

## RESEARCH ARTICLE

# Effect of GA<sub>3</sub>, Waxing and Micro Perforated Bags on shelf Life and Selected Quality Attributes of Papaya Fruit

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## ABSTRACT

Papaya fruit is characterized by a relatively short shelf-life. To extend the shelf-life and to investigate the effect of various postharvest treatments on shelf-life and quality, a study was conducted on papaya (*Carica papaya*) cv. Hortus Gold. The treatments included gibberellic acid (GA<sub>3</sub>), waxing and micro-perforated bags (MPB). Fruits were held at four different temperatures (5.5, 7, 10 or 22°C). Percentage weight loss (PWL), firmness, skin colour change and respiration rate were evaluated on a weekly basis during the storage period. Selected quality attributes such as total soluble solids (TSS), titratable acids (TA), pH and sugar:acid ratio were also measured after storage. Based on the colour change and softening days to ripen was determined. PWL, softening, yellowing and respiration rate increased irrespective of treatments as the storage time and temperature was increased. MPB and waxing significantly (P<0.001) reduced PWL and softening compared to the control fruits. This was consistent for all storage temperatures. GA<sub>3</sub> resulted in significantly lower (P<0.001) PWL compared to the control at 7, 10 and 22°C, but not at 5.5°C. Moreover, waxing and GA<sub>3</sub> treatments significantly reduced colour development and the respiration rate at all storage temperatures. An increased respiration rate was evident in MPB at 5.5 and 22°C. Fruits at 7 and 10°C exhibited an increased shelf-life up to eight and six weeks, respectively, while fruits at 5.5°C showed chilling injury, which resulted in an increase in respiration rate and PWL. Similarly, fruits at 22°C showed a rapid respiratory climacteric after two weeks of storage and deteriorated very rapidly. There was no measurable difference among treatments in their TSS, TA, pH and sugar:acid ratio at all storage temperatures. Waxing, GA<sub>3</sub> and MPB are, therefore, promising means of controlling papaya postharvest loss and, hence, increase shelf-life with no significant effect to the quality within the conditions of poor infrastructure and poor storage facilities.

**Key words:** GA<sub>3</sub>, micro-perforated bags, papaya and waxing.

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## INTRODUCTION

Cultivation of papaya has spread from tropical Central America, where it originated, to all tropical and warmer subtropical areas of the world. Despite its popularity, little attention has been given to postharvest maintenance and handling, especially in poor resourced countries. Papaya fruits have poor quality outturn and high postharvest losses if harvesting, treatments and handling techniques are inadequate and inappropriate (Medlicott, 2001). The fruit under ambient tropical conditions (30°C) have a maximum storage life of seven days (Maharaj, 1988). It is this short shelf life resulting in to poor quality that limits their export to distant markets after harvest. Most of the postharvest losses of the fruit occurs during the unwanted or/and uncontrolled ripening of the fruit after harvest. These losses can assume a considerable economic and social importance, especially in tropical

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regions, which include a large proportion of the developing countries (Wills *et al.*, 1998) and which suffer from lack of storage facilities. Understanding the biological and environmental factors involved in fruit deterioration and use of postharvest technology procedures is, therefore, important because it has implications to delay senescence and maintain the best possible quality (Kader, 1992). It has been reported previously that lower storage temperature by reducing weight loss, respiration rate and colour development retards fruit ripening and thus increases shelf life. But this becomes difficult to apply in most of the tropical areas where there is lack of storage facilities. Packaging and handling systems were found to improve postharvest life of papaya fruit. According to Lazan, Ali and Sim (1990) fruit weight loss was reduced considerably by packaging in polyethylene bags as compared to non-sealed control fruits. However, it was noted by many workers that high build up CO<sub>2</sub> and development of off flavour was evident inside the polyethylene bag as the bags were highly impermeable (Miller, Spalding and Hale, 1986; Nunes *et al.*, 1998). It was, also reported by Parikh, Nair and Modi (1990) where possibility of controlling mango fruit ripening by plant growth regulators was discussed. However, most of the reports were conducted under developed countries with full storage chains and facilities, which was aimed at export purpose. Apart from this Ferris (1997) added that GA<sub>3</sub> was only effective to retard ripening at high humidity but not at low humidity. Similarly in all the above methods very little information is available concerning to the quality of the fruit after harvest.

This experiment was conducted to investigate and evaluate the effect of packaging material micro perforated (to avoid off flavour development) and postharvest treatments including growth regulator (GA<sub>3</sub>), and waxing on the postharvest maintenance and shelf life of papaya cv. Hortus Gold within the context of poor infrastructure. The finding of the current study would contribute to minimize the excessive postharvest loss witnessed in most developing countries like Eritrea with poor or limited storage facilities.

## **MATERIALS AND METHODS**

Papaya fruits (*Carica papaya* cv. Hortus Gold) were obtained from Ukulinga, the University of Natal experimental farm in Pietermaritzburg, KwaZulu-Natal, South Africa. For this study freshly harvested, clean, bright, firm and bruise free fruits were used. On arrival at the laboratory of the Horticultural Science Department, University of Natal, fruits were washed with tap water and dipped in a fungicide solution containing 670g/1000L (w/v) of Magnate sulphate® (Makhteshim-Agan, Israel). After drying in air, fruits were randomized to the following treatments with five replications to each treatment: Control (untreated), GA<sub>3</sub>, Waxing (citrus carnauba), or micro-perforated bags with 9 µm perforation and coated with anti-mist (MPB). For GA<sub>3</sub> fruits were dipped into an aqueous solution of 100 ppm for 30 min. For the wax treatments, fruits were lightly waxed with citrus carnauba using a cloth, and allowed to dry. Fruits were then stored at 5.5, 7, 10 or 22°C while at the same time data for PWL, firmness, colour change, and respiration rate were recorded weekly. Fruits were allowed to ripen at the designated temperature naturally until the visually table ripe stage (scale 6) and fruits moved to room temperature for final ripening. Time taken to ripen was noted and used to determine the shelf-life. After fruits were fully ripened, a portion of the fruit pulp was cut longitudinal (from end to end) to minimize within fruit variation in sugar concentrations (Garner *et al.*, 2001) and stored in a deep freezer for further analysis of TSS, pH, TA and sugar: acid ratio. All data were subjected to analysis of variance (ANOVA) using the GenStat® 5<sup>th</sup> edition (VSN, 2001). Treatments were compared at P<0.05 according to Fisher's protected LSD Test.

### **Physico-chemical Analyses**

Each fruit was weighed before any treatment was applied. At weekly intervals fruits were reweighed and PWL calculated. Firmness of the fruit was measured using mechanical densimeter, USA, with a reading ranging from 0-100 (the higher the reading the firmer the fruit and vice versa). Data was taken from two different sides of the fruit and the mean result was calculated. Colour change of the fruits was scored numerically using a standard banana ripening chart with colour plates ranging

from 1-7 where: 1=green; 2= green with yellow tracks; 3= more green than yellow; 4=more yellow than green; 5=yellow with green tips; 6=all yellow and 7= yellow flecked with black spots. The respiration rate of each fruit was determined in terms of CO<sub>2</sub> release using an Infra Red Gas Analyzer (IRGA). Each fruit was placed in a separate enclosed jar of seven-liter volume. The CO<sub>2</sub> release was monitored after 10 min by determining the increase in CO<sub>2</sub> concentration in to the jar. TSS was determined from a finely ground fresh (5g) sample, homogenized with 5mL-distilled water according to (Illeperuma and Jayasuriya, 2002). The homogenate was then centrifuged (Sorvall RC 5C Plus, USA) at 6000g for 10min. The TSS of the supernatant was measured using hand held digital refractometer (PR-101, 0-45%, ATAGO,CO, Ltd, Japan). The supernatant was diluted to 80mL with distilled water and pH was measured with a pH meter (Corning 430, USA) (Garner *et al.*, 2001). The diluted supernatant was titrated against 0.1N NaOH until pH 8.1-8.3 and TA expressed as percentage malic acid (Illeperuma and Jayasuriya, 2002). Sugar:acid ratio was then calculated as TSS/TA.

## RESULTS

### Percentage weight loss (PWL)

Increased weekly PWL of fruits was evident for all fruits as the storage period and temperature increased (Fig 1). Most of the water loss (as measured by weight loss) was probably due to fruit transpiration. Highest and most rapid weight loss was noted from fruits stored at 22°C, which may be associated with the effect of temperature on transpiration rate. Although this result agrees with the previous result by Aung *et al.* (1996), the current experiment reveals that the effect of the treatments overcome this detrimental effect of temperature with regard to weight loss. MPB showed reduced PWL significantly ( $P<0.001$ ) as compared to the other treatments. Several workers reported similar results (Chen and Paull, 1986; Lazan *et al.*, 1990) in papaya (Hobson and Burton, 1989) in tomato and mushroom (Miller *et al.*, 1983; Singh and Janes, 2001) in mango and (Wang, 1999) in many other fruits. The authors reported that polyethylene packaging markedly reduced fruit weight loss. This reduced weight loss due to sealed MPB can be ascribed to the effect of modified atmosphere (MA) around the fruit on the transpiration or evaporation from the fruit surface. Maintaining the micro atmosphere of the produce brings about saturation thus transpiration loss is minimized and there is no shrinkage or shrivelling of the produce (Salunkhe, Bolin and Reddy, 1991; Wills *et al.*, 1981). Although all the above workers reported reduced PWL due to polyethylene bags, high build up of water vapour, however, was evident inside bags, which leads fruit fermentation and mould development especially at higher storage temperatures. To avoid this problem in this experiment micro perforated bags coated with anti mist was used. And thus there was no build up of water vapour inside the bag as it was designed with small perforations to allow some gas exchange. MPB was also effective at lower storage temperatures of 5.5°C. It was reported by Wills *et al.* (1998) chilling injury may cause high water loss due to surface pitting. Although all the fruits at this storage temperature suffered chilling injury especially when they transferred to room temperature for ripening still MPB exhibited significantly ( $P<0.001$ ) lower weight loss as compared to the other treatments. As a result fruits were stored for 50, 45, 38, 20 days at 7, 5.5, 10 and 22°C without any visible damage to the fruits. Reduced PWL of MPB was followed by waxing at all storage temperatures (Fig 1). This is in general agreement with previous results (Chen and Paull, 1986; Sankat and Maharaj, 1997) in papaya and (Khader, 1992) in mango. This can be related to the permeability effect of waxing whereby fruit transpiration rate and water loss is reduced. Sankat and Maharaj (1997) and Meheriuk and Porrit (1972) added in their report that waxing not only reduced water loss (and shrivelling) but served a twofold purpose by improving the fruit appearance to consumer as well. This experiment proved the effect waxing to reduce weight loss both at lower and higher storage temperatures, which revealed its applicability indifferent environmental condition including tropical environments. Many workers reported that untreated fruits lose water rapidly during storage hence deteriorate rapidly. This report held true in this experiment as well, as a result maximum storage of fruit was 43, 41, 29 and 15 days as compared to waxing with 48, 55, 42 and

21 days at 5.5, 7, 10 and 22°C, respectively. GA<sub>3</sub> in most cases resulted in retarded PWL as compared to control fruits. This is in agreement with previous results (Khader, 1992) in mango fruits. GA<sub>3</sub> exhibited a significant delay in ripening as evidenced by colour and aroma and also the biochemical changes in constituents measured during storage. GA<sub>3</sub> significantly ( $P < 0.001$ ) reduced weight loss at 10 and 22°C as compared to control, but at 5.5 and 7°C an effect was only seen when the fruits were transferred to room temperature after storage of seven weeks.

Although the role of GA<sub>3</sub> on PWL is not clear its effect to reduce PWL at higher storage temperatures implies the potential feasibility of this treatment as an alternative method in tropical environment. Although improper storage or environmental temperatures causes about detrimental effect to the fruit both in quality, and shorten shelf life, appropriate handling and treatments will minimise the problem. It was reported by (Arjona, Matta and Garner, 1992; Aung *et al.*, 1996; Pekmezci, Erkan and Gübbük, 1997) that increased temperature increased weight loss and thus decrease shelf life. However, from this results it can be inferred that MPB, waxing and GA<sub>3</sub> have the potential for possible prevention of fruit weight loss and hence increased shelf life both at high and low storage temperature.

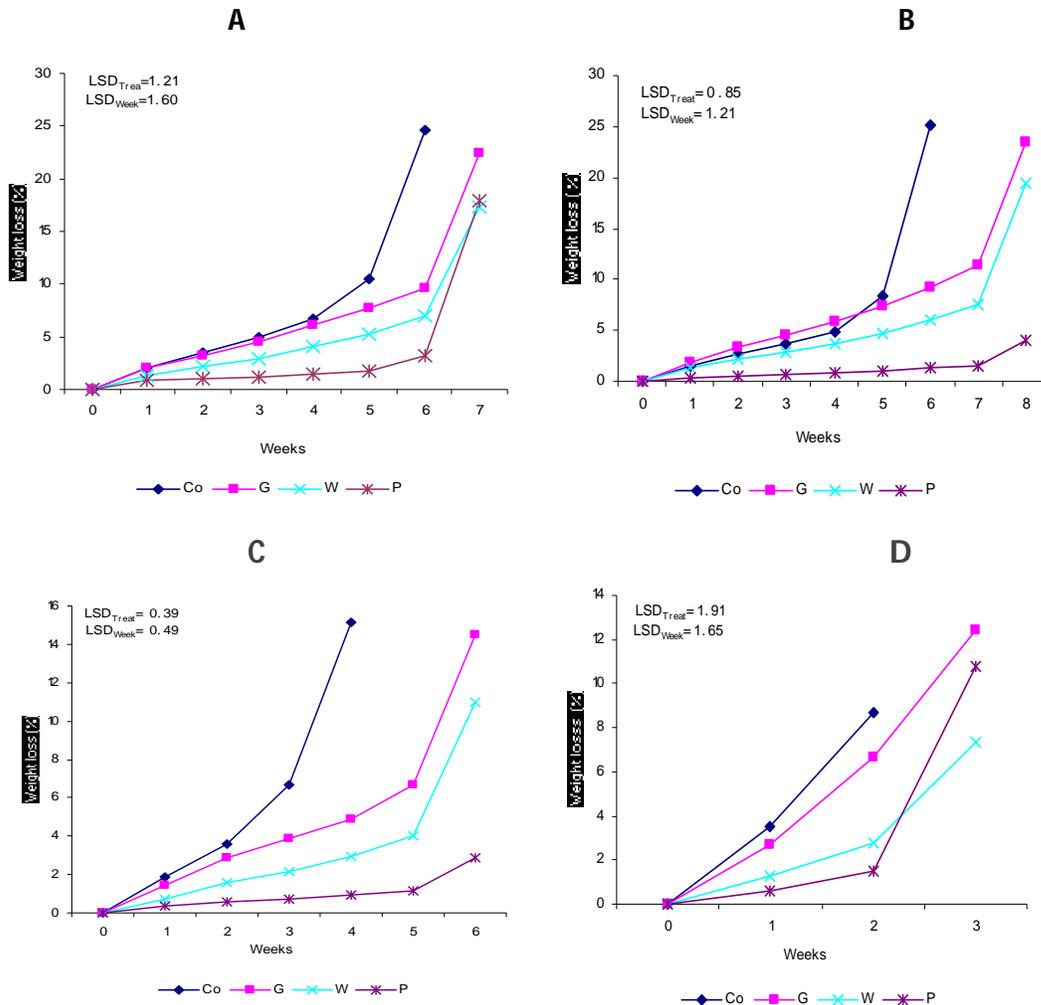


Fig 1: Percentage weight loss of papaya fruits during storage as affected by pre-storage treatments and storage temperatures; at 5.5°C (A), at 7°C (B), at 10°C (C) and 22°C (D). For all figures, data points are means of five replicates. Least significant difference (LSD) at 5% level for treatments (LSD<sub>Treat</sub>) and time (LSD<sub>Week</sub>) are shown. Weight losses for each fruit were monitored to the table ripe stage (scale 6). Note data collection for control fruits terminated shortly. Co=control, G= GA<sub>3</sub>, W=waxing and P= micro perforate polypropylene bag.

### Fruit firmness change

Softening is one of the most significant quality alterations consistently associated with ripening (Aung *et al.*, 1996; Kays, 1991). Hence, control of fruit softening is important for the reduction of mechanical damage and of fruit quality (Smith *et al.*, 1990). All fruits from this experiment exhibited reduced firmness irrespective of treatments as the storage period was extended. This is supported by (Aung *et al.*, 1996; Harker *et al.*, 1997; Lazan, Ali and Selamat, 1993). The authors reported that all the papaya fruits, regardless of their storage treatments, did ultimately experience not only extensive softening but also extensive depolymerization of wall pectins when reaching their full ripe or full yellow stage. The implication of a close link between firmness and PG and PME activity was reported previously by (Kays, 1991; Lazan *et al.*, 1993).

Although softening was evident to all fruits concomitant to ripening there was, however, some variability between the treatments. Waxing performed good results to maintain fruit firmness at all storage temperatures. It significantly ( $P < 0.004$ ) reduced fruit softening at 7, 10 and 22°C as compared to the other treatments (Fig. 2) and thus fruit shelf life was extended. Similar result was reported by (Baldwin, Nisperos-Carriedo and Campbell, 1992; Chen and Paull, 1986) in papaya (Durand *et al.*, 1984) in avocado, and (Meheriuk and Porrit, 1972) in apples where they found reduced fruit softening by waxing. There was rapid and remarkable fruit softening at higher storage temperature of 22°C. This is in general agreement with the report of (An and Paull, 1990) in papaya (Agar *et al.*, 1999) in kiwi fruits.

The storage temperature had a significant effect on both number of days to ripen and the firmness when ripe (Hobson, 1987). Despite of that waxing consistently reduced softening including at higher storage temperatures, which can effectively be used in tropical environment with poor storage facilities. All fruits showed no significant difference ( $P < 0.05$ ) at 5.5°C. All the fruits were hard this may be related to high water loss at 5.5°C that causes fruit wilting and hence, tough skin texture. This can be supported by the latest report of (Amarante and Banks, 2001). The authors found wilting to toughen the flesh and causes higher firmness reading that did not then truly reflect the stage of ripening.

In contrast to this Harker *et al.* (1997) reported that low temperature inhibits a wide range of metabolic process including those associated with fruit softening and the deterioration of various textural attributes. MPB was next effective treatment to overcome the obvious fruit softening during ripening. It significantly ( $P < 0.001$ ) reduced fruit softening at 7°C and showed a trend of reduced fruit softening at 10 and 22°C, especially as compared to control fruits (Fig 2). A similar result was reported by Chen and Paull (1986) in papaya where fruits were less shriveled as compared to control fruits. This is further ascribed to the effect of high CO<sub>2</sub> atmospheres inside the bag, which retard metabolic activity responsible for fruit softening (García, Medina and Olías, 1998; Rosen and Kader, 1989). Previous results (Lazan *et al.*, 1993) in papayas, confirm that seal packaging reduces fruit colour development and softening. All these reports in agreement with the current result confirm the use of MPB for the maintenance of fruit firmness after harvest including at higher storage temperatures. GA<sub>3</sub> showed inconsistent results among the different storage temperatures. It showed a trend of retarded softening at 5.5°C as compared to the control fruits at. This result was in contrast to the reports made by (Desai and Deshpande, 1978; Khader, 1992) where they found retarded softening by GA<sub>3</sub>.

With proper application of waxing (thickness to avoid off flavour) and /or MPB can, therefore, be an alternative method to be used as a postharvest application to retard fruit softening. They performed positively, and decreased softening rate even at higher temperature and thus are recommended.

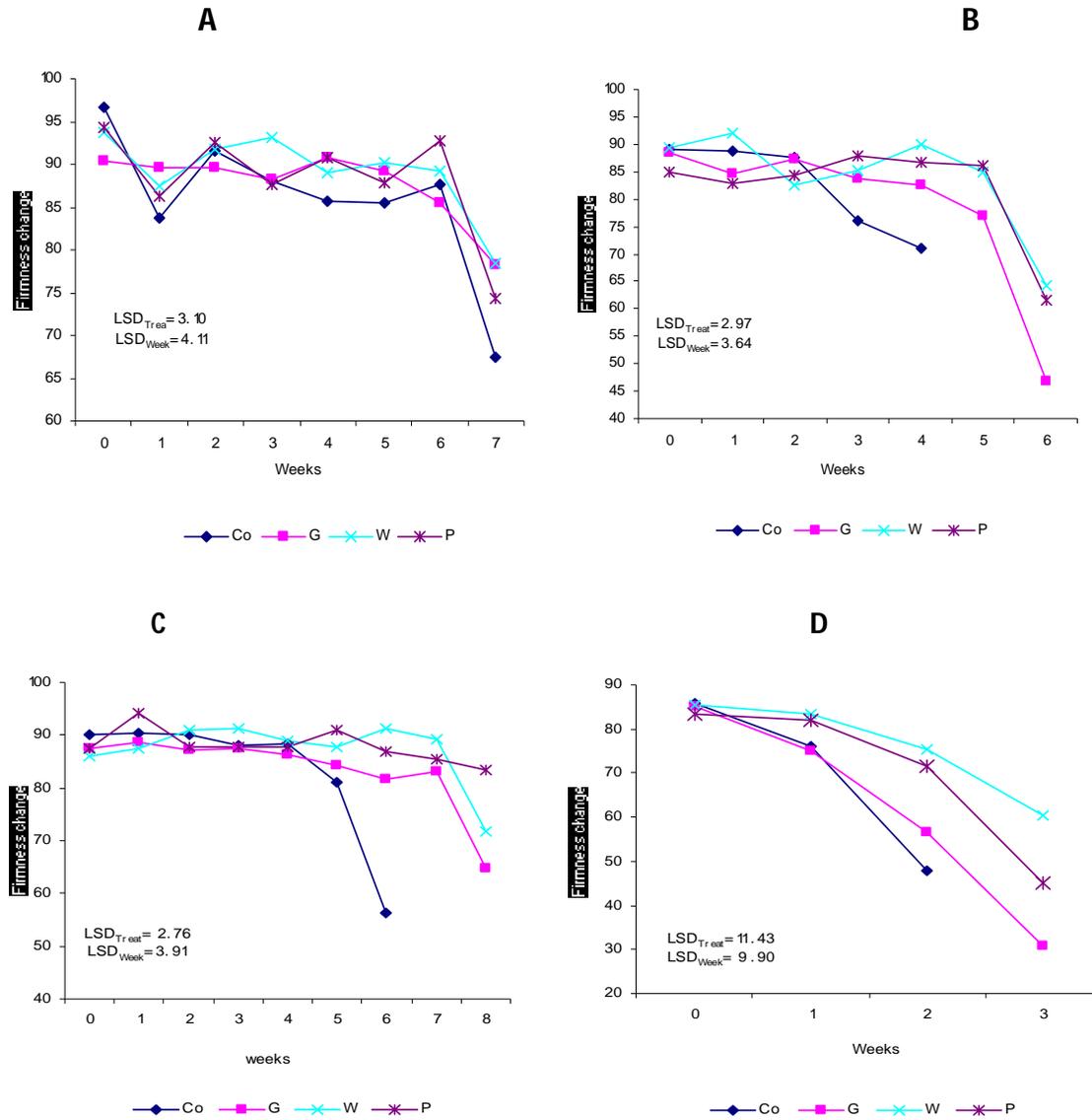


Fig 2: Firmness changes of papaya fruits during storage as affected by pre-storage treatments and storage temperatures; at 5.5°C (A), at 7°C (B), at 10°C (C) and at 22°C (D) For all figures, data points are means of five replicates. Least significant difference (LSD) at 5% level for treatments (LSD<sub>Treat</sub>) and time (LSD<sub>Week</sub>) are shown. Firmness changes for each fruit were monitored to the table ripe stage (scale 6). Note data collection for control fruits terminated shortly. Co=control, G= GA<sub>3</sub>, W=waxing and P= micro-perforated bag.

**Fruit skin colour development**

The external appearance of fruits, particularly their colour, is of prime importance when considering the different attributes, which define quality (de Guevara *et al.*, 1996). Results from this experiment reveal that there was an increase colour development as the storage time was extended in all fruits irrespective of treatment. These observations were in general agreement with Yoneya *et al.* (1990). Colour development was pronounced when storage temperature was increased. Control untreated fruits exhibited significantly more rapid (P<0.001) colour development at all storage temperatures as a result fruits were stored for shorter period (Tables 1-4). Waxing and GA<sub>3</sub> followed by MPB, however, retarded colour change significantly. Waxing performed better to retard colour change as compared to the other treatments at all storage temperatures (Fig 3). This agrees with a previous report

by Olorando (2000) where Tal-pro-long surface coating agent delayed colour development by up to eight days. Paull and Chen (1989) and Sankat and Maharaj (1997) also reported that coated papaya exhibited less colour development than did untreated fruits. This can be conjectured to its limiting permeability to CO<sub>2</sub> and O<sub>2</sub>. Fuchs and Temkin-Gorodeiski (1971) have demonstrated that a high concentration of CO<sub>2</sub> around the fruit interferes with the colour development in banana fruit. However, all the above reports were conducted under favorable storage conditions mainly for export purpose. Fruits at higher storage temperature exhibited higher and remarkable colour change within short period of time. Hence, fruits were stored for a maximum (waxing and GA<sub>3</sub>) of three weeks. Wills and Widjanarko, 1995 reported that ripening time expressed by colour change was reduced at 25 and 30°C as compared to 20°C. This experiment helped, therefore to investigate the positive effect of waxing even at higher storage temperature, which reveals the application potential of the treatment at low resourced tropical environment.

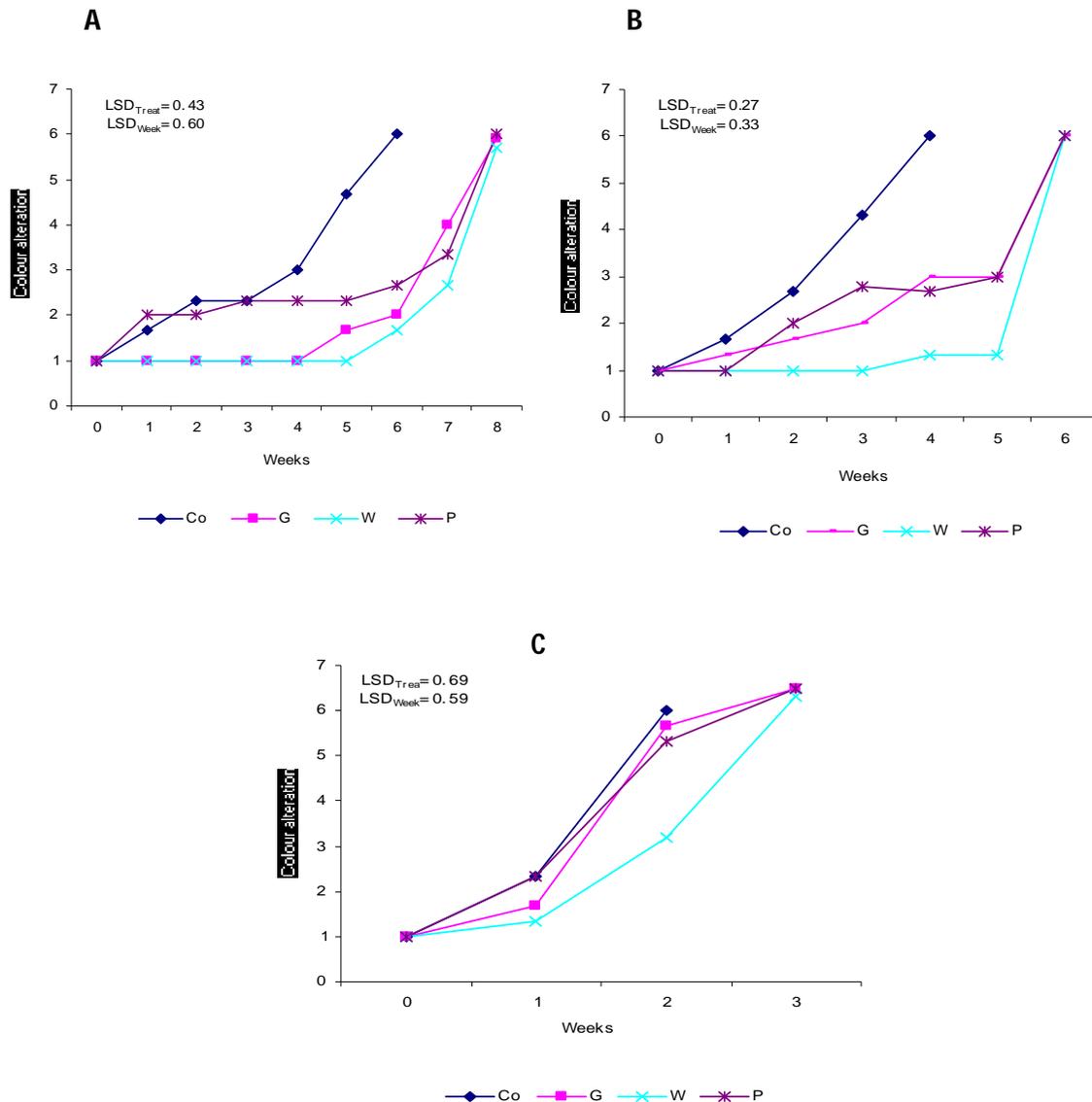


Fig 3 Colour changes of papaya fruits during storage as affected by pre-storage treatments and storage temperatures; at 7°C (A) at 10°C (B) and at 22°C (C). For all figures, data points are means of five replicates. Least significant difference (LSD) at 5% level for treatments (LSD<sub>Treat</sub>) and time (LSD<sub>Week</sub>) are shown. Colour alteration for each fruit was monitored to the table ripe stage (scale 6). Note data collection for control fruits terminated shortly Co=control, G= GA<sub>3</sub>, W=waxing and P= micro perforate bags.

Similarly, the positive effect of GA<sub>3</sub> can be supported by previous results of (Desai and Deshpande, 1978; Salunkhe *et al.*, 1991) in banana (Khader, 1992) in mango and (Vendrell and Palomer, 1997) in other climacteric fruits. The authors reported that GA<sub>3</sub> significantly retarded fruit skin colour development as compared to control fruits. This can be ascribed to the effect of GA<sub>3</sub> to act against fruit senescence, which is characterized by colour development. Apart from this Lazan *et al.* (1990), Paull and Chen (1989) and Sankat and Maharaj (1997) reported that MPB packaging retarded colour development. Mango fruits packed in MPB with small perforations inhibited carotenoid synthesis (Macnish Joyce and Hetherington, 1997; Yantarasir *et al.*, 1995). Modification of O<sub>2</sub> and CO<sub>2</sub> concentration in the atmosphere within and around the fruit by either waxing or MPB and treatment of fruits with GA<sub>3</sub> may therefore be a possible technique to extend shelf life with retarded colour development even at increased environmental temperatures.

**Table 1 Average Physico-Chemical Change of Papaya Fruit after Storage at 5.5°C as Affected by Different Postharvest Treatments**

Treatments	Shelf-life (Days)*	TSS (°Brix)	pH	TA (% malic)	Sugar:acid ratio
Control	43	7.60 <sup>a</sup>	5.39 <sup>a</sup>	1.32 <sup>a</sup>	6.15 <sup>a</sup>
GA <sub>3</sub>	48	7.50 <sup>a</sup>	5.31 <sup>a</sup>	1.35 <sup>a</sup>	7.18 <sup>a</sup>
MPB	45	7.79 <sup>a</sup>	5.06 <sup>a</sup>	1.73 <sup>a</sup>	4.82 <sup>a</sup>
Wax	48	6.49 <sup>a</sup>	5.16 <sup>a</sup>	1.80 <sup>a</sup>	3.85 <sup>a</sup>
LSD	-	1.68	0.39	0.72	3.44
P value	-	NS	NS	0.035	NS

#### Fruit respiration rate

The climacteric patterns of ethylene production and respiration rate can be used as a means to measure physiological status or degree of ripening of the fruit (Strydom, 1991) and deterioration in postharvest life (Wilson, Boyette and Estes, 1999). From this experiment it was noted that treatments affected the rate differently at different storage temperatures. This experiment proves the theory behind the direct relationship of temperature and respiration rate. Similar result was reported (George and Marriott, 1985; Salunkhe *et al.*, 1991) in plantains (Yahia, 1998) in papaya. Fruits at 22°C exhibited higher respiration rate during storage period. Subsequently, fruits were deteriorated rapidly as a result they were only able to be stored for a maximum of three weeks.

**Table 2 Average Physico-Chemical Change of Papaya Fruit after Storage at 7°C as Affected by Different Postharvest Treatments**

Treatments	Shelf-life (Days)*	TSS (°Brix)	pH	TA (% malic)	Sugar:acid ratio
Control	41	9.17 <sup>ab</sup>	4.56 <sup>a</sup>	2.58 <sup>b</sup>	3.85 <sup>a</sup>
GA <sub>3</sub>	53	7.70 <sup>a</sup>	4.86 <sup>a</sup>	2.42 <sup>b</sup>	3.21 <sup>a</sup>
MPB	50	9.40 <sup>b</sup>	4.36 <sup>a</sup>	2.48 <sup>b</sup>	3.81 <sup>a</sup>
Wax	55	7.57 <sup>a</sup>	4.95 <sup>a</sup>	1.69 <sup>a</sup>	4.48 <sup>a</sup>
LSD	-	1.68	0.39	0.72	3.44
P value	-	NS	NS	0.035	NS

**Table 3 Average Physico-Chemical Change of Papaya Fruit after Storage at 10°C as Affected by Different Postharvest Treatments**

Treatments	Shelf-life (Days)*	TSS (°Brix)	pH	TA (% malic)	Sugar:acid ratio
Control	29	8.23 <sup>a</sup>	4.36 <sup>a</sup>	1.43 <sup>a</sup>	5.61 <sup>a</sup>
GA <sub>3</sub>	42	7.87 <sup>a</sup>	4.48 <sup>a</sup>	2.12 <sup>ab</sup>	4.39 <sup>a</sup>
MPB	38	7.60 <sup>a</sup>	4.62 <sup>a</sup>	2.57 <sup>b</sup>	4.17 <sup>a</sup>
Wax	42	9.20 <sup>a</sup>	4.74 <sup>a</sup>	2.51 <sup>b</sup>	4.53 <sup>a</sup>
LSD	-	1.68	0.39	0.72	3.44
P value	-	NS	NS	0.035	NS

**Table 4 Average Physico-Chemical Change of Papaya Fruit after Storage at 22°C as Affected by Different Postharvest Treatments**

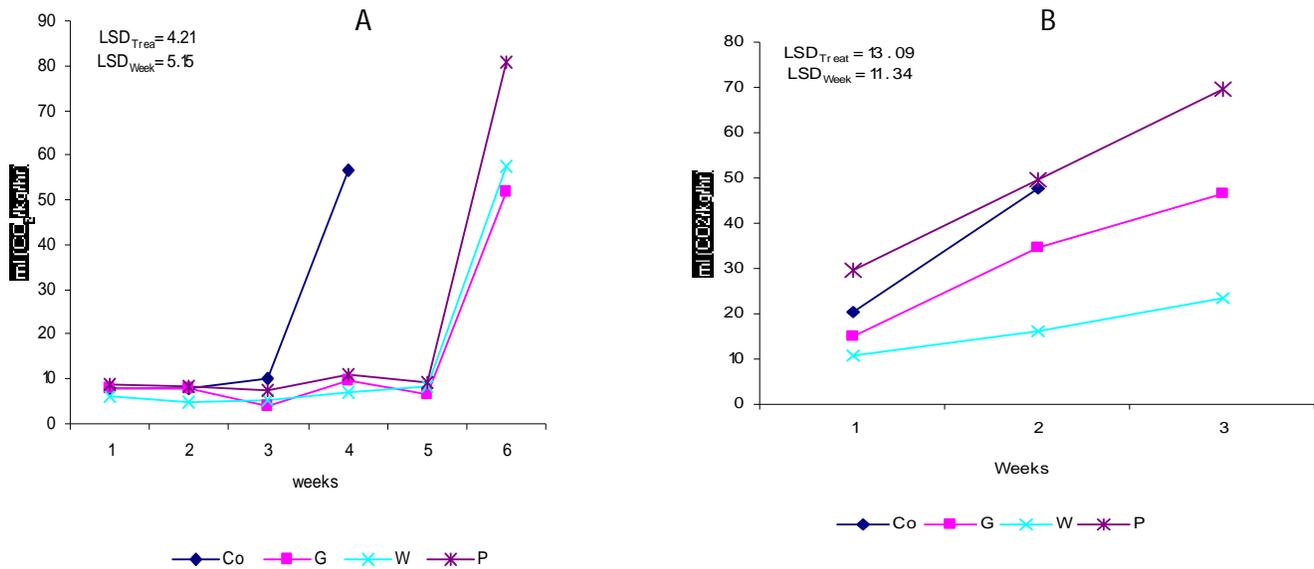
Treatments	Shelf-life (Days)*	TSS (°Brix)	pH	TA (% malic)	Sugar:acid ratio
Control	15	8.20 <sup>ab</sup>	4.70 <sup>a</sup>	2.13 <sup>a</sup>	4.06 <sup>a</sup>
GA <sub>3</sub>	21	7.13 <sup>a</sup>	4.85 <sup>a</sup>	1.90 <sup>a</sup>	3.77 <sup>a</sup>
MPB	20	9.70 <sup>b</sup>	4.48 <sup>a</sup>	2.16 <sup>a</sup>	4.84 <sup>a</sup>
Wax	21	6.93 <sup>a</sup>	4.93 <sup>a</sup>	1.81 <sup>a</sup>	3.97 <sup>a</sup>
LSD	-	1.68	0.39	0.72	3.44
P value	-	NS	NS	0.035	NS

Means in each columns of all tables followed by the same letter are not significantly different at 5% level. NS= Not Significant.

\* Days were determined when the fruit reaches table ripe stage (Scale -6)

Waxing and GA<sub>3</sub> significantly reduced ( $P < 0.001$ ) respiration rate at all storage temperatures. It was noted that all the waxed fruits exhibited a lower respiration rate and the least colour and firmness change. Waxing was effective at extending the shelf-life even at higher temperature (22°C). Waxed fruits exhibited a respiratory climacteric after 15 days at 22°C, 35 days at 10°C, 42 days at 5.5°C and 50 days at 7°C only when fruits were transferred to room temperature for final ripening, whereas control fruits showed respiratory climacteric after 7, 21 and 35 days at 22, 10, 7 and 5.5°C, respectively (Fig 4). A similar result was reported recently by Amarante and Banks (2001) noting that coating delayed ripening of fruits at higher temperature as compared to lower temperature storage. Waxing restricts O<sub>2</sub> diffusion into the fruit (Durand *et al.*, 1984) and exerts its effect on skin permeance by blocking a greater or lesser proportion of the pores on the fruit surface (Amarante and Banks, 2001). This in turn, limits fruit respiration rate. Waxing thus has the potential to extend the storage life of fruits at higher temperatures in a tropical environment. The positive effect of GA<sub>3</sub> also agrees with previous results for papaya (Mehta Shiva and Raju, 1986) and for tomato (Babbitt, Powers and Patterson, 1973). The shelf-life extension by GA<sub>3</sub> can be attributed to a decrease in respiration rate as a result of less succinate and malate dehydrogenase activity associated with the TCA cycle (Mehta *et al.*, 1986). Similarly, Salunkhe *et al.* (1991) reported that GA<sub>3</sub> markedly retards colour change, the climacteric peak and the respiration rate of both, tomato and

banana. This reduction of ripening and the increase in shelf-life is related to the inverse relationship of respiration rate and shelf-life (Paull and Chen, 1989). On the other hand, MPB exhibited significantly higher ( $P < 0.001$ ) rate of respiration at 10 and 22°C storage temperatures as compared to the other treatments. This agrees with a previous report for papaya by Lazan *et al.* (1990) and for strawberry by García *et al.* (1998) and may be attributed to the differential permeability of the bags. The film provided a barrier to normal atmospheric conditions and as a result fruits within the film presumably exposed to lower O<sub>2</sub> and higher CO<sub>2</sub> than the ambient atmosphere. It has been reported by Zagory (1998) that an elevated CO<sub>2</sub> suppresses plant tissue sensitivity to the effect of the ripening hormone ethylene, which results in an increased respiration rate. However, when the fruits were removed from the bag (for measurement of respiration), the fruits started to respire rapidly after they were exposed to ambient higher O<sub>2</sub> concentration. This might be the cause for the increased measurement of respiration rate of fruits in MPB. Although the increased CO<sub>2</sub> level inside the bag retards respiration rate, CO<sub>2</sub> concentration beyond the tolerable level, however, might cause undesirable damage to the fruit. Polyethylene bags apart from their ability to reduce water loss may cause high build-up of CO<sub>2</sub> inside the bag, which can result in off-flavour and decay. According to Tan and Ali (1989) high build-up of CO<sub>2</sub> inside the bag leads to cellular disorganization and subsequent tissue collapse manifesting itself as CO<sub>2</sub> injury. Interestingly, there was no any off-flavour development, fruit decay and/or CO<sub>2</sub> injury to the fruits in this experiment. This may be related to the kind of packaging used. The micro-porous and micro-perforated films allow much more rapid gas exchange than other plastic films (Zagory, 1998). It has been reported that relatively increased hole size and number provides better ventilation and gas exchange, however, this may be at the expense of excessive water loss. If the high build-up of CO<sub>2</sub> inside the MPB can be reduced by any means, such packaging could become the most effective method to store fruits for an extended period



**Fig 4** Respiration rates of papaya fruits during storage as affected by pre- storage treatments and storage temperatures; at 5.5°C (A) at 7°C (B), at 10°C (C) and at 22°C (D). For all figures, data points are means of five replicates. Least significant difference (LSD) at 5% level for treatments (LSD<sub>Treat</sub>) and time (LSD<sub>Week</sub>) are shown. Respiration rate for each fruit was monitored to the table ripe stage (scale 6). Note data collection for control fruits terminated shortly. Co=control, G=GA<sub>3</sub>, W=waxing and P= micro-perforated bag

**Physio-chemical change in fruits**

There was no significant difference ( $P < 0.05$ ) among treatments and storage temperatures for fruit TSS, although waxing and GA<sub>3</sub>, in most cases, showed a trend to a lower value (Tables 1-4). As the ripening process is retarded by GA<sub>3</sub> (Desai and

Deshpande, 1978; Khader, 1992) and waxing (Paull and Chen, 1989) so is the TSS level of the fruits. On the other hand, control fruits and MPB exhibited a trend toward an increased TSS value. This was evident at all storage temperatures. This increased level may be related to increased water loss and respiration rate, which may lead to accelerated ripening and deterioration (Ben-Yehoshua, 1985). Similar to these results, no significant difference in TSS was reported for mango for various storage treatments by Yantarasri *et al.* (1995) and for banana by Chamara *et al.* (2000). Although, storage temperature affected fruit TSS content, no trend was visible. The lowest TSS value was determined at 5.5°C, followed by 22°C. On the other hand, fruits at 7°C followed by 10°C exhibited relatively higher TSS values (Tables 1-4). From this result it can be inferred that there was no direct or inverse relationship between TSS and storage temperatures as whole. Therefore, the shelf-life increase either by waxing, GA<sub>3</sub>, and/or MPB did not have any significant effect on the fruit TSS quality.

The pH value of all fruits displayed an opposite pattern to the TSS value, but there was no significant difference ( $P < 0.05$ ) among treatments. This was evident at all storage temperatures. Lazan *et al.* (1990) for papaya and Chamara *et al.* (2000) for banana reported that there were no measurable difference among treatments after fruits were stored for an extended period using various seal-packaging. The change of tissue pH in this experiment appeared to be affected by the storage temperature rather than treatments. Fruits at 5.5 and 22°C exhibited a trend of increased pH content as compared to the 7 and 10°C storage temperatures (Tables 1-4). Waxing, GA<sub>3</sub> and MPB might thus be used to extend the shelf-life without any quality defect to the fruit.

Similar to the other quality parameters the TA value of fruits showed no significant difference ( $P < 0.05$ ) among the treatments used. This was evident at all storage temperatures, which is similar to that of (Chamara *et al.*, 2000) where they reported no significant difference between MA treated and control banana fruits after ripening. The TA value was more affected by temperature than by the treatments. Fruits at 5.5°C exhibited relatively low TA value as compared to the other temperatures. This may be attributed to the effect of temperature on the general physio-chemical activities of ripening fruit (Wang, 1999). Increase TA content during ripening of papaya fruit was reported by (Paull, 1993; Wills and Widjanarko, 1995) and this may be associated partly with the increase of free galacturonic acid during ripening. On the other hand Kays (1999) and Wills *et al.* (1989) reported that during ripening most of the common fruit TA reduced as the acids are used in respiration or converted to sugars. Similarly, Sankat and Maharaj (1997) reported that non-volatile organic acids formed the major portion (about 80-90%) of total acid in fruits; and this decreases as the fruit ripens. This makes it difficult to use TA as a sole parameter to evaluate fruit ripening. As there was no significant difference between treatments, there is a potential of using waxing, GA<sub>3</sub> and MPB as storage techniques with no detrimental harm to the quality.

There was no significant difference ( $P < 0.05$ ) between treatments at all storage temperatures for the sugar:acid ratio. This is also another quality parameter that proves the applicability of these treatments even at higher temperatures. Changes in sugar:acid ratio of all sample fruits showed almost a similar pattern to TSS with the same profile corresponding to treatments. Fruits at 5.5°C exhibited higher sugar:acid ratio as compared to the other storage temperatures. This was related to the lower TA value of the fruits.

## Conclusion

There is a need for technological advances in methods for extending the shelf-life of perishable fruits (Hintlian and Hotchikiss, 1986). Papaya, like most tropical fruits, suffers from the detrimental effect of surrounding temperature affecting the shelf-life considerably. This becomes more pronounced in areas with poor storage facilities, which implies the need for an intervention after harvest to overcome the problem. Although postharvest techniques cannot improve the quality of the fruit, good handling helps to manipulate and maintain initial quality in the best possible manner until consumption (Wang, 1999). This experiment

helped to investigate and identify possible techniques and methods for postharvest maintenance of fruit metabolic activity and thus shelf-life, particularly techniques suited to poor resourced regions. Waxing, GA<sub>3</sub> and MPB reduced postharvest deterioration at all storage conditions. Therefore, these treatments can provide valuable means to retard PWL, softening, colour development and respiration rate (except MPB). Thus all these treatments are recommended as alternative methods to reduce postharvest deterioration of papaya fruit, particularly at higher ambient temperatures. Application of different packaging material, notably micro-perforated bags coated with anti-mist, reduced the high build-up of CO<sub>2</sub> inside the bags. This type of packaging material overcomes the common drawback of polyethylene bags to cause high build-up of CO<sub>2</sub>. No pathological decay development and/or off-flavour symptoms commonly known as CO<sub>2</sub> injury were observed. It is, therefore, advisable that MPB to be used as a postharvest treatment to extend fruit shelf-life. Determination of certain quality parameters (TSS, TA, pH and sugar:acid ratio) after storage showed no significant difference among treatments at any of the storage temperatures. This indicates the feasibility of using waxing, GA<sub>3</sub> and MPB to extend fruit shelf-life with no significant effect to fruit quality.

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