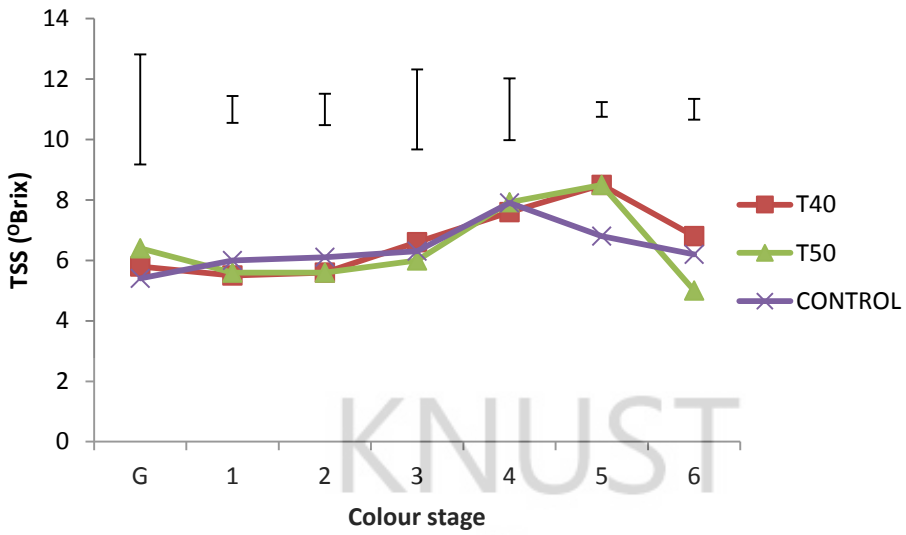

Figure 4.2 shows the effect of heat treatment on total soluble solids of Solo papaya.

4.4 pH OF PAPAYA FRUIT

Figure 4.3 shows the effect of heat treatment on pH of Solo papaya. A linear pH pattern was observed for the Solo papaya. The highest pH value of 6.10 was recorded by treatment T_{40} at colour stage 2 and T_{50} at green colour stage of the papaya fruits. The control fruits had a pH value of 6.15 at colour stage 1. However, no significant difference was observed among the treatments at the different colour stages ($P>0.05$).

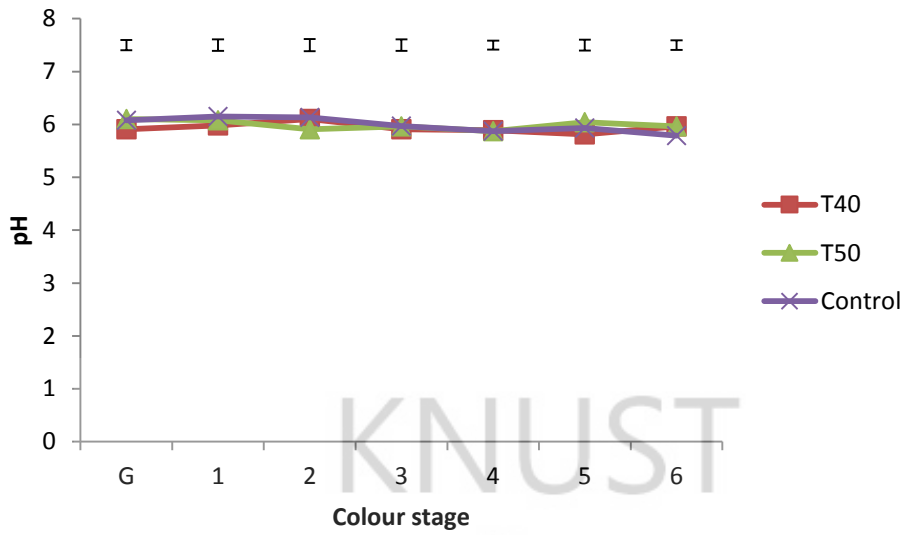

Figure 4.3: Effect of heat treatment on pH of Solo papaya

4.5 TOTAL TITRATABLE ACIDITY (TTA) OF PAPAYA FRUIT

Figure 4.4 shows the effect of heat treatment on total titratable acidity of Solo papaya. Generally, an irregular pattern was observed in total titratable acidity of the fruit with a decrease in TTA from the green colour stage to colour stage 4 then a rise to colour stage 6. The highest total titratable acidity of 0.73 was recorded by T_{40} at colour stage 2, T_{50} at colour stage 1 and control at colour stage 6. Significant differences were observed among the treatments at colour stage 4, 5 and 6 ($P<0.05$). However, there were no significant differences observed among the treatments at colour stage 1, 2, 3 and the green stage ($P>0.05$).

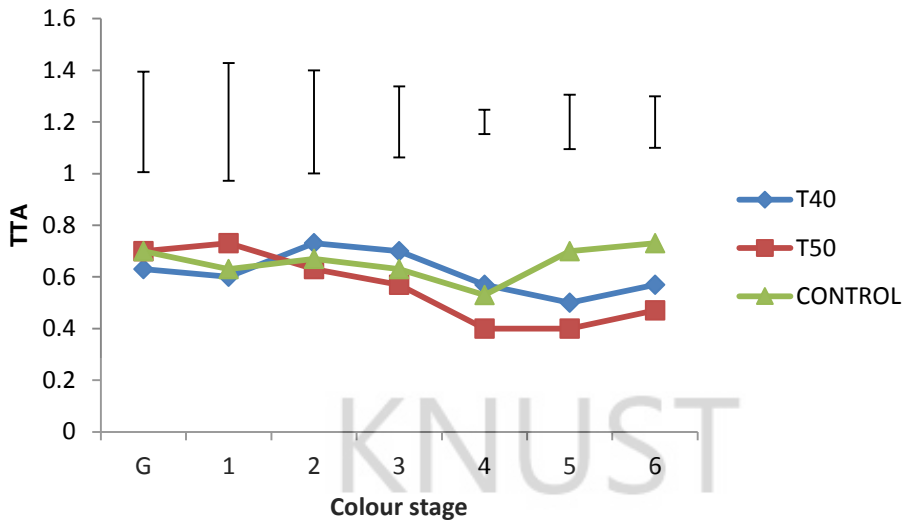

Figure 4.4: Effect of heat treatment on total titratable acidity of Solo papaya

4.6 SHELF LIFE STUDIES OF PAPAYA FRUIT

Table 4.3: Effect of heat treatment on shelf life studies of Solo variety

Treatment	Storage life (days)
T_{40}	7
T_{50}	8
Control	6
Lsd $_{(0.05)}$	2.0
Cv%	14.3

The results of the shelf life studies conducted on the Solo papaya fruit are presented in Table 4.3. Treatment T_{50} fruits exhibited the longest shelf life of 8 days, followed by T_{40}which lasted 7 days and the control fruits which had a shelf life of 6 days. However, there were no significant differences in shelf life among the treatments at the end of the study.

CHAPTER FIVE

DISCUSSIONS

5.1 CUMULATIVE WEIGHT LOSS (%) OF SOLO PAPAYA FRUIT

From the research conducted, there was a high cumulative weight loss in the treatments applied. The percentage cumulative weight loss increased with increasing days in storage. The heat treatment T_{50} showed a lower percentage weight loss and this can be explained by the fact that the temperature could have been high enough to interfere with enzymatic processes which may have retarded the metabolic processes within the fruits. Stover and Simmonds,(1987) attributed the loss of moisture fromthe fruit to its peel (skin) and the pulp (flesh). In addition, fruits in their green stage (unripe) aremainly composed of starch which constitute about 20-25% ofthe fresh weight of the pulp and 3% of the fresh weight of the peel (Seymour *et al*.,1993). Dadzie and Orchard (1997) also attributed the loss in weight to the conversion of starch to sugars (sucrose, glucose, fructose and maltose) which havelower molecular weight.

5.2 COLOUR STAGES FOR SOLO PAPAYA FRUIT

Solo papaya fruits are usually harvested at the mature green stage. During temporary holding prior to consumption, they remain firm and green without any significant changes in skin colour, texture or composition for a period of time before the commencement of ripening. Once the green-life of the fruit has ended, ripening begins. The study revealed 6 distinct colour stages and their corresponding chemical attributes (Table 4.1). Generally, pH varied between 5.79 and 6.15. on the other hand, total

titratable acidity ranged between 1.50 and 2.4 whereas total soluble solids was 5.4-7.35 ^{o}Brix.

It was observed that the quality of the fruits showed signs of loss of quality at colour stage 4 which continued to colour stage 6. At colour stage 6, the fruits were not marketable as there was structural collapse of the pulp. According to Felipe *et al*. (2009) colour stages 4 coincides with maximum respiration rate and ethylene production hence the observed poor quality.The loss in quality alsoreduces the market value and makes the fruit unmarketable. The disappearance or loss of skin green colour and the corresponding increase in orange colouring of the skin during ripening are the obvious manifestations in the Solo variety. The loss of green colour is due to degradation of the chlorophyll structure (Mer0dio and De La Plaza, 1997This is because maturity stage of the fruit at harvest greatly influences the postharvest fruit behaviour during marketing and storage. Colour of the skin and pulp can therefore be considered as good maturity stage indicators and reliable quality standards in Solo papaya. Based on the ripening response of the fruits in storage, stages 1 and 2 are the proper times to harvest for long distance shipment (export), while fruit can be harvested in stage 3 for the local markets.

Reid (2002) reported colour changes as widely usedvisual maturity index in many fruits including. Aked (2000) indicated that fruit colour intensity and uniformity greatly affect fruit quality since in many fruits these involve loss of chlorophyll, synthesis of new pigments such as carotenoids and unmasking of other pigments previously formed during fruit development.Wainwright and Hughes (1990) established that external changes in skin colour during ripening often reflected changes in pulp colour. The

colour chart developed during the study would help producers and consumers predict the stage of ripening and quality of Solo papaya fruits.

5.3 TOTAL SOLUBLE SOLIDS (TSS) OF PAPAYA FRUIT

Generally, all treatments showed a gradual increase in total soluble solids to a peak and, thereafter, a declined as the Solo papaya fruits ripens. This is because there might have been a gradual conversion of starch to simple sugars as the fruits ripens (Rathore *et al* 2007). Also, the increase in total soluble solids is due to alteration in the cell wall structure and breakdown of complex carbohydrates into simple sugars during the storage period. Rathore *et al*. (2007) working on mango found similar trends in total soluble solids. The hydrolytic changes in starch and conversion of starch to sugars in climacteric fruits including papaya resulted in the increase and decrease in total soluble solids could be attributed to

during storage (Kays, 1991 and Kittur *et al*., 2001). From the study, the heat treatment given to the papaya fruits significantly affected the total soluble solids during the full ripe stages of the fruit. It could therefore be concluded that the exposure of the Solo variety to high temperatures influenced the ripening and biochemical processes within the fruit, thus affecting total soluble solids.

5.4 pH OF PAPAYA FRUIT

The pH of the Solo papaya fruits ranged between 5.9 to 6.1 at the green stage and 5.7 to 6.0 at the final colour stage 6. Gowen (1995) reported that at harvest, pulp pH of banana fruits ranged between 5.4 and 6.0 and decreases to 4.0 during ripening. In general, there was a slow decline in pH in the Solo papaya fruits. Dadzie and Orchard (1997) also

reported similar trend in banana where there was a rapid decline in pulp pH in response to increasing ripeness. They further added that pulp pH was high especially when fruits are harvested at the matured green stage, but pH drops as ripening progresses pH drops. From the study, it could be concluded that the heat treated fruits did not differ significantly from the control treatment; hence exposure of the fruits to high temperatures did not affect the pH of the Solo fruits.

5.5 TOTAL TITRATABLE ACIDITY (TTA) OF PAPAYA FRUIT

The Solo papaya fruits showed an inconsistent pattern in total titratable acidity as ripening progressed in storage. Selvaraj *et al*. (1982) indicated that during papaya fruit ripening, titratable acidity increased up to the climacteric peak and then declined afterwards. Similar trend was reported by Caussiol (2001) where total titratable acidity increased as the fruit ripened and then decreased as the fruit became overripe. Tucker (1990) attributed the rise and fall in the levels of acids in the fruits during ripening, probably due to the utilization of the acids as respiratory substrates and the increase in sugar levels within the fruit due to the mobilization of starch reserves within the fruit. Wills *et al*. (1989) also reported that organic acids decline in fruits during ripening. Significant differences were observed between the heat treated fruits and the control when the fruit was ripe, thus from colour stage 4 to 6. These differences observed could be attributed to the heat treatments given to the fruits and can be concluded that the exposure of the fruits to high temperatures affected the ripening and biochemical processes occurring within the fruits.

5.6 SHELF LIFE STUDIES OF PAPAYA FRUIT

Observations from the work conducted showed that treatment T_{50} had a better shelf life of 8 days than treatment T_{40}which had 7 days. The control fruits recorded the shortest shelf life of 6 days. The heat treatment given to the Solo papaya fruits extended the shelf life of the fruit better than the control which was not exposed to high temperatures. The longer shelf life exhibited by the heat treatment T_{50} could be attributed to the high temperature the fruits were exposed to which affected the ripening process and development of rot organisms.The exposure of the Solo variety to high temperatures therefore retarded ripening and contributed to the shelf life of the fruits under ambient condition better than the control without any heat treatment. An and Paull (1990) reported that papaya fruit had a maximum storage life of 7 days under ambient tropical conditions.According to Archbold *et al*. (2003) papaya fruit could store better under refrigeration (one month at 4^{o}C) with little loss in quality than under ambient conditions. Koslanuud (2003) reported that longer storage periods resulted in external and internal discoloration of the papaya fruit. Wills *et al*. (1998) concluded that respiration rate was an excellent indicator for metabolic activity of the tissues, and thus is a useful guide for the potential storage life of fresh fruits. Day (1993) further expressed respiration rate to be inversely proportional to shelf-life of the product, hence the lower the respiration rate the longer the shelf-life.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 SUMMARY OF FINDINGS

The study was conducted to determine the ripening response and fruit quality of Solo papaya variety to heat treatment at the Laboratory of the Department of Horticulture, KNUST, Kumasi.

The lowest cumulative weight loss of 9.47% by T_{50} 10 days in storage with T_{40}recording the highest cumulative weight loss of 11.72%. However, no significant differences were observed among the treatments during the storage period.

The quality of Solo papaya fruits at colour stage 3 could be considered as good for consumption. Colour stages for the Solo using skin and pulp colour indicated that Stage 1 and 2 could be used as an indicator of physiological maturity and as a harvest index for export markets requiring distant shipment. Stage 3 could also be used as harvest index for nearby local markets.

The highest total soluble solids of 8.5 ^{o}Brix was recorded by both heat treatments T_{40} and T_{50} at colour stage 5 respectively.

The highest pH value of 6.15 was recorded by the control at colour stage 1 and the lowest of 5.79 at colour stage 6.

The lowest total titratable acidity of 1.05 was recorded by T_{50} at colour stage 5 with heat treatment T_{40} at recorded the highest of 3.0 at colour stage 5.

Exposing Solo papaya fruits to temperatures of about 50ºC (T_{50}) delayed ripening and extended the shelf life to 8 days after harvesting. Untreated Solo papaya fruits had the shortest shelf-life of 6 days after harvesting.

6.2 CONCLUSION

Fruit ripening in*Carica papaya* cultivars varies widely in terms of skin colour changes and shelf life. Yellow colour in the fruit skin has been used as a harvest index criterion to ensure adequate ripening and maximum shelf life. From 4.1 on the effect heat treatment on weight loss T40 had the highest mean weight loss of 6.43% and the lowest mean weight of 5.45% was recorded by T50. The study also showed that, T50 recorded the least value of 0.56 on the effects of heat treatment on total titratable acidity (TTA) on the Solo papaya fruit. The highest mean pH values of 5.99 was recorded by T50 and control treatment respectively. T40 also recorded the highest mean total soluble solids (TSS) with a mean value of 6.63 on the effects of heat treatment on total soluble solids (TSS). On the effects heat treatment on shelf life studies of the Solo papaya fruit, it was shown that T50 had the longest shelf life of 8 days. In conclusion, the study has shown that, when the Solo papaya delays in ripening is desirable, therefore heat treating the Solo papaya fruit would be appropriate.

6.3 RECOMMENDATIONS

From the results of study, the following recommendations were made.

1. Further investigation should be done on the effects of different temperature treatments on quality and shelf life of other varieties of papaya fruits.
2. Further studies should be conducted on quality and shelf life response of Solo papaya fruits to other post harvest treatments such as hot water and exposure of fruits to sunlight to determine whether it could also prolong shelf life and maintain quality.

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APPENDICE

Appendix 1a: Effect of heat treatment on mean weight loss (%) of Solo papaya

Treatment	Weight loss (%)
T_{40}	6.43
T_{50}	5.45
Control	6.02
Lsd	1.54
Cv%	12.90

Appendix 1b: Effect of heat treatment on mean total soluble solids (ºBrix) of Solo papaya

Treatment	Total soluble solids (ºBrix)
T_{40}	6.63
T_{50}	6.43
Control	6.39
Lsd	1.15
Cv%	8.89

Appendix 1c: Effect of heat treatment on mean pH of Solo papaya

Treatment	pH
T_{40}	5.94
T_{50}	5.99
Control	5.99
Lsd	0.11
Cv%	1.10

Appendix 1d: Effect of heat treatment on mean total titratable acidity of Solo papaya

Treatment	Total titratable acidity
T_{40}	0.66
T_{50}	0.56
Control	0.66
Lsd	0.18
Cv%	14.99

Appendix 2: ANOVA Tables For Cumulative Weight Loss (%)

Completely Randomized AOV for mean weight loss

Source	DF	SS	MS	F	P
TRT	2	1.46839	0.73420	1.24	0.3543
Error	6	3.55411	0.59235		
Total	8	5.02251			

Grand Mean 5.9672 CV 12.90

Completely Randomized AOV for day1

Source	DF	SS	MS	F	P
TRT	2	0.06036	0.03018	0.75	0.5122
Error	6	0.24160	0.04027		
Total	8	0.30196			

Grand Mean 0.9122 CV 22.00

Completely Randomized AOV for day 2

Source	DF	SS	MS	F	P
TRT	2	0.08242	0.04121	0.16	0.8517
Error	6	1.49913	0.24986		
Total	8	1.58156			

Grand Mean 2.1922 CV 22.80

Completely Randomized AOV for day 3

Source	DF	SS	MS	F	P
TRT	2	0.31429	0.15714	0.66	0.5510
Error	6	1.42993	0.23832		
Total	8	1.74422			

Grand Mean 3.2956 CV 14.81

Completely Randomized AOV for day 4

Source	DF	SS	MS	F	P
TRT	2	0.70782	0.35391	1.39	0.3186
Error	6	1.52500	0.25417		
Total	8	2.23282			

Grand Mean 4.3856 CV 11.50

Completely Randomized AOV for day 5

Source	DF	SS	MS	F	P
TRT	2	0.62207	0.31103	0.44	0.6627
Error	6	4.23153	0.70526		
Total	8	4.85360			

Grand Mean 5.8833 CV 14.27

Completely Randomized AOV for day 6

Source	DF	SS	MS	F	P
TRT	2	0.70807	0.35403	0.30	0.7518
Error	6	7.09633	1.18272		
Total	8	7.80440			

Grand Mean 6.6633 CV 16.32

Completely Randomized AOV for day 7

Source	DF	SS	MS	F	P
TRT	2	2.49860	1.24930	1.52	0.2916
Error	6	4.91780	0.81963		
Total	8	7.41640			

Grand Mean 7.3833 CV 12.26

Completely Randomized AOV for day 8

Source	DF	SS	MS	F	P
TRT	2	3.79682	1.89841	1.86	0.2346
Error	6	6.10953	1.01826		
Total	8	9.90636			

Grand Mean 8.3978 CV 12.02

Completely Randomized AOV for day 9

Source	DF	SS	MS	F	P
TRT	2	5.8863	2.94314	2.09	0.2046
Error	6	8.4449	1.40748		
Total	8	14.3312			

Grand Mean 9.7678 CV 12.15

Completely Randomized AOV for day 10

Source	DF	SS	MS	F	P
TRT	2	8.3390	4.16948	2.15	0.1982
Error	6	11.6588	1.94313		
Total	8	19.9978			

Grand Mean 10.792 CV 12.92

Appendix 3: ANOVA Tables For Total Soluble Solids

Completely Randomized AOV for mean TSS

Source	DF	SS	MS	F	P
TRT	2	0.09937	0.04968	0.15	0.8642
Error	6	1.99361	0.33227		
Total	8	2.09297			

Grand Mean 6.4825 CV 8.89

Completely Randomized AOV for Green stage

Source	DF	SS	MS	F	P
TRT	2	1.5200	0.76000	0.23	0.8020
Error	6	19.9200	3.32000		
Total	8	21.4400			

Grand Mean 5.8667 CV 31.06

Completely Randomized AOV for Colour stage 1

Source	DF	SS	MS	F	P
TRT	2	0.42000	0.21000	1.05	0.4064
Error	6	1.20000	0.20000		
Total	8	1.62000			

Grand Mean 5.7000 CV 7.85

Completely Randomized AOV for Colour stage 2

Source	DF	SS	MS	F	P
TRT	2	0.50000	0.25000	0.93	0.4462
Error	6	1.62000	0.27000		
Total	8	2.12000			

Grand Mean 5.7667 CV 9.01

Completely Randomized AOV for Colour stage 3

Source	DF	SS	MS	F	P
TRT	2	0.5400	0.27000	0.15	0.8608
Error	6	10.5400	1.75667		
Total	8	11.0800			

Grand Mean 6.3000 CV 21.04

Completely Randomized AOV for Colour stage 4

Source	DF	SS	MS	F	P
TRT	2	0.20222	0.10111	0.10	0.9105
Error	6	6.36667	1.06111		
Total	8	6.56889			

Grand Mean 7.8111 CV 13.19

Completely Randomized AOV for Colour stage 5

Source	DF	SS	MS	F	P
TRT	2	5.78000	2.89000	48.17	0.0002
Error	6	0.36000	0.06000		
Total	8	6.14000			

Grand Mean 7.9333 CV 3.09

Completely Randomized AOV for Colour stage 6

Source	DF	SS	MS	F	P
TRT	2	5.04000	2.52000	21.00	0.0020
Error	6	0.72000	0.12000		
Total	8	5.76000			

Grand Mean 6.0000 CV 5.77

Appendix 4: ANOVA Tables For pH

Completely Randomized AOV for mean pH

Source	DF	SS	MS	F	P
TRT	2	0.00735	0.00368	0.85	0.4585
Error	9	0.03885	0.00432		
Total	11	0.04620			

Grand Mean 5.9700 CV 1.10

Completely Randomized AOV for Green stage

Source	DF	SS	MS	F	P
TRT	2	0.09172	0.04586	3.22	0.0882
Error	9	0.12825	0.01425		
Total	11	0.21997			

Grand Mean 6.0283 CV 1.98

Completely Randomized AOV for Colour stage 1

Source	DF	SS	MS	F	P
TRT	2	0.05352	0.02676	1.36	0.3042
Error	9	0.17678	0.01964		
Total	11	0.23029			

Grand Mean 6.0692 CV 2.31

Completely Randomized AOV for Colour stage 2

Source	DF	SS	MS	F	P
TRT	2	0.11902	0.05951	3.00	0.1001
Error	9	0.17827	0.01981		
Total	11	0.29729			

Grand Mean 6.0442 CV 2.33

Completely Randomized AOV for Colour stage 3

Source	DF	SS	MS	F	P
TRT	2	0.00755	0.00378	0.20	0.8245
Error	9	0.17228	0.01914		
Total	11	0.17983			

Grand Mean 5.9425 CV 2.33

Completely Randomized AOV for Colour stage 4

Source	DF	SS	MS	F	P
TRT	2	0.00072	0.00036	0.03	0.9685
Error	9	0.10037	0.01115		
Total	11	0.10109			

Grand Mean 5.8742 CV 1.80

Completely Randomized AOV for Colour stage 5

Source	DF	SS	MS	F	P
TRT	2	0.10582	0.05291	3.42	0.0786
Error	9	0.13928	0.01548		
Total	11	0.24509			

Grand Mean 5.9258 CV 2.10

Completely Randomized AOV for Colour stage 6

Source	DF	SS	MS	F	P
TRT	2	0.07940	0.03970	3.05	0.0972
Error	9	0.11703	0.01300		
Total	11	0.19642			

Grand Mean 5.9025 CV 1.93

Appendix 5: ANOVA Tables For Total Titratable Acidity

Completely Randomized AOV for mean TTA

Source	DF	SS	MS	F	P
TRT	2	0.01651	0.00825	0.98	0.4270
Error	6	0.05034	0.00839		
Total	8	0.06685			

Grand Mean 0.6111 CV 14.99

Completely Randomized AOV for Green stage

Source	DF	SS	MS	F	P

trt	2	0.00889	0.00444	0.12	0.8910
Error	6	0.22667	0.03778		
Total	8	0.23556			

Grand Mean 0.6778 CV 28.68

Completely Randomized AOV for Colour stage 1

Source	DF	SS	MS	F	P
trt	2	0.02889	0.01444	0.28	0.7675
Error	6	0.31333	0.05222		
Total	8	0.34222			

Grand Mean 0.6556 CV 34.86

Completely Randomized AOV for Colour stage 2

Source	DF	SS	MS	F	P
trt	2	0.01556	0.00778	0.19	0.8283
Error	6	0.24000	0.04000		
Total	8	0.25556			

Grand Mean 0.6778 CV 29.51

Completely Randomized AOV for Colour stage 3

Source	DF	SS	MS	F	P
trt	2	0.02667	0.01333	0.71	0.5305
Error	6	0.11333	0.01889		
Total	8	0.14000			

Grand Mean 0.6333 CV 21.70

Completely Randomized AOV for Colour stage 4

Source	DF	SS	MS	F	P
trt	2	0.04667	0.02333	10.50	0.0110
Error	6	0.01333	0.00222		
Total	8	0.06000			

Grand Mean 0.5000 CV 9.43

Completely Randomized AOV for Colour stage 5

Source	DF	SS	MS	F	P
trt	2	0.17556	0.08778	7.90	0.0208
Error	6	0.06667	0.01111		
Total	8	0.24222			

Grand Mean 0.5444 CV 19.36

Completely Randomized AOV for Colour stage 6

Source	DF	SS	MS	F	P
trt	2	0.10889	0.05444	5.44	0.0448
Error	6	0.06000	0.01000		
Total	8	0.16889			

Grand Mean 0.5889 CV 16.98

Appendix 6: ANOVA Tables For Shelf-life Studies

Completely Randomized AOV for shelf- life studies

Source	DF	SS	MS	F	P
TRT	2	6.0000	3.00000	3.00	0.1250
Error	6	6.0000	1.00000		
Total	8	12.0000			

Grand Mean 7.0000 CV 14.29