Incidence of Chilling Injury in *Salacca zalacca*

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THE susceptibility of tropical and subtropical fruits to chilling injury has been widely reported in the literature (Lyons 1973; Couey 1982; Brown 1986; Wills et al. 1989; Kays 1991). At temperatures of 0–13°C the tissues of many horticultural crops of both temperate and tropical origin weaken because of the failure to maintain normal metabolic activities (Wang 1992).

In bananas cv. Lady Fingers it has been reported that chilling injury is only a slight problem when they are stored at 12.5°C (Mahendra et al. 1992). Low temperature storage is widely used to extend fruit shelf life. For fruit with a marked seasonal production or in fruits that are transported over considerable distances resulting in a long period between harvesting and consumption, there is a need to extend the shelf life of the product. The sensitivity of tropical fruit to chilling limits the use of reduced temperature as a means of preserving fresh fruit for consumption at some later time.

While there have been detailed reports of the low-temperature susceptibility of many tropical fruits, there appears to have been limited work on the incidence of chilling injury in salak (*Salacca zalacca*). The plant which produces the edible fruit, salak, belongs to the lepidocaryoid palms (Beccari 1918, in Mogea 1978) which include sago and raphia palms. The fruit has a scaly pericarp containing three creamy, edible, fleshy 'fruits' of varying size. The edible parts are not fruits botanically, but fleshy arils that surround the brown, stony seeds. The arils are outgrowths of the funiculus (stalk) of each ovule (I.A. Staff, pers. comm. 1993).

Salak has a marked seasonality of production in Bali, the major fruit season being December–February following a minor fruiting in June–July. The fluctuating supply of fruit and the distance it has to travel to markets on other islands dictates a need to extend its shelf life.

The aim of the experiment reported here was to evaluate the effects of storage temperatures between 3 and 32°C on harvested salak fruit, with special attention being given to the occurrence of chilling injuries.

Materials and Methods

Fruit were obtained from a local farmer in Bali. They were picked at maturity about 6 months after flowering. All fruit were examined individually on arrival at the laboratory and only those in good condition were allocated randomly to each treatment in the experiment. The experiment was conducted in a randomised block design (RBD) which consisted of five treatments with 4 replications. The five treatments consisted of storage in air temperatures of 3–5°C, 7–10°C, 15°C, 22–24°C, and at ambient temperatures (29–32°C). Each treatment unit consisted of 10 fruit. An analysis of variance of data from the randomised block experiment was carried out. A square root transformation of data expressed as percentages was applied before analysis (Gomez and Gomez 1976). Further to analysis of variance, where significance was shown, differences between treatments were established using Duncan's Multiple Range Test.

Observations were made on the first visible symptom and on the rate of development of chilling injury using the following score: 0 = none; 1 = slight injury; 2 = moderate injury; and 3 = severe injury (Mahendra et al. 1992). Fruit shelf life was visually assessed daily. Fruit was considered unsaleable and discarded from the experiment when the sample reached 10% damage. The criteria for damage were: mouldy, soft texture, wrinkled, and skin discoloration. Fruit firmness was measured objectively with a fruit pressure tester (Effegi Model FT. 011, Alphonsine, Italy) fitted with a 0.8 cm plunger. The pressure (kg force) required to puncture the fruit was recorded. The mean value of an individual fruit was calculated from three readings taken at three points around the fruit. The fruit weight loss was assessed by subtracting final fruit weight after storage from the initial weight.

Results and Discussion

The most common symptoms of chilling injury observed in the fruit of *Salacca zalacca* were skin pitting and external discoloration. The more severe symptoms were necrotic areas, wilting, and a smoky to dark or brownish black peel colour. Fruit flesh tended to turn brown and became soft textured.

The development of chilling injury in the fruit over time at low temperatures is shown in Figure 1. It was observed that fruit stored at 3–5°C and 7–10°C exhibited chilling injury symptoms after 2 and 3 days (score 1), respectively. The symptoms became moderate (score 2) after 15 days and severe (score 3) after 32 and 33 days of storage at each of the two lowest temperature regimes (3–5° and 7–10°C). Chilling injury of the

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fruit pulp was indicated by flesh that had turned brown and soft. No symptoms of chilling injury were observed on fruit stored at 15°C or above. These results indicate that the fruit of *Salacca zalacca* are as susceptible to chilling injury as other tropical and subtropical fruit.

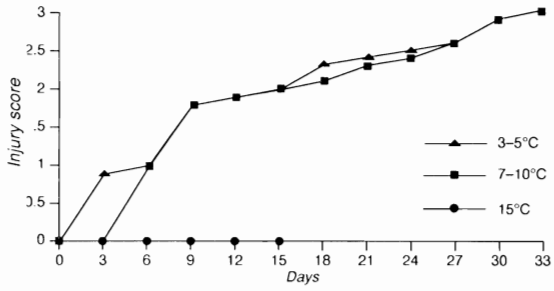

Figure 1. The pattern of development of chilling injury in fruit of *Salacca zalacca*.

The longest storage life was shown by fruit stored at 3–5°C (25 days), followed by fruit stored at 7–10°C (23 days) (Fig. 2.). However, both these groups suffered from moderate to severe chilling injury. While the storage life of the fruit was extended 15 and 14 days, respectively, in the two lowest temperature conditions compared with fruit stored under ambient temperatures, this advantage was offset by moderate to severe chilling injury. Cooling the fruit to 15°C achieved a gain in storage life of only 2.5 days with no chilling injury evident. This result represents only marginal improvement in storage life which would be of limited value to local and regional marketing of the fruit and of little assistance to the exported product.

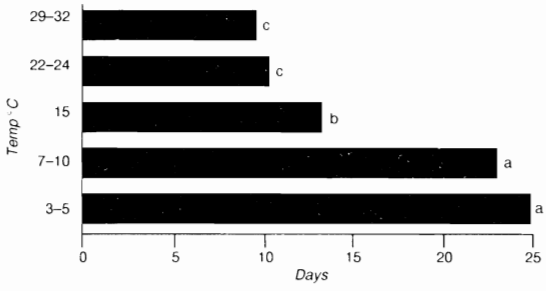

Figure 2. Storage/shelf life of fruit of *Salacca zalacca* stored under different temperature regimes. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

The fruit firmness was measured after 0, 7, 14, 21, and 28 days at each of the temperature regimes (Fig. 3). No significant difference ($P > 0.05$) in the value of fruit pulp firmness was observed on day 0, with the values for the determination ranging from 6.1–6.8 kg force. Fruit firmness deteriorated with an increase in storage temperature. It was observed that fruit stored at ambient temperature (29–32°C) had the lowest value measured after both 7 (5.8 kg force) and 14 days (3.0 kg force). Fruit stored at 3–5 and 7–10°C showed an increase in fruit firmness measured after 7 days (8.55 and 8.0 kg), which then decreased gradually after 14 days (6.6 and 8.0 kg), 21 days (6.5 and 6.8 kg), and 28 days (6.4 and 6.3 kg), respectively. A rapid decrease in fruit firmness during storage was observed on fruit stored at 15 and 22–24°C measured after 7 days (8.0 and 7.2 kg) and 14 days (8.0 and 5.8 kg), respectively.

Fruit weight loss was measured over the period of 1–4 weeks at each of the temperature treatments. It was observed that percentage of fruit weight loss increased significantly with increase in storage time (Fig. 4). The lowest value was observed on fruit stored at 3–5 and 7–10°C measured after either 1 (9.8 and 8.9%) or 2 weeks (14.2 and 14.5%), while a significantly higher percentage of weight loss was observed on fruits stored at 15, 22–24, and 29–32°C measured after 1 (16.9, 15.3, and 13.7% and 2 weeks (22.9, 23.6, and 22.4%), respectively. The fruit stored at the two lowest temperatures lost a considerable amount of water at 3 weeks (18.1 and 18.9%), and 4 weeks (21.0 and 22.9%), respectively. These results indicate that considerable fruit weight loss occurred over the storage period and methods to control this loss may be worth investigating.

Conclusion

Cooling was shown to extend the storage life of the fruit of *Salacca zalacca* by up to 15 days but the low temperature treatments imposed, namely 3–5°C and 7–10°C caused moderate to severe chilling injury. Methods that may reduce the incidence of chilling injury in the fruit need to be researched if the benefits of increased storage life by refrigeration of the salak fruit are to be realised.

Acknowledgments

The authors wish to thank Dr B.R. Champ (Research Program Coordinator) of ACIAR (Australian Centre for International Agricultural Research), and AFHB (ASEAN Food Handling Bureau) who financially supported the presentation of this paper. The authors also wish to thank I.G.P.A. Anom, L. Suryati, I.B.W. Gunam, and IAEUP (Indonesia Australia Eastern Universities Project) who made this paper possible, and Dr Ian Staff for his helpful comments.

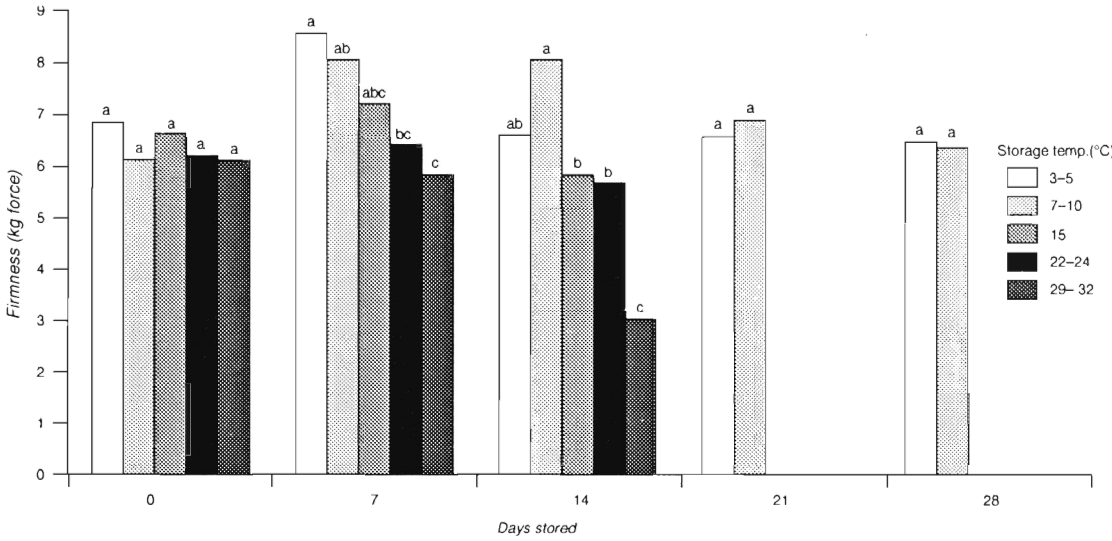

Figure 3. The effect of storage temperature on the firmness of fruit over the period of storage. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

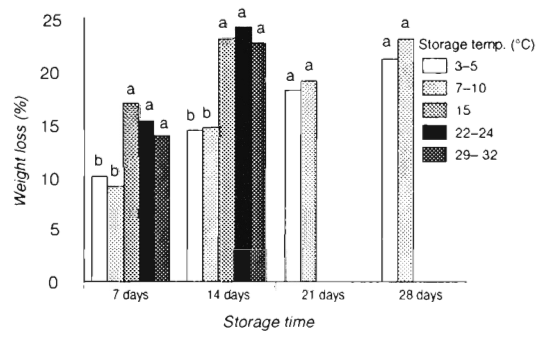

Figure 4. Percentage weight loss of the fruit of *Salacca zalacca* stored at the different temperatures over the period of storage. The same letters indicate that there is no significant difference between means at the 0.05 level of probability.

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Internal Carbon Dioxide and Ethylene of Avocado Fruit (*Persea americana* Mill.) Measured by an Equilibration Technique

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RIPENING of avocado fruit does not occur as long as the fruit remains attached to the tree (Schroeder 1953; Tingwa and Young 1975). Changes in the internal atmosphere of avocado fruit after harvest are associated with ripening (Burg and Burg 1962a; Ben-Yehoshua et al. 1963). The means used for obtaining the internal atmosphere of avocado fruit include vacuum extraction (Burg and Burg 1962a,b; van Eeden et al. 1990) and sampling from a cavity bored in the fruit mesocarp (Ben-Yehoshua et al. 1963).

The purpose of the present study was to measure the internal concentrations of carbon dioxide (CO_2) and ethylene of mature avocado fruit during preharvest and postharvest periods. A non-injurious equilibration technique was used to obtain samples of atmosphere in equilibrium with the internal atmosphere of the fruit.

Materials and Methods

Five uniform fruit were tagged on each of 2 'Hass' avocado trees. Glass tubes (1.8-2.0 mL internal volume), each with a septum secured beneath a screw cap, were attached with Blu-tack® [Bostik (Australia) Pty Ltd] to the widest circumference of these fruit (Fig. 1). Two 0.2 mL gas samples were withdrawn for each fruit for analysis of CO_2 and ethylene. A Shimadzu GC-8A gas chromatograph (TCD detector) operated at oven and detector temperatures of 20 and 30°C, respectively, was used to measure CO_2. A Shimadzu GC-8A gas chromatograph (FID detector) operated at oven and detector temperatures of 80 and 120°C, respectively, was used for ethylene measurement. The lower limit of detection was approximately 0.004 µL ethylene/L in a 10 mL air sample (V. Robertson, pers. comm.).

After sampling on the tree for 15 days the 10 fruit were harvested and randomly allocated to two sample lots. The samples of unwrapped and wrapped (PWGS cling-wrap plastic film) fruit were then held at 20°C and 50-60% relative humidity. CO_2 and ethylene concentrations in the attached tubes were generally measured daily. Fruit colour changes were monitored using a colour rating scale of 0 (green), 1 (25% darkening), 2 (50% darkening), 3 (75% darkening), and 4 (100% darkening).

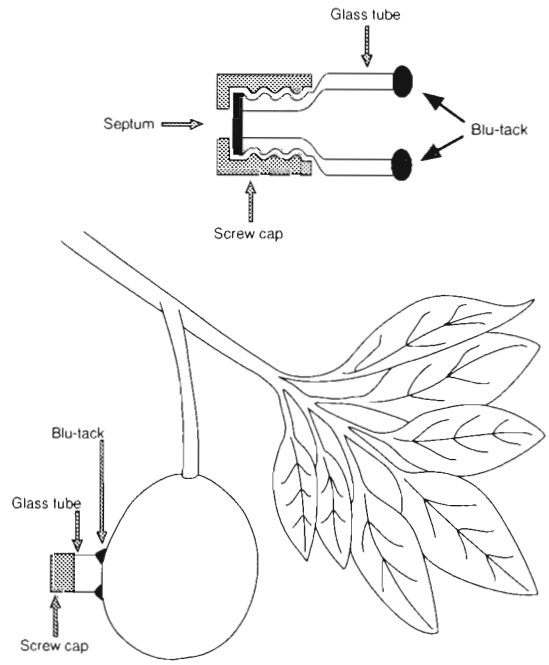

Figure 1. Gas equilibration system used for obtaining samples of the internal atmosphere of 'Hass' avocado fruit.

Results and Discussion

No measurable internal ethylene was detected during the preharvest period (Fig. 2). Thus, preharvest equilibrium ethylene concentrations were in the order of 0.004 µL/L or less. Ethylene was first detected 7 and 15 days after harvest in unwrapped and wrapped fruit, respectively (Fig. 2).

Burg and Burg (1962a) found by vacuum extraction that the internal concentration of ethylene in 'Cho-

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quette' avocados at the time of harvest ranged from <0.01 to 0.06 μL/L. The lowest concentration of ethylene which could be measured in their study was 0.01 μL/L. Very low ethylene concentrations in 'Hass' avocados 4 days after harvest were determined in gas samples obtained by partial vacuum extraction (van Eeden et al. 1990). The absence of detectable ethylene before the climacteric peak could indicate a difference between the equilibration and vacuum extraction techniques. Vacuum extraction may remove dissolved or bound ethylene from the tissue, not just from the intercellular space.

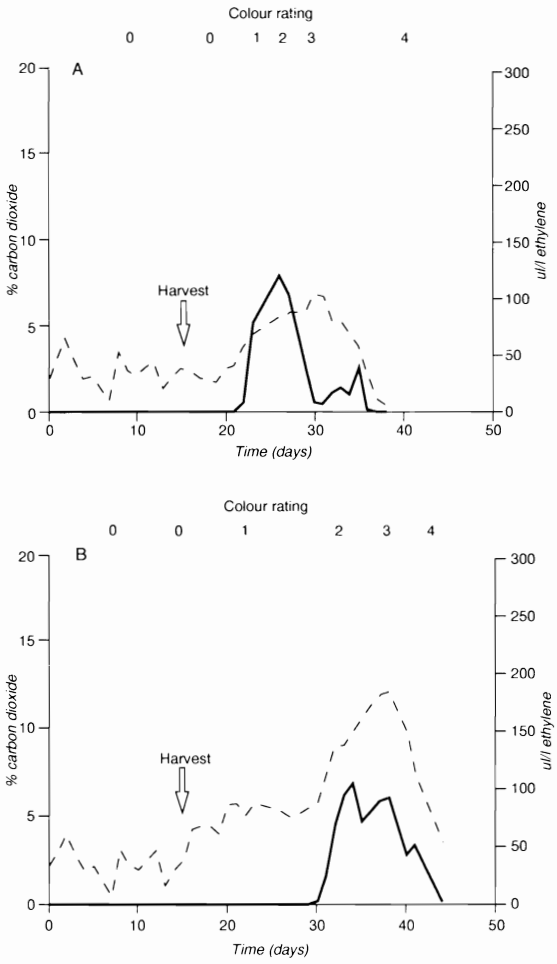

Figure 2. The average internal concentrations of CO_2 (dashed line) and ethylene (solid line) and colour rating of unwrapped (A) and wrapped (B) avocado fruit. Data represent 5 fruit. Arrow indicates the time of harvest.

Concentrations of CO_2 fluctuated around 1–4% before harvest (Fig. 2). After harvest, CO_2 concentrations in wrapped fruit were consistently higher than in unwrapped fruit (Fig. 2). The peak CO_2 concentrations for unwrapped and wrapped fruit were recorded 15 and 23 days after harvest, respectively (Fig. 2). Peak ethylene concentrations in unwrapped and wrapped fruit occurred 11 (at colour rating 1–2) and 19 (at colour rating 2–3) days after harvest, respectively (Fig. 2).

Film wrapping with PGWS film after harvest increased the internal CO_2 concentration from 1–4% to 5–7% during the preclimacteric period and delayed peak CO_2 and ethylene levels (Fig. 2). Wrapping also delayed fruit colouring (Fig. 2). Similarly, Joyce and Shorter (1992) reported that wrapping in LDPE cling film extended the green life of 'Hass' avocado fruit, with an associated decrease in the rate of water loss and an increase in CO_2 concentrations beneath the wrap.

Attaching vials to the surface of avocado fruit with Blu-tack to obtain equilibrium atmosphere samples was used successfully during both pre- and postharvest periods. The technique is simple and non-destructive, and appears to be a valid means for measuring internal CO_2 and ethylene concentrations for avocado. Film wrapping after harvest increased the internal CO_2 concentration and delayed peak CO_2 and ethylene levels in association with delayed fruit ripening.

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Effects of Plantation and Postharvest Management Factors on Shelf Life of 'Williams' Banana

J.A. Seberry and D.R. Harris*

ALTHOUGH New South Wales (NSW) growers consistently supply about 25% of the 3.8 million cartons of bananas sold annually on the market in Sydney, Australia, NSW bananas consigned there have gained a reputation for poor quality. There is a marked preference in retail demand throughout the year for north Queensland (NQ) bananas, which constitute the remaining 75% supplied to the market. Despite a lack of documented evidence, bananas grown in NSW are often regarded as inferior to those from Queensland, because they are perceived by retailers and wholesalers to have a shorter shelf life (SL) (Moody 1993). This is reflected by the prices paid for NSW bananas which are often $4–7 per 13 kg carton lower than for comparable fruit from NQ. The lower prices paid for their bananas are estimated to be costing NSW growers between $3 million and $6 million annually. Because of concern about these problems, the NSW Banana Industry Committee (BIC) and the Horticultural Research & Development Corporation (HRDC) agreed to fund research on banana SL by NSW Agriculture.

There are significant climatic differences between the NQ and NSW banana production areas. Most of the fruit from NQ is grown in wet tropical conditions on the 100 km coastal strip between Innisfail (17°30'S) and Cardwell (18°15'S). Annual rainfall is 2100–3800 mm, but most plantations are irrigated and capable of a more regulated supply of fruit than those in southern areas. However, NQ is subject to summer cyclones and temperature fluctuations, with occasional chilling conditions. Production areas in NSW are located on the coast between Tweed Heads (28°S) and Macksville (31°S), with annual average rainfall of 1500–2200 mm and subtropical temperatures. Plantings are mostly on hillsides and slopes to avoid frost and provide cold air drainage. The bunch-to-bunch cycle in NSW plantations is 14–16 months, compared with about 12 months in NQ.

It has been suggested that SL of fruit might be related to a range of plantation factors, such as soil type, plant nutrition, pest and disease control (particularly leaf diseases), soil moisture levels, bunch pruning, and physiological age of the fruit at harvest, as well as ripening and storage practices in the market.

Sample cartons of 10–12 commercial lines of green bananas (cv. 'Williams') from NSW districts and NQ have been purchased each month from Sydney Market since the project commenced in October 1991. The bananas have been transported to Gosford, ripened with ethylene under simulated commercial conditions for 4–5 days at 16–18°C to CSIRO standard colour index 3 or 4 (Anon. 1971), and then stored at 20°C for SL assessments.

On removal from the ripening room, the bananas were rated each day by a panel of 8–10 people for quality of skin colour and general appearance, until the fruit was considered to be commercially unacceptable because it was overripe or rotting, as described by Peacock (1980). Changes in peel colour, pulp firmness, and development of postharvest rots were monitored as the fruit ripened. Fruit weight and finger length/diameter were recorded, and pulp and peel samples were oven-dried to determine dry matter content. Samples of the dried fruit were also analysed for mineral nutrients in an attempt to determine whether there is any correlation between composition and fruit SL.

Seasonal differences in SL between NSW and NQ bananas

Between October 1991 and June 1993, 158 grower lines from NSW and 56 from NQ were evaluated. The comparative SL of fruit sourced from NSW districts and Queensland varied according to season (Figs 1 and 2). The mean SL of Queensland fruit was longer than that of NSW fruit in the spring months of October and November in both 1991 and 1992. Much of the NSW fruit marketed in these periods showed brown discoloration under the peel after ripening, and had a dull yellow colour, a typical indication of chilling injury which probably occurred in the plantation. However, in both years by mid-summer fruit from both sources had similar SL and colour. By February and March (autumn), SL of NSW fruit was superior. From late autumn through to early spring, there were differences in keeping quality between fruit from NSW and Queensland, but these did not appear to be consistent from year to year.

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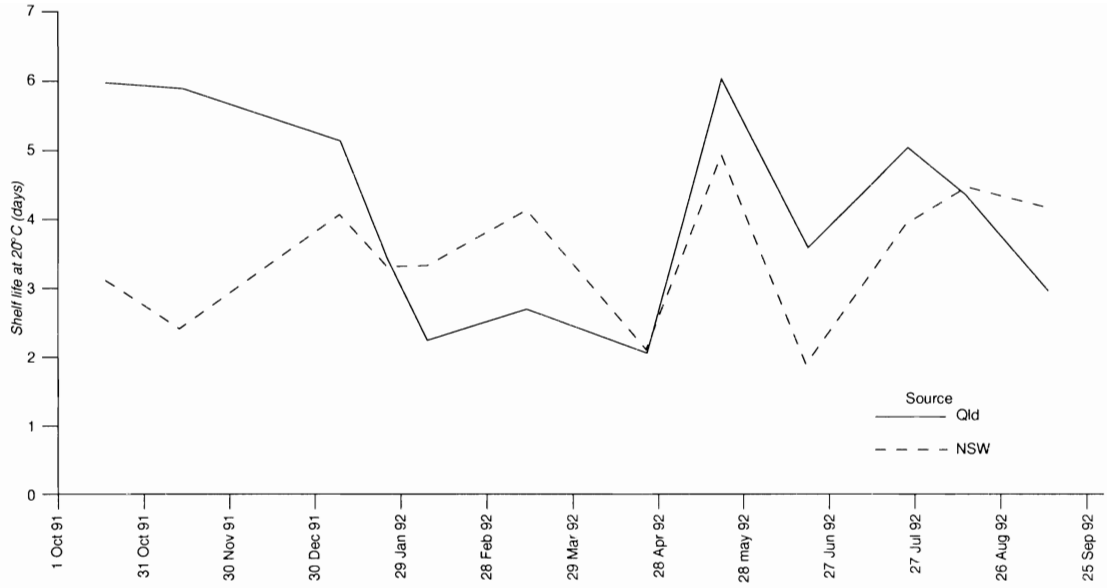

Figure 1. Seasonal fluctuations in shelf life at 20 °C, after ripening, of bananas from New South Wales and north Queensland sampled between October 1991 and September 1992.

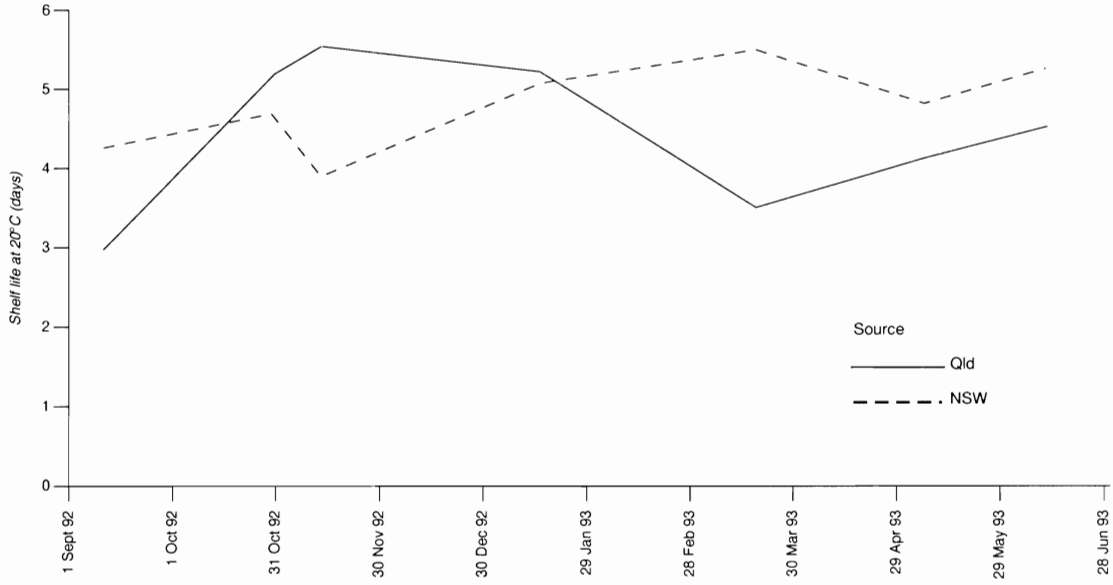

Figure 2. Seasonal fluctuations in shelf life at 20°C, after ripening, of bananas from New South Wales and north Queensland, sampled between September 1992 and June 1993.

Chemical composition of banana fruit in relation to SL

Over the past two years we also analysed 71 lines of the fruit obtained for SL assessments, using inductively coupled plasma (ICP) techniques and Kjeldahl extractions to determine 6 major and 5 minor nutrient elements. Samples consisted of two fruits from a single hand of green bananas from each grower line, separated into peel and pulp, weighed, and oven-dried to constant

Table 1. Mean concentrations of N, P, K, Ca, Mg, B, and Mn in banana peel dry matter in relation to fruit shelf life (SL)

Month of sampling	State of origin	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Mn (ppm)	SL (days)
Apr 1992	NSW	1.2	0.16	6.7	0.19	0.17	22	120	2.1
	QLD	1.5	0.19	6.8	0.22	0.21	22	94	2.1
May 1992	NSW	1.3	0.17	6.5	0.16	0.19	20	61	5.0
	QLD	1.5	0.16	5.9	0.16	0.18	22	167	6.1
Sep 1992	NSW	1.3	0.18	6.9	0.17	0.11	24	133	3.6
	QLD	1.4	0.15	6.1	0.16	0.12	23	169	2.6
Oct 1992	NSW	1.4	0.20	7.5	0.20	0.14	23	87	4.5
	QLD	1.6	0.17	6.1	0.20	0.19	23	73	5.1

weight, before being stored in a freezer. This material provided dried samples of peel and pulp from hands with a wide range of SL scores. Results of analysis of samples, taken in April, May, September, and October 1992, to determine nutrient concentrations in peel dry matter in relation to fruit SL, are shown in Table 1. There were no consistent correlations between any of the peel and pulp mineral elements and the mean SL scores for these lines of fruit.

Precooling and refrigerated transport

Until recently, unrefrigerated rail vans were the most common method of transport for NSW bananas to Sydney, with refrigerated road transport being used by Queensland producers. In summer, NSW fruit could often be subjected to high temperatures at the railhead and during transport for 3–4 days. A series of trials has been commenced to compare the effects on SL of rail or road transport at ambient temperatures in summer with precooling and refrigeration. To date we have been unable to demonstrate that the latter have any beneficial effect on SL.

Discussion

There is a general perception among merchants and retailers in Sydney that NSW bananas have a shorter SL than Queensland fruit, especially on either side of the NSW peak season between January and April when supplies of NSW fruit are greatest. The major supplies of fruit to the southern Australian markets from NQ are between May and December. The survey described here confirmed that NSW bananas harvested in the spring months are generally of poorer quality than comparable fruit from NQ. The NSW fruit marketed in this period comes from bunches which have hung in the plantation over winter.

Our results provide evidence that the cool winter conditions in many NSW plantations, and the occurrence of chilling injury, are not only affecting the appearance and colour of fruit adversely, but may be also directly or indirectly reducing SL. It is possible that poor leaf health is reducing spring fruit SL. The effects of severe leaf disease, especially sigatoka leaf spot, on fruit filling and premature ripening are well known. It has also been suggested that bunch pruning during stress periods will improve the quality of the remaining fruit, but this has not been tested. However, we were unable to show any relationship between gross fruit composition and SL.

Acknowledgments

This research project and presentation have been undertaken with the financial support of the NSW Banana Industry Committee and the Horticultural Research and Development Corporation of Australia which is gratefully acknowledged. The tissue analyses of banana samples were carried out by the Chemistry Branch of NSW Agriculture at the Biological & Chemical Research Institute, Rydalmere. The authors are indebted to Dr Geoff Johns for his advice on the project and Mr Ken Ward for his competent assistance with the experiments.

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Optimisation of Indigenous Ripening Systems for Bananas in the Philippines

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BANANA is the prime fruit commodity in the Philippines. Producers and entrepreneurs, 80% of whom are smallholders, usually harvest the fruit green and ripen it with calcium carbide (CaC_2), or with leaves of gliricidia (*Gliricidia sepium* Steud.) or rain tree (*Samanea saman* Merr.). Ethylene is used only by the large, export-orientated firms.

Very little research has been done to examine and improve the indigenous ripening systems in bananas. Earlier studies by the authors in 'Saba' bananas (*Musa*, BBB Group) showed that the conventional rate of CaC_2 application of 25 g/100 fruit produced during a 24-hour treatment at least 10 times more acetylene (10,000 µL/L) than required for inducing ripening. It was also found that gliricidia leaves at 5% of fruit weight (w/w) applied for 1 day effectively enhanced ripening. This is much lower than the traditional rate of 10–30% of fruit weight (w/w) applied for 2–4 days. Moreover, fruit disorders such as CaC_2 injury, soft-green disorder, ripe flesh hardening and poor flavour development, are not uncommon in fruit ripened by traditional methods.

This study optimised the treatment with CaC_2 and leaves of gliricidia or rain tree on 'Saba' banana, the most important commercial cultivar. CaC_2 treatment was also optimised on 'Latundan' banana (*Musa*, AAB Group), the leading table cultivar. Freshly harvested fruits of 'Saba' (full three-quarters stage) and 'Latundan' (full stage) were used. CaC_2 at 0–25 g/100 fruit was applied for 1 day in a 20-L bucket covered with four layers of newsprint. The CaC_2 was wrapped in newsprint and placed at the bottom of the container. Gliricidia at 5–10% of fruit weight (w/w) was applied for 1–2 days in a 0.05-mm thick, 35 cm × 25 cm polyethylene (PE) bag with 16 diffusion holes. Immature, fully expanded leaves were used since they produced higher ethylene levels than mature ones. Ten fruit were treated in each PE bag. The effect of gliricidia was also compared to that of ethephon (2-chloroethyl phosphonic acid) at 1000 µL/L applied as a 5-minute dip. Rain tree treatment was the same in rate and procedure as that of gliricidia but mature leaves were used. Since the leaves produced high CO_2 levels, a CO_2 scrubber — calcium oxide (CaO) or ordinary lime at 10% of leaf weight (w/w) and wrapped in newsprint — was incorporated during treatment. Ethylene, CO_2, and O_2 levels during gliricidia and rain tree treatment were measured by gas chromatography. After treatment, the fruit were kept in air. The experiments were done on a non-commercial scale under ambient conditions (26–31°C, 68–85% relative humidity). A completely randomised design with 3 replicates (10 fruit/replicate) was used. Two trials were done for each experiment and results were consistent.

CaC_2 at 5 g or more per 100 fruit enhanced ripening of 'Saba' and 'Latundan' fruits (Table 1). However, 'Saba' required a higher level (15 g CaC_2) than 'Latundan' (5 g CaC_2) to ripen in 2 days from harvest, similar to that effected by the conventional rate of 25 g CaC_2.

Table 1. Ripening period and weight loss at the ripe stage of 'Saba' and 'Latundan' bananas treated with 0–25 g CaC_2/100 fruit for 1 day.

CaC_2 level (g/100 fruit)	Ripening period[a] (days from harvest)	Weight loss (%)
A. 'Saba' (*Musa*, BBB Group)		
0	11.0a	11.1a
5	3.2b	4.2b
10	2.5c	4.4b
15	2.4cd	4.2b
20	2.1d	5.7b
25	2.1d	5.4b
B. 'Latundan' (*Musa*, AAB Group)		
0	7.5a	11.1a
5	2.3b	5.5b
10	2.0b	4.3b
15	2.0b	4.4b
20	2.0b	4.2b
25	2.0b	4.4b

[a] Number of days to reach peel colour stage 4–5 for 'Saba' and 6 for 'Latundan', the ripeness stage when the fruits are usually utilised (inclusive of treatment period). Peel colour index (CI): 1–green; 2–first trace of yellow; 3–more green than yellow; 4–more yellow than green; 5–yellow with green tips and/or angles; 6–full yellow.

Means having a common letter within columns per cultivar are not significantly different by DMRT 5%.

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At the ripe stage, total soluble solids, titratable acidity, and sensory quality did not vary between CaC_2-treated and untreated fruit but weight loss of the former was about 50% lower than that of the latter (Table 1). CaC_2 injury was not observed.

Gliricidia leaves at 5% of fruit weight (w/w) applied for 1 day ripened 'Saba' fruit in 3–4 days from harvest (Fig. 1a), confirming earlier results. Treatment with 10% leaves did not result in faster ripening than with 5% leaves. Two-day treatment slowed down peel yellowing (Fig. 1a) due possibly to high CO_2 and low O_2 (Table 2). Untreated fruit ripened in 7–10 days from harvest. Relative to ethephon, gliricidia was less effective in advancing ripening, but only by 1 day. The same trend in respiration and ethylene production was observed, except that ethephon-dipped fruit evolved high amounts of ethylene immediately after treatment and thereafter. Their internal ethylene content concomitantly increased to 3–4 µL/L, which can initiate ripening if treated for 8 hours. In contrast, during gliricidia treatment, ethylene slowly accumulated and on the 6th hour, was about 0.3 µL/L which is the minimum concentration for a 24-hour treatment to initiate ripening. The 6-hour lag period can render the treatment ineffective. However, the accumulated ethylene on the 12th hour, about 1.0 µL/L, was sufficient to enhance ripening as it requires only 12 hours treatment time.

Rain tree treatment had a similar effect as gliricidia in enhancing 'Saba' fruit ripening (Fig. 1b). However, when the leaves were applied for 2 days, about 30–40% of the fruit became soft but green. This was observed immediately after treatment and 1 day later. The green-soft fruit eventually turned yellow during holding in air but they became unacceptably soft.

Higher ethylene and CO_2, and lower O_2 levels prevailed during rain tree treatment as compared with those during gliricidia treatment (Table 2). These conditions, particularly those during the second day of treatment, possibly induced green-soft development. Reducing CO_2 levels with CaO slightly increased ethylene accumulation (Table 2) and improved the ripening-enhancing effect of rain tree only when applied for 2 days. The fruit turned yellow more rapidly than those

Table 2. Ethylene, CO_2, and O_2 levels in PE bags during treatment of 'Saba' bananas with 5% gliricidia or rain tree leaves (w/w) for 1–2 days.

	Days from treatment	Ethylene (µL/L)	CO_2 (%)	O_2 (%)
A. *Gliricidia*				
	1	5.2b	7.6b	10.2a
	2	8.5a	13.0a	7.2b
B. Rain tree				
without CaO	1	6.6b	10.7b	7.7
	2	9.1a	14.5a	6.2
with CaO	1	7.6b	2.4c	7.3
	2	9.9a	11.7b	6.8

Means having a common letter within columns per leaf type are not significantly different by DMRT 5%.

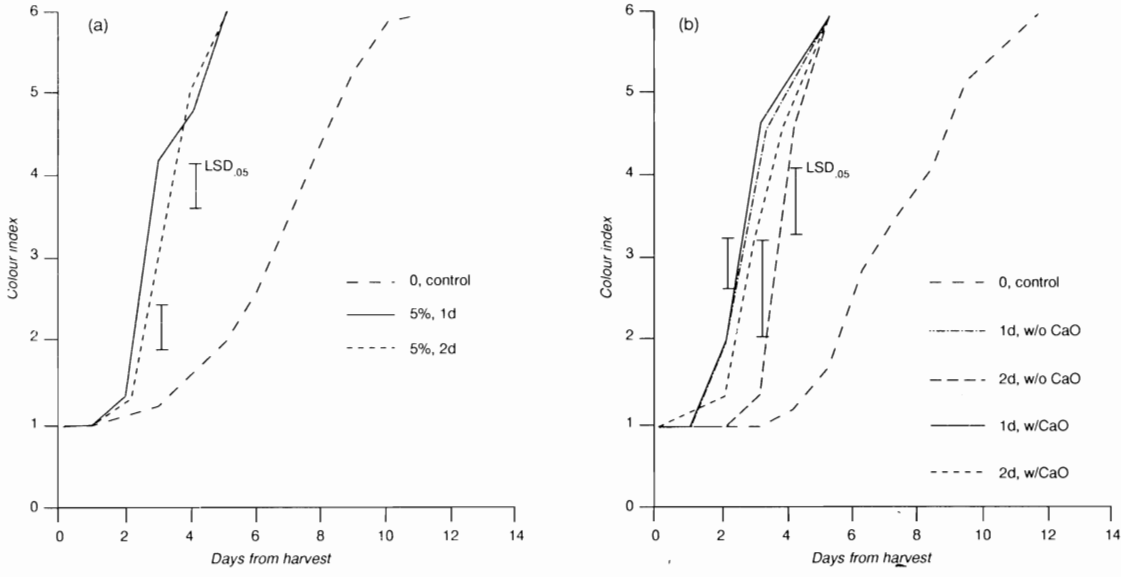

Figure 1. Peel colour development of 'Saba' bananas treated with 5% (w/w) gliricidia (a) or rain tree leaves (b) for 1–2 days.

treated without CaO (Fig. 1b). The green-soft disorder was also inhibited, affecting less than 5% of the 2 day-treated fruit.

The results indicate that the traditional quantities of CaC_2, gliricidia, or rain tree used for ripening bananas are excessive. Using traditional rates, the fruit are exposed for prolonged periods to conditions such as low O_2 and high CO_2 which can antagonise the effect of the ripening agent and induce the development of fruit disorders. Optimisation studies have been on a non-commercial scale. The identified optimum rates of CaC_2, gliricidia, and rain tree application need to be validated under normal commercial treatment where large volumes of fruit of mixed maturities are involved. Only then can a technically and economically efficient indigenous resource-based ripening system in bananas be established.

Fundamental Studies on Respiration Rates and Storage Properties of Some Tropical Fruits Grown on Okinawa

Takayoshi Akinaga and Yoshihiro Kohda*

IT is a essential to know the rate of respiration governing the storage life of fresh fruits so that the precooling facilities can be designed for maximum efficiency. The rate of respiration is a good index of the quality of fresh produce, and can be measured nondestructively. There is a large body of scientific literature on the rates of respiration in fruit, vegetables, and cut flowers (see, e.g., Lutz and Hardenburg 1968). However, the measurement methods, maturity of samples, and time after harvest have not been reported in detail.

Respiration rates of fruit are usually measured by infrared CO_2 gas analyser, a high-cost item (e.g. Yen 2 000 000 per unit). There is also a chemical method, however, using a CO_2-absorbent agent (Matsumoto 1936), which does not require a high-price measuring instrument. This paper reports chemical measurements of rates of respiration of some Okinawan-grown subtropical and tropical fruits at various temperatures.

Materials and Methods

Measurement of respiration rate by titration

Twenty-five mL of 2N KOH were placed in an evaporating dish on the bottom of a fixed-volume plastic vessel. Test fruits were placed in the vessel, which was then tightly sealed. The plastic vessel, test fruits, and the chemical were kept in the dark at a constant, pre-set temperature in a constant temperature and humidity chamber. The CO_2 generated in the vessel was absorbed by the KOH. After a fixed time (2–4 hours), the evaporating dish was removed and the KOH immediately poured into a 250 mL graduated flask containing 10 mL of 25% $BaCl_2$. Distilled water was added to constant volume and the contents of the flask allowed to settle after shaking well. $BaCO_3$ settled as a white precipitate. Fifty mL of the supernatant liquid were taken and neutralised with 0.2N HCl, using phenolphthalein as an indicator. As a control, 25 mL of KOH held in a plastic vessel under the same conditions as the test fruit was titrated.

The following equations describe the chemical reactions involved (Nakagawa 1981).

$$CO_2 + 2KOH = K_2CO_3 + H_2O$$

$$2HCl + 2KOH = 2KCl + 2H_2O$$

Therefore 1 mL of 0.2N HCl was equivalent to 4.4 mg of CO_2, and CO_2 generated

$$= 4.4 \times a \times (1/t) \times (1/w) \times f \times (250/50)$$
$$= 22\ af/tw \text{ (mg/kg/hr)}$$

where a = (volume of 0.2N HCl in control) – (volume of 0.2N HCl on sample) (mL)
w = sample mass in (kg)
t = measuring time in (hours)
f = factor of 0.2N HCl

Materials

Green-ripe banana cv. Ogasawara were harvested in 1992 in the courtyard of the College of Agriculture. Sound fingers were selected. Respiration rates of bananas were measured at fruit temperatures of 0–35°C, at 5°C intervals. Fully ripe pineapples cv. N67-10 were harvested on 8 December 1992 in Nago. Respiration rates of pineapples were measured every 5°C from 0–30°C. Fully ripe mangoes cv. Irwin were harvested on 20 July 1992 in Ginoza. Respiration rates of mango fruits were measured every 5°C from 5–35°C. Full ripe papaya fruits cv. Solo-Sunrise were harvested on 18 November 1992 in Higashi. Respiration rates of papaya fruits were measured every 5°C from 5–35°C.

Arrhenius plot

Respiration rates and inverse absolute temperatures were plotted on semilogarithmic graph paper as Arrhenius plots (Kitagawa 1986). It was found that they lay approximately on two straight lines. There was a large change at the lower temperature end of the line, which suggested a chilling temperature.

Storage tests

Storage tests were carried out to estimate the suitable storage temperatures of tropical fruits produced on Okinawa. Bananas, pineapples, mangoes, and papayas were stored from 7–14 days in constant temperature and

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humidity chambers, and were periodically inspected for qualities such as fruit hardness, peel colour, weight loss, moisture content, total soluble solids, and acidity.

Results and Discussion

Figure 1 shows the typical Arrhenius plots of respiration rates of bananas and temperatures. The critical chilling injury temperature was estimated from this plot at about 15°C. The recommended storage temperature for bananas given in the USDA handbook (Lutz and Hardenburg 1968) is 13–14°C. Thus, the storage temperatures for the test were set at 15°C and 25°C at 85% RH.

Figure 2 shows the plots of pineapples. The critical temperature for pineapples was estimated at about 10°C. The USDA-recommended storage temperature for fully ripe pineapples is 7–10°C (Lutz and Hardenburg 1968). Storage tests of pineapple were therefore carried out at 5,10, and 25°C and 80% RH.

Figure 3 shows the plots of fully ripe mangoes. The critical temperature of fully ripe Irwin mangoes was about 7°C. as compared with the USDA-recommended

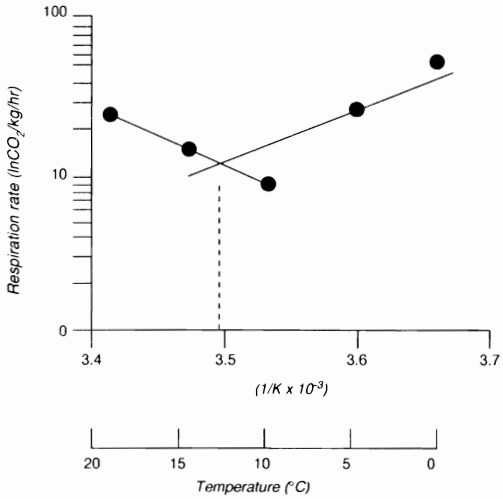

Figure 1. Arrhenius plots of respiration rates of bananas and temperatures

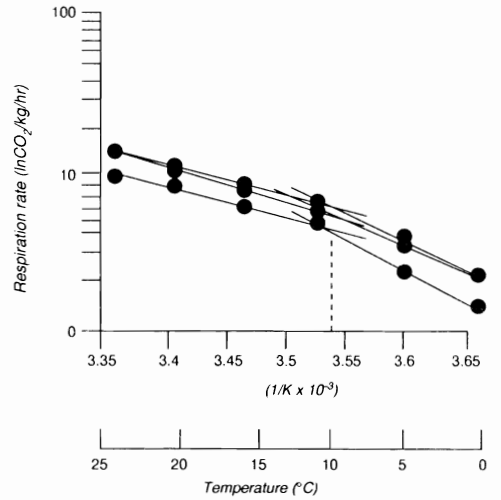

Figure 3. Arrhenius plots of respiration rates of mangoes and temperatures

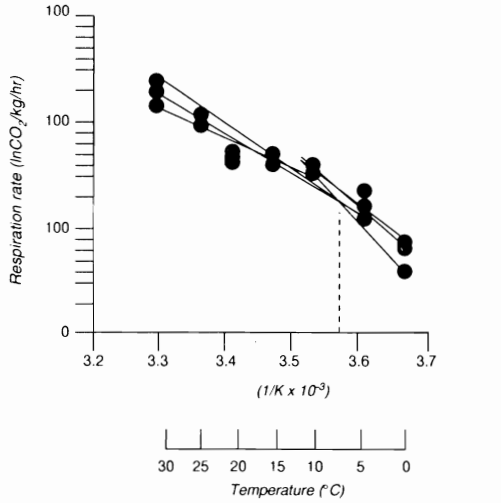

Figure 2. Arrhenius plots of respiration rates of pineapples and temperatures

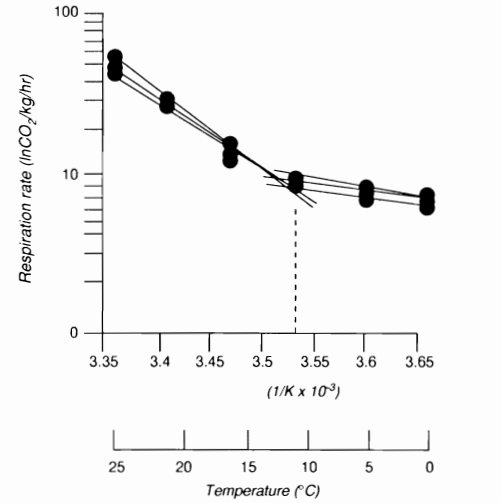

Figure 4. Arrhenius plots of respiration rates of papayas and temperatures

10°C. Storage tests of mangoes were carried out at 5, 12, and 25°C at 85% RH.

The plots for papayas (Fig. 4) show a critical temperature of about 10°C. From the USDA handbook, since papayas are subject to chilling injury, they should be held at a temperature close to, but not below 7°C. Storage tests of papayas were carried out at 5, 10, and 25°C at 85% RH.

From the results of storage tests, the recommended storage temperatures for bananas, pineapples, mangoes, and papayas were estimated at 15, 10, 12, and 12°C, respectively.

Conclusion

Arrhenius plots of respiration rates and fruit temperatures were an effective method for predicting the temperature below which fruit chilling injury will occur. Respiration rates of the tropical fruits were easily measured by the titration method, at lower cost than use of an infrared gas analyser.

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Reducing Decay and Extending Shelf Life of Bell-peppers and Mangoes by Modified Atmosphere Packaging

V. Rodov, S. Ben-Yehoshua, S. Fishman, S. Gotlieb, T. Fierman, and D.Q. Fang*

PREVIOUS research has shown that seal-packaging fruits in plastic films reduces weight loss and preserves the firmness and freshness of stored produce (Ben-Yehoshua et al. 1983). However, this method also has problems with some fruits. With peppers (*Capsicum annum* L.), in spite of positive results reported for individual seal packaging, high relative humidity may increase the risk of fungal decay, especially late in the season. With mangoes, the altered in-package atmosphere inhibits normal ripening of the fruit (Ben-Yehoshua et al. 1990; Sornsrivichai et al. 1992). In this paper, we present some modified atmosphere packaging (MAP) approaches enabling the reduction of the undesirable effects of sealing.

Materials and Methods

Bell-peppers of Maor and Maccabi cultivars were packed in plastic trays sealed in low density polyethylene (LDPE) of 20, 40, and 80 μm thickness, four fruit per tray. Sodium chloride (NaCl) was added to bell-pepper packages within the pouches of spunbonded polyolefin (Tyvek, Du Pont Co.). Mangoes of Tommy Atkins and Keitt cultivars were individually sealed in shrinkable Cryovac polyolefin films of 15 or 19 μm, either non-perforated (MD film) or perforated: MPY (8 holes of 1.7 mm diameter per square inch) or SM60M (8 holes of 0.4 mm diam. per sq. inch). Part of the fruit was sealed in the same films within foam polystyrene trays. Rotronic I-108 probes were used for monitoring the in-package relative humidity (RH).

Results and Discussion

Modified humidity packaging of bell-pepper

Relative humidity in the sealed tray-packages holding 4 fruit reached 99–100%, and condensation occurred on the film. Hygroscopic material (NaCl) was used to control the RH in the packages (Shirazi and Cameron 1992). The humidity level was stabilised by the amount of NaCl added, varying from 96–98% with 5 g NaCl to 86–90% with 15 g. Water condensation inside the packages was prevented or significantly reduced, depending on the amount of NaCl added. Lowering relative humidity in the package markedly reduced the decay of bell-peppers (Fig. 1). Nevertheless, fruit in the packages with modified humidity still had significantly lower weight loss and retained better firmness and quality than the non-sealed control (Fig. 1).

It should be added that decay in the tray packages was higher than that observed on individually sealed fruit. This difference may relate to the absence of water droplets and the lower RH (97%) in the individually sealed packages (Ben-Yehoshua et al. 1983).

Effect of film perforation on mango quality

According to predictions based on a mathematical model of the package, perforation of the film markedly changes the package atmosphere while only slightly influencing the relative humidity. In our experiments, using perforated polyolefin films for mango packaging enabled normal ripening of the fruit and reduced weight loss and decay as compared with a non-sealed control (Fig. 2). The best results after 2–3 weeks of storage at 14°C and one additional week at 17°C were achieved when film with 0.4 mm perforations was combined with increased free volume inside the package by sealing the fruit within polystyrene trays.

Prolonged storage of sealed Keitt mango

The delayed ripening of fruit sealed in non-perforated film was advantageous during prolonged storage of Keitt mango. After 3 weeks of storage and 1 week of shelf life the sealed fruit displayed inferior quality to the control because ripening was inhibited. However, with longer storage (4–6 weeks plus 1 week shelf life) the difference in physicochemical parameters (TSS, acidity, firmness) between sealed and non-sealed fruit became less, and sealed fruit received higher taste scores because overripening was prevented. The effect of sealing on fruit colour was less significant for typically green Keitt mango than for yellow varieties. However, sealing did not reduce decay of mangoes stored for long periods. The combination of sealing with decay-control measures such as hot water or fungicide dips may be useful in these cases.

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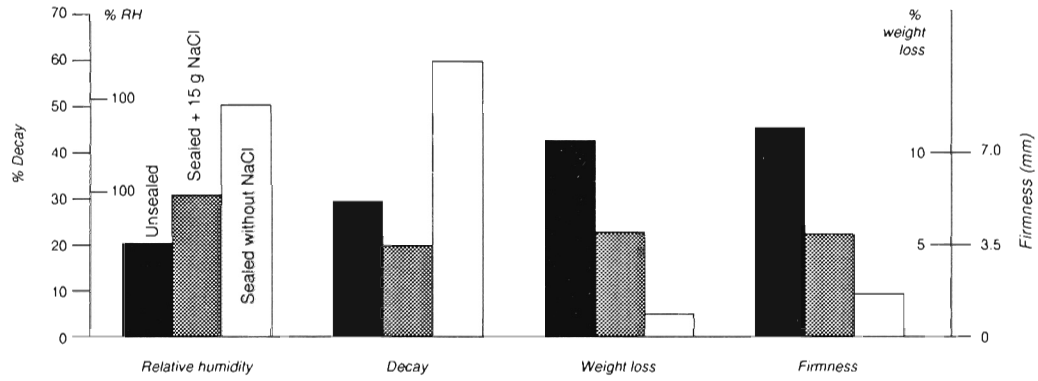

Figure 1. Effects of hygroscopic material on keeping qualities of bell-pepper stored for 3 weeks at 8°C and 1 week at 17°C. Firmness measured as residual deformation (mm) after 19.8 N pressure.

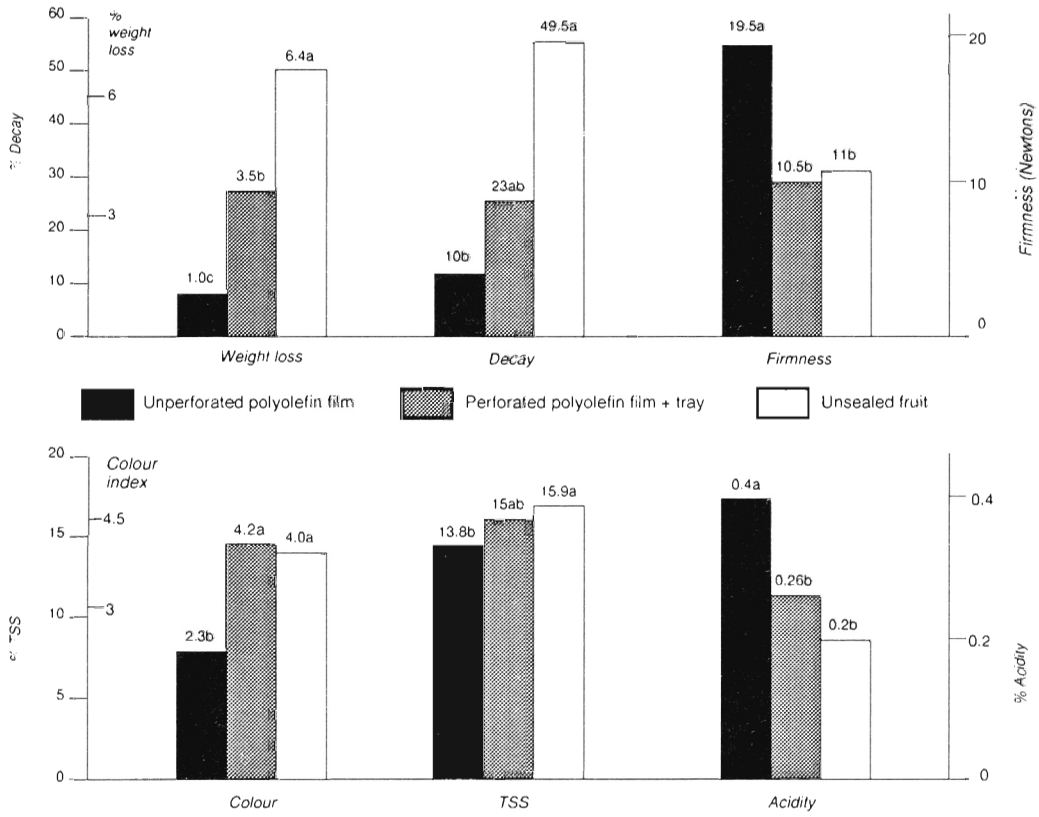

Figure 2. Effect of seal-packaging on keeping qualities of Tommy Atkins mango stored for 3 weeks at 14°C and 1 week at 17°C.

Conclusion

These results show that application of additional factors such as hygroscopic materials or perforation may prevent the harmful effects of tray-sealing in plastic film while retaining its advantages. Mathematical modelling may help to predict the optimal packaging parameters.

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Modified Atmosphere Storage of Bananas at Chilling Temperatures

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THE green life of Cavendish bananas can be extended using a modified atmosphere (MA) in which oxygen is reduced and CO_2 concentration increased (Scott et al. 1971; Scott and Gandenagara 1974). This was achieved by sealing the fruit in polyethylene bags which allowed the development of a stabilised MA in 3–4 days. Shorter stabilisation times were obtained in bags evacuated before sealing (Badran and Lima 1969). This technique has been adopted commercially and is known as the 'banavac' system. In addition to extending storage life, MA storage has been reported to reduce the incidence of chilling injury for avocado (Scott 1978) and tomato (Hobson 1987). The green life for bananas could be extended by lowering the temperature below 13.5°C if the incidence of chilling injury could be minimised by MA. This paper reports experiments in which bananas were held in a MA below the critical 13.5°C.

Material and Methods

Cavendish bananas harvested approximately 2 weeks earlier in Equador and sea transported at 14°C were used for the study. Hands were separated into clusters which contained 5 fingers. Individual clusters were enclosed in 41 × 28 cm, 0.05 cm gauge, low density polyethylene bags (PEB). Excess gas in the bag was evacuated until the film adhered to the fruit surface and the bag was then sealed. Another set of clusters was enclosed in similar size perforated PEB. Immediately after sealing, 12 bags from each were transferred to 8, 11, and 14°C.

Oxygen and CO_2 concentrations in the PEB system were measured three times per week. Gas concentrations were measured using a gas chromatograph with alumina column and thermal conductivity detector. Four bags of each treatment were removed from the store at 10-day intervals for peel colour measurements. Bags were unsealed and peel colour of fruits was monitored using a Minolta colour meter (CR 200 Japan). L* value of the colour meter was used to measure the chilling injury of the fruits.

A centimetre thickness of transverse section of fruit was used to measure firmness of pulp using a Macmesin electronic force gauge with a 6 mm plunger. A 10 g sample of pulp from the middle of the finger was homogenised using a known amount of distilled water and filtered through cotton wool. A few drops of the filtrate were used to measure total soluble solids (Brix) using an Abbe type refractometer at 20°C. A 10 mL aliquot of filtrate was titrated against 0. 1N NaOH to measure the titratable acidity and the acidity was expressed as malic acid. Three fingers from each cluster were treated with 1000 ppm ethylene to induce ripening at 17°C. Peel colour, firmness, TSS, and TA of the ripe fruit were measured as described earlier. Organoleptic evaluations were conducted to test the quality of ripe fruit.

Results

Oxygen levels within the MA at each temperature are given in Figure 1. At 14°C, the O_2 concentration remained stable (10–12%) throughout the storage period. The initial higher levels of O_2 at both 11 and 8°C declined, and became significantly lower than at 14°C and 6 days storage. However, the O_2 level in the bags stored at 11°C gradually increased up to the level of bags stored at 14°C. The oxygen content of the MA in the bags stored at 8°C remained significantly lower than at 11 and 14°C throughout the storage period. The CO_2 content of the MA (results not shown) behaved in a manner converse to that of O_2.

Peel colour measured as L* of green and ripe fruit at each sampling time is presented in Table 1. After 10 days storage, L* was significantly lower in MA stored fruit at 8°C. There were no differences in green fruit stored in either sealed or perforated bags after 10 days of storage. No difference in L* of green fruit was detected after 20 days of storage. A higher L* was observed in fruit stored in perforated bags after 30 days of storage, compared with those stored in sealed bags, due to ripening of some fruit in the perforated bags.

A one-way analysis of the results showed that firmness, TSS, and TA of both green and ripe fruit stored in sealed bags were not significantly affected by storage temperature (results not shown). No significant differences in sensory parameters (flesh colour, aroma, flavour, and texture) were detected by the taste panel assessment of ripe fruit (results not shown).

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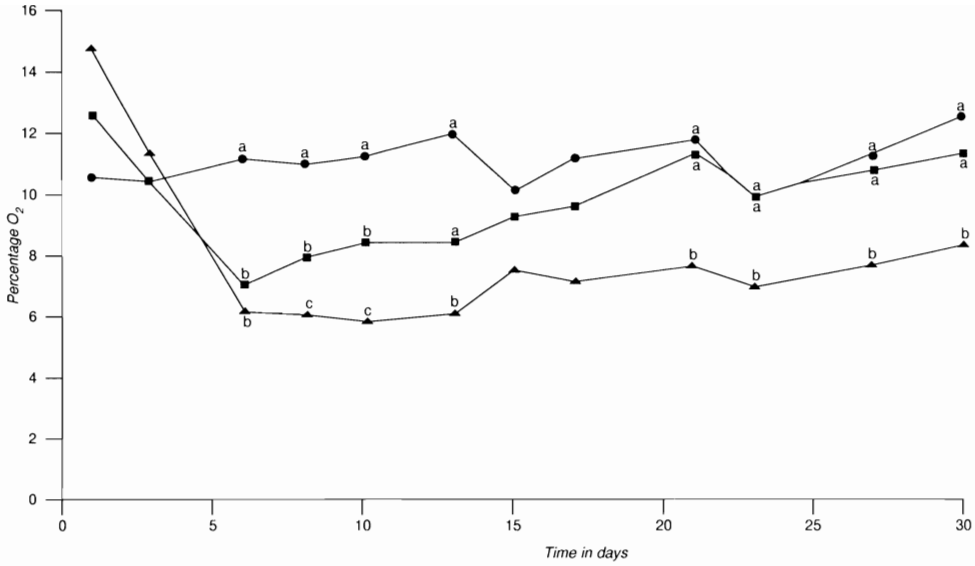

Figure 1. Percentage O_2 content developed in polyethylene bags stored at 14, 11, and 8°C: (●) 14°C, (■) 11°C, and (▲) 8°C. Treatment means having a common letter in a day are not significantly different by DMRT 5%.

Table 1. Peel colour of green and ripe bananas expressed as L* after storage for 10, 20, and 30 days in modified atmosphere and perforated polyethylene bag. Treatment means having a common letter(s) in a column of green or ripe fruit are not significantly different by DMRT 5%.

Treatment	Storage time in days		
	10	20	30
Green fruit			
Sealed 14°C	60.11a	58.79	56.69bc
Sealed 11°C	58.02ab	55.19	54.17d
Sealed 8°C	53.16c	54.72	54.73cd
Perforated 14°C	57.47ab	58.69	61.09a
Perforated 11°C	57.31ab	56.04	55.33bcd
Perforated 8°C	55.42bc	55.54	57.31b
Ripe fruit			
Sealed 14°C	64.33a	72.34a	71.48a
Sealed 11°C	59.07bc	65.46b	66.17b
Sealed 8°C	56.82c	54.99d	56.65c
Perforated 14°C	61.65ab	69.84a	70.84a
Perforated 11°C	58.50bc	63.45bc	63.45b
Perforated 8°C	58.50bc	60.51c	58.03c

Discussion

The consistently lower O_2 levels in the MA at 8°C could have been due to chilling-induced respiration or changes in permeability of the film at low temperature. A chilling-induced rise in respiration has been observed in sweet potatoes (Lewis and Morris 1956) and cucumbers (Eaks and Morris 1956). Temperature is also known to affect the gas permeability of plastic films at lower temperatures (Hayankawa et al. 1975). Further research is required to measure the contribution of each factor with respect to the gas composition of the MA.

Lower values of L* in low-temperature stored fruit compared with those stored at 14°C are indicative of chilling damage having occurred in fruit stored at the former. Chilling injury damage developed at 11 and 8°C, and the MA in the bags failed to prevent the damage. The chilling damage observed in green fruit was more pronounced after ripening. In addition to the colour meter assessments, ripe fruit stored at chilling temperatures appeared dull and less attractive.

With the exception peel colour, other physicochemical parameters remained unaffected by chilling temperatures. No difference in eating quality between chilled and unchilled fruit was detected by the taste panel in bananas at these temperatures. These results confirm those of Aziz et al. (1976).

Conclusion

The MA achieved using evacuated PEB was not effective in alleviating chilling injury in bananas stored at 11 or 8°C for a minimum of 10 days. The MA may be effective for periods less than 10 days. Although the green life was equally extended at either 11or 8°C under MA conditions, chilling damage limits the opportunity to use these temperatures.

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Storage of Fresh Pineapples

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As with many other fruits the pineapple is very sensitive to storage temperature. Storage at 7–8°C and 10°C has been recommended for ripe and unripe fruit, respectively (Anon. 1989). Akamine et al. (1975) indicated that the maximum storage period at 7°C was 4 weeks. Pineapples which are stored at less than 7°C for longer than 7 days will develop chilling injury, usually manifested as internal browning. Fruit which were stored at 4°C and 8°C for 10–20 days, followed by storage at 20°C developed internal browning. Also, fruit stored at 10°C for 50 days developed this symptom (Wills et al. 1985). Rohrbach and Paull (1982) reported that storage of pineapple at 8°C for 1 week was long enough to cause the development of internal browning. Paull and Rohrbach (1985) found that storage of pineapple at 3, 8, and 12°C for 2–3 weeks can induce internal browning within 2 days when fruit were transferred to 18–30°C. In a storage experiment with the cultivar Mauritius, fruit were stored at 7–9°C for up to 19 days without developing internal browning (Thompson 1987). Internal browning was detected in this cultivar when it was stored at 8°C and 12°C for 3 and 2 weeks, respectively. On storage at 5°C for 3 weeks the fruit suffered chilling injury but did not develop internal browning (Hassan and Atan 1983).

Akamine and Goo (1971) found that the storage life of Smooth Cayenne pineapple was significantly extended under 2% O_2 at 7.2°C compared with air. Dull et al. (1967) found that the respiration rate of pineapple decreased as the concentration of O_2 decreased. CO_2 levels up to 10% had no detectable effect on the respiration rate of pineapple at the commercial maturity stage. Kader et al (1985) recommended 5% O_2 and 10% CO_2 at 10–15°C for pineapple storage. Paull and Rohrbach (1985) found that storage at 3% O_2 and 5% CO_2, or 3% O_2 and 0% CO_2 did not suppress internal browning symptoms in Smooth Cayenne stored at 8°C. If fruit were exposed to 3% O_2 in the first week of storage at 22°C followed by 8°C, the occurrence was reduced. Storage of pineapple under hypobaric conditions was reported to extend the storage life by up to 30–40 days (Staby 1976). Storage of Mauritius pineapple under modified atmosphere, using polyethylene film bags, for 2 weeks at 10°C resulted in black heart development. The final O_2 and CO_2 contents in the bags were 10% and 7%, respectively (Hassan et al. 1985).

Smooth Cayenne pineapples from Mexico were harvested at two maturities and stored at gas compositions of 2% O_2 + 0% CO_2, 2% O_2 + 10% CO_2, and 1% O_2 + 0% CO_2, and temperatures of 4, 8, and 12°C. After storage, fruit were transferred to 22°C for 3 and 6 days. Pineapples stored under 1% O_2 or 2% O_2 and 10% CO_2 showed a delay in the development of internal browning. The shell colour of pineapple changed at a slower rate when fruits were stored under controlled atmospheres rather than air. The half mature pineapples could be stored longer than mature fruit by approximately 3 days at 22°C. The change in shell colour of the fruit was retarded at 4°C but the subsequent development of the colour was incomplete at 22°C. Fruit also suffered from chilling injury during subsequent storage. The shell colour of the mature fruit changed to slightly orange–yellow at 8°C and 12°C after 3 weeks storage. The development of internal browning occurred with fruits stored at 12°C without being subjected to subsequently higher temperatures. The results indicate that pineapples should be stored for less than 3 weeks in all the conditions tested in these experiments.

Materials and Methods

Fresh Smooth Cayenne pineapples were shipped from Mexico by air. Fruit were originally graded from the field into mature and half mature.

Controlled atmosphere storage

Weighed fruits were placed in 25-litre sealed plastic boxes fitted with inlet and outlet tubes in temperature controlled rooms. The humidity inside the box was created by placing 300 mL of water in each box with the fruit stored above, but not touching the water. Each gas mixture from a premixed cylinder was passed continously through the fruit boxes at a flow rate of 400 mL/minute. The gas compositions used were: 2% O_2 + 0% CO_2, 2% O_2 + 10% CO_2, 1% O_2 + 0% CO_2 and an air control. Storage was at 8°C for 2 weeks followed by 1 week under normal air.

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Storage temperature

Pineapples were stored at 4, 8, and 12°C for 3 weeks.

Assessment

After storage fruits were transferred to 22°C for 3 and 6 days before evaluation of fruit quality. The mature fruit were evaluated after 3 days while the half mature fruit were evaluated after 6 days using scales described by Rohrbach and Paull (1985). The scale of shell colour was 0–5, where 0 = green and 5 = yellow, orange–yellow, and coppery red. The scale of pulp translucency was 0–4, where 0 = no translucency and 4 = maximum translucency. The internal browning scale was 0–6, where 0 = none and 6 = complete browning. Browning was scored separately for each fruit both on the basis of incidence and severity. Brix and acidity were measured using the juice from the centre slices of the fruit. Brix was measured using an Atago digital refractometer. Acidity, as percentage of citric acid, was determined by titration with 0.125N NaOH using bromothymol blue as indicator.

Results

Controlled atmosphere storage

After 2 weeks storage the shell colour of the fruit was very similar to the initial colour, the change of colour started in the third week of storage. This continued more rapidly when the fruit were removed to 22°C (Table 1).

Table 1. Effect of controlled atmosphere storage at 8°C on the shell colour of pineapple (0 = green; 5 = yellow orange)

Controlled atmosphere	Original colour	Days at 22°C following CA storage		
		0	3	6
2% O_2 + 0% CO_2				
Mature	1.75	3.5	5.0	–
Half mature	0.5	1.5	–	3.5
2% O_2 + 10% CO_2				
Mature	2.25	3.0	3.0	–
Half mature	0.75	0.75	–	4.5
1% O_2 + 0% CO_2				
Mature	2.25	3.75	4.5	–
Half mature	1.25	2.25	–	4.5
Air				
Mature	2.0	4.0	5.0	–
Half mature	1.0	2.5	–	5.0

Internal browning was not detected in the flesh when pineapples were stored at 8°C for 3 weeks in all treatments. The symptom developed when fruit were subsequently stored at 22°C. The mature fruit did not develop internal browning within 3 days at 22°C following storage in a mixture of 2% O_2 + 10% CO_2 or 1% O_2 + 0% CO_2 but the half mature developed internal browning within 6 days. The half mature fruit developed severe internal browning symptoms at 22°C following storage, which might be due to a too long storage period for the stage of maturity. The results showed that both the mature and the half mature fruit can develop this disorder (Table 2). From this experiment it was noted that, at low oxygen concentration, the additive effect of high carbon dioxide could delay the development of internal browning for a short period.

The pulp of the mature fruit from all storage treatments turned translucent after 3 days at 22°C. The pulp of the half mature fruit was checked after 6 days at 22°C and the degree of translucency was about the same as that of the mature fruit. Translucency of the pulp is related to senescence which might be retarded if fruits were kept at low temperature under controlled atmosphere. The results from this experiment showed that the benefit of controlled atmosphere on the translucency of the pulp was limited (Table 3).

Storage temperature

The degreening of the shell of pineapple was affected by temperature. At 4°C the shell colour remained unchanged during storage for 2 or 3 weeks for both the mature and the half mature fruit. At 8°C and 12°C the shell colour of both types changed during storage. During storage at 22°C, following the low temperature storage, the shell colour of the mature fruit changed to light orange–yellow within 3 days while for the half mature fruit the colour change took 6 days. Degreening of the shell colour of pineapple was temperature dependent (Table 4). The shell colour did not appear bright yellow after fruit had been stored at any of the low temperatures used in this experiment. It was observed that the development of the yellow colour was better after storage at 12°C than at 4°C and 8°C, particularly at 4°C the fruit developed a coppery red colour which indicated that the fruit had suffered from low temperature injury (Table 4).

Pineapples stored at 4°C and 8°C did not develop internal browning during storage, but the symptom developed after they were transferred to 22°C (Table 5). Fruit previously stored at 4°C for 2 weeks developed symptoms of chilling injury and no development of internal browning. At 12°C fruit developed internal browning before or after they were stored at 22°C. It was found that about half of the sample did not show the symptom of internal browning while they were held at

Table 2. Development of internal browning (0 = none; 6 = complete browning) of pineapples under controlled atmosphere at 8°C.

Controlled atmosphere	Days at 22°C following CA storage					
	0		3		6	
	incidence	severity	incidence	severity	incidence	severity
2% O_2 + 0% CO_2						
Mature	0.0	0.0	2.0	2.0	–	–
Half mature	–	–	–	–	4.0	5.0
2% O_2 + 10% CO_2						
Mature	0.0	0.0	0.0	0.0	–	–
Half mature	–	–	–	–	6.0	5.0
1% O_2 + 0% CO_2						
Mature	0.0	0.0	0.0	0.0	–	–
Half mature	–	–	–	–	2.0	2.0
Air						
Mature	0.0	0.0	1.0	3.0	–	–
Half mature	–	–	–	–	1.0	1.0

Table 3. The effect of controlled atmosphere at 8°C on the translucency (0 = no translucency, 4 = maximum translucency) of pineapple pulp.

Controlled atmosphere	Days at 22°C following CA storage		
	0	3	6
2% O_2 + 0% CO_2			
Mature	0.5	4.0	–
Half mature	–	–	3.0
2% O_2 + 10% CO_2			
Mature	0.0	4.0	–
Half mature	–	–	3.5
1% O_2 + 0% CO_2			
Mature	0.5	3.0	–
Half mature	–	–	4.0
Air			
mature	1.0	3.5	–
Half mature	–	–	3.0

Table 4. The effect of low temperature storage on the shell colour (0 = green; 5 = yellow–orange) of pineapple under normal air.

Storage temperature	Original colour	Days at 22°C following low temperature storage		
		0	3	6
4°C				
Mature[a]	1.4	1.4	4.0	–
Half mature	0.3	0.3	–	3.0
8°C				
Mature	2.0	4.0	5.0	–
Half mature	1.0	2.5	–	5.0
12°C				
Mature	2.0	4.9	5.0	–
Half mature	0.6	3.8	–	5.0

[a] Pineapple stored for 2 weeks

12°C. The results from this experiment showed that internal browning can develop at 12°C without being subject to higher temperature storage.

At 22°C, the pulp of the mature and the half mature fruit had become translucent within 3 and 6 days respectively regardless of the previous storage condition (Table 6). When the half mature fruit were stored at 12°C for 4 weeks, without subsequent storage at 22°C, the flesh was slightly opaque but the fruit was severely diseased. This could have been due to initial bruising of the fruit during transit from Mexico.

Discussion

Paull and Rohrbach (1985) found that CO_2 at 5% had no effect on internal browning development in pineapples. CO_2 elevation has an additive effect with low oxygen concentration so that the optimum concentration should

Table 5. Development of internal browning (0 = none; 6 = complete browning) of pineapples stored at low temperature.

Storage temperature	Days at 22°C following low temperature storage					
	0		3		6	
	incidence	severity	incidence	severity	incidence	severity
4°C						
Mature	0	0	1.25	1.25	–	–
Half mature	0	0	1.0	1.0	2.0	5.0
8°C						
Mature	0	0	1.0	3.0	–	–
Half mature	–	–	–	–	1.0	1.0
12°C						
Mature	1.5	1.5	1.75	2.75	–	–
Half mature	–	–	–	–	5.5	5.5

be specified for each commodity. However, the effect of controlled atmosphere storage on pineapples was not extended to the fruits when they were removed to air. To overcome this problem, Hassan et al. (1985) suggested storing Mauritius pineapples in modified packaging until they reached consumers. This limitation of controlled atmosphere storage of pineapples indicates that the shelf life time after removal must be specified.

Table 6. The effect of low temperatures on the translucency (0 = no translucency; 4 = maximum translucency) of pineapple pulp.

Storage temperature	Days at 22°C following low temperature storage		
	0	3	6
4°C			
Mature	0.5	3.5	–
Half mature	0.0	3.5	4.0
8°C			
Mature	1.0	3.5	–
Half mature	–	–	3.0
12°C			
Mature	1.75	3.0	–
Half mature	–	–	2.0

The result of our experiments also agree with previous work (Wills et al. 1985; Paull and Rohrbach 1985) indicating chilling temperatures induced internal browning. The range of temperature that favours the development of internal browning is from 5°C to 21°C (Smith 1983). At 4°C fruit showed the development of chilling injury in the subsequent higher temperature storage with no development of internal browning. The same observation was reported with Mauritius pineapple (Hassan and Atan 1983). However, not all of the tested samples developed chilling injury which might have been related to the stage of maturity of each individual fruit. Grading of fruit by using shell colour cannot reliably reveal the physiological maturity of fruit (Smith 1983).

Chilling injury was more severe on bruised fruits than on undamaged ones. The bruised area extended as the fruit were stored for longer periods and became contaminated with microorganisms which resulted in spoilage of the fruit during subsequent storage at 22°C. Fruit stored at 8°C developed internal browning after being placed at 22°C. In other work, maximum development of internal browning for fruit stored at this temperature occurred within 10 to 20 days (Wills et al. 1985).

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The Effect of Sucrose Ester Coating on Ambient Temperature Storage of Several Fruits

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REFRIGERATION facilities are required for reducing the temperature of produce and holding it at the desired temperature until it is sold or used. Where this is not possible, other means of extending the shelf life have to be considered. One possibility is to reduce the gaseous exchange of the produce. This will lower the rate of respiration and therefore retard the rate of deterioration.

It has been found that sucrose ester coatings affect gaseous exchange (Kader et al. 1986; Lidster 1987) by reducing oxygen uptake and carbon dioxide loss. These coatings also reduce transpiration. It was therefore suggested that they might be useful when refrigeration facilities are not available. A trial was begun in January 1990 at the Horticultural Research Centre (HRC) in Marondera, Zimbabwe, using 'Semperfresh' as the sucrose ester.

Materials and Methods

Five experiments were conducted on grapes, apples, and passion fruit.

Experiment 1. 0 and 0.7% Semperfresh on five table grape cultivars — Black Sultana, Earlihane, Giant Isabella, Steuben and Thompson Seedless.

Experiment 2. 0, 1, and 1.5% Semperfresh on the apple cultivars Drakenstein and Mollies Delicious.

Experiment 3. 0, 1, and 1.5% Semperfresh on passion fruit (Purple variety, *Passiflora edulis).*

Experiment 4. 0, 1, and 1.5% Semperfresh on the wine grape cultivar Chenin Blanc.

Experiment 5. 0, 1, and 1.5% Semperfresh on the apple cultivars Anna, Elah, Michal, and Maayan.

Fruit from the HRC orchard were harvested at full maturity and treated immediately. There were 12–20 fruit per treatment.

The 'Semperfresh' concentrations were prepared by first mixing the required amount with a small volume of water in a blender. This slurry was then stirred into the required volume of water in order to achieve the desired concentration.

The fruit were dipped in the required concentration and allowed to drip dry. For the shelf-life observations, they were then placed on newsprint-lined trays in the laboratory. The control treatment (0% Semperfresh) was applied by dipping the fruit in water only.

The fruit were kept in the open at ambient temperature and observations made on daily weight changes and the occurrence of blemishes. Each fruit was discarded when symptoms of deterioration became obvious.

The results were analysed by analysis of variance (with arcsine transformation for percentage weight loss data).

Results

Table grapes

Coating table grapes with 0.7% Semperfresh significantly ($p < 0.0001$) reduced weight loss by between 2.2 and 19.1% (9 days after treatment) compared with controls (Table 1). The rate of weight loss reduction varied with cultivar, with Steuben showing least response and Thompson Seedless the highest. For shelf-life extension Thompson Seedless showed the greatest response — 12 days — followed by Black Sultana with 6 days (Table 2). Earlihane, Giant Isabella, and Steuben all had three days shelf-life extension for coated material. The main cause of loss of shelf life was disease development and shrivelling.

Table 1. Effect of Semperfresh on weight loss of table grapes after 9 days at ambient temperature.

Grape cultivar	Percent weight loss/bunch	
	0	0.7% Semperfresh
Black Sultana	25.3	15.9 ***
Earlihane	25.4	22.4 n.s.
Giant Isabella	27.4	19.5 ***
Steuben	14.8	12.6 n.s.
Thompson Seedless	33.6	14.5 ***

n.s. = not significant *** = significant at the 0.5% level

Apples

Weight loss by Drakenstein and Mollies Delicious six days after treatment was small and there were no significant differences between the different Semperfresh

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concentrations (Table 3). However for all three levels cultivar Drakenstein lost significantly ($p < 0.0001$) more weight than Mollies Delicious. The 1% Semperfresh coat had no effect on shelf life of Drakenstein but extended Mollies Delicious shelf life by 2 days (Table 4). The 1.5% coat extended Drakenstein shelf life by 4 days, but had no effect on Mollies Delicious.

Table 2. Effect of Semperfresh dip on the shelf life of table grapes held at ambient temperature.

Grape cultivar	Shelf life (days)	
	0	0.7% Semperfresh
Black Sultana	3	9
Earlihane	3	6
Giant Isabella	3	6
Steuben	9	12
Thompson Seedless	6	18

Table 3. Effect of Semperfresh on weight loss of fruit of apple, passion fruit and grape after 6 days at ambient temperature.

Fruit	Weight loss (%)		
	0	1.0	1.5% Semperfresh
Apple			
Drakenstein	5.2	5.5	5.7n.s.
Hollies Delicious	3.3	3.7	4.3n.s.
Passion fruit	27.3a	19.1b	18.5b**
Grape			
Chenin Blanc	17.5	19.1	15.2n.s.

n.s.= not significant; ** = significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Table 4. Effect of Semperfresh on the shelf life (days) of 2 apple varieties, passion fruit, and a wine grape variety held at ambient temperature.

Fruit	Shelf life (days)		
	0	1.0	1.5% Semperfresh
Apple			
Drakenstein	8	8	12
Mollies Delicious	2	4	2
Passion fruit	2	6	6
Grape			
Chenin Blanc	2	2	2

Weight loss of apples after 9 days was generally small and the response to Semperfresh not significant (Table 5), except for Michal and Maayan which showed significant reduction for 1 and 1.5% as compared with the control. There was no effect of Semperfresh coating on shelf-life extension of Michal and Maayan (Table 6). The 1.5% concentration had an adverse effect on Elah, reducing the shelf life, while the 1% coating had a positive effect. For Anna the 1 and 1.5% coatings extended shelf life by 3 and 4 days, respectively.

Table 5. Effect of Semperfresh on cumulative weight loss (%) of 4 apple varieties after 9 days at ambient temperature.

Apple variety	Weight loss (%)		
	0	1.0	1.5% Semperfesh
Anna	6.79b	5.13a	5.77a**
Elah	5.47b	3.52a	4.69b**
Michal	9.40b	6.67a	6.18a**
Maayan	8.29b	5.47a	5.26a**

n.s. = not significant; ** significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Table 6. Effect of Semperfresh on the shelf life (days) of 4 apple varieties.

Apple variety	Shelf life (days)		
	0	1.0	1.5% Semperfesh
Anna	12a	15b	16b**
Elah	14a	18b	llc**
Michal	9	9	9n.s.
Maayan	7	7	7n.s.

n.s. = not significant; ** significant at the 1% level
Across rows, means followed by the same letter are not significantly different.

Passion fruit

Coating purple passion fruit with Semperfresh significantly ($p < 0.05$) reduced weight loss (Table 3). However, there was no significant difference in weight loss between 1 and 1.5% concentrations. Semperfresh coating extended the shelf life of passion fruit by 4 days and, as with weight loss, increasing the concentration from 1 to 1.5% had no effect on shelf life (Table 4).

Wine Grape cv. Chenin Blanc

Treating Chenin Blanc with 1.0% Semperfresh accelerated weight loss (Table 3), whereas a 1.5% coating significantly ($p < 0.05$) reduced it. There was no effect of Semperfresh on shelf life (Table 4).

Discussion

The positive effect of Semperfresh on weight loss reduction and shelf-life extension of table grapes (almost 20% weight loss reduction for Thompson Seedless) was most probably due to reduction of moisture loss, as the untreated material shrivelled at a much faster rate than coated fruit. Gourley (1922) attributed the greatest loss in weight to moisture loss. That the extension of shelf life was related to weight loss further confirms this observation. Grape cv. Steuben had a longer shelf life for the control than other cultivars, most probably because of its thick skin, further supporting the notion that moisture loss is a major contributor to weight loss.

The variability in response to Semperfresh coating shown by both the conventional and low-chill apple cultivars might be due to differences in cuticle thickness or inherent ability to control water loss. However, the small weight losses suggest that the effect on shelf life was mainly a result of metabolic activity. This is supported by the observation that coated material had a lower rate of colour loss and texture deterioration. The importance of texture and ground colour as quality attributes was stressed by Smith et al. (1987).

The response of passion fruit to Semperfresh shows that increasing concentration from 1 to 1.5% is of little benefit to both weight loss reduction and shelf-life extension. The delay in the external wrinkling of the skin of treated fruit has important implications in the marketing of fresh passion fruit.

The wine grape Chenin Blanc showed no response to Semperfresh treatment, highlighting the variable range of responses to sucrose ester coatings.

The variability in the degree of weight loss for the various fruit types, apart from species and concentration differences, was also due to the magnitude of the mass:surface area ratio (Smith et al. 1987), with larger-sized fruit (with a higher ratio) such as apples, losing less weight than grapes.

Acknowledgments

We are grateful to L. Kusure, M.W. Nyapokoto, and J. Xaba for their valuable assistance. Cooperation of Africa Produce Marketing and Semperfresh Biotechnology is gratefully acknowledged.

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Effects of Different Precooling Methods and Times on the Storage Quality of Carambola Variety B_{10}

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CARAMBOLA or starfruit *(Averrhoa carambola* L., family Oxalidaceae) is quickly gaining market recognition (Sankat and Balkissoon 1992). It is popular in major markets of Singapore, Hong Kong, and Tokyo, as well as in Europe and America. Malaysia's exports of carambola are increasing annually (Mohd Idris 1987). However, postharvest handling is complicated by the thin epidermis, and the fragile, ribbed shaped, and easily damaged fruit. Storage of carambola at as low as 10°C was found to be an effective means of prolonging shelf life (A. Osman, unpublished data). The objective of the study reported here was to determine the effect of different precooling methods and times before cold storage (10°C) on the storage characteristics of carambola.

Materials and Methods

Fruit source

Fruit of commercial maturity were obtained from one of the fruit farms owned by FELCRA at Cheras, Kajang. Only sound fruit, free from any mechanical injury and rots were used in the study.

Precooling methods

Fruit were subjected to different precooling methods (room temperature, rapid cooling, and hydrocooling: hereafter denoted as RT, RC, and HDr, respectively) and times (0, 12, 24, 36, and 48 hours) before cold storage (10 ± 1°C; 85–88% relative humidity). Fruit for RT precooling were left at ambient temperature (27 ± 1°C; 60–80% relative humidity, RH), while fruit for RC precooling were placed near the fan (with air velocity of 6.4 metre/hour) of the cold room (5 ± 1°C; 61–84% RH). Hydrocooling was achieved by placing the fruit in a mixture of water and ice (to ensure that the water temperature was in the range of 0–3°C throughout the precooling time).

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Weight loss and surface glossiness

Three fruit × 3 replicates from each precooling method and time were weighed and assessed for skin surface glossiness on a scale from 5 = 100% of fruit surface glossy to 1 = 0% of fruit surface glossy) at 10-day intervals until day 40.

Measurements of other physicochemical parameters

Triplicate samples of 2 fruit from each precooling method and time were used in each determination. Texture was determined using the Instron Universal Testing Machine model 1140. Colour was evaluated subjectively according to the colour index for carambola (FAMA 1990).

The same 2 fruit used for texture determination were blended and pooled together for the determination of other parameters. Total soluble solids were determined using a hand refractometer (Kyoma HR-14 model). pH values were determined by Corning digital pH meter model 240. Titratable acidity was estimated by titrating the juice with 0.1 M NaOH using phenolphthalein as the indicator. Ascorbic acid was determined by the method of Ranganna (1977).

Results and Discussion

The results of this study are shown in Tables 1–4. The different precooling methods had a highly significant effect on all the physicochemical parameters. Hydrocooled fruits lost less weight and exhibited less colour change (Table 3). The different precooling times had a highly significant effect on all the physicochemical parameters except for rate of moisture loss and ascorbic acid content. For the physical parameters, values generally decreased with increased precooling times, but no consistent trend was observed for the chemical parameters.

The different storage times showed highly significant effects on all the physicochemical parameters studied. A longer storage time significantly reduced the surface glossiness, firmness, and titratable acidity, but significantly increased colour index, rate of moisture loss, ascorbic acid content, pH, and total soluble solids.

Significant interactions were shown between the three main treatments in most of the physicochemical parameters, suggesting that suitable combinations of these treatments could improve carambola quality during storage.

Conclusion

The three different precooling methods — RT, RC, and HDr — had variable influences on the physicochemical parameters associated with storage quality of carambola.

Table 1. Mean squares of the analyses of variance of four physical parameters of carambola variety B_{10}.

Source of variation	df	Colour index	Glossiness (score)	Rate of moisture loss	Firmness (kg force)
Precooling method (PM)	2	4.011**	1.731**	83.372**	1.502**
Precooling time (PT)	4	3.286**	0.803**	19.605	0.163**
Storage time (ST)	4	140.627**	120.003**	908.560**	18.000**
PM × ST	8	1.137	0.242**	29.320	0.901**
PM × PT	8	1.368	0.133**	16.051	0.128**
ST × PT	16	2.398**	0.156**	16.370	0.154**
PM × PT × ST	32	0.805	0.043	13.742	0.077**
Error	150	0.728	0.056	16.618	0.016
Total	224				

*, ** are significant at 5% and 1% levels respectively.

Table 2. Mean squares of the analyses of variance of five chemical parameters of carambola variety B_{10}.

Source of variation	df	Ascorbic acid (mg/100 g)	Titratable acidity (TA) (%)	pH	Total soluble solids (TSS) (°Brix)	Ratio of TSS:TA (%)
Precooling method (PM)	2	150.226**	16.484**	0.012**	2.090**	1.149**
Precooling time (PT)	4	21.192	3.509**	0.024**	0.721**	0.125**
Storage time (ST)	4	514.433**	74.704**	0.143**	0.403**	6.169**
PM × ST	8	60.898**	4.036**	0.004**	0.298**	0.289**
PM × PT	8	27.279*	1.264**	0.003*	0.489**	0.095**
ST × PT	16	26.662**	2.509**	0.013*	0.211*	0.205**
PM × PT × ST	32	13.391	0.583**	0.003*	0.105	0.055**
Error	150	12.102	0.239	0.001	0.109	0.035
Total	224					

*, ** are significant at 5% and 1% levels respectively.

Table 3. Mean values for colour index, glossiness, rate of moisture loss, and firmness of carambola variety B_{10}

Main effect[a]	Colour index	Glossiness (score)	Rate of moisture loss (%)	Firmness (kg force)
Precooling method (PM)				
RT	3.65	2.87	6.08	1.63
RC	3.43	2.69	6.69	1.46
HDr	3.19	2.56	4.86	1.35
$LSD_{0.05}$	0.31	0.09	1.31	0.09
Precooling time (PT)				
0 hours	3.58	2.85	6.99	1.54
12 hours	3.57	2.80	6.11	1.54
24 hours	3.61	2.76	5.95	1.46
36 hours	3.39	2.62	5.48	1.41
48 hours	2.96	2.53	5.31	1.44
$LSD_{0.05}$	0.39	0.11	NS	0.11
Storage time (ST)				
0 days	1.00	5.00	0.00	2.17
10 days	2.35	3.57	3.33	2.13
20 days	3.68	2.56	6.46	1.27
30 days	4.75	1.48	8.43	0.94
40 days	5.33	0.94	11.62	0.88
$LSD_{0.05}$	0.39	0.11	1.69	0.11
Grand Mean	3.42	2.71	5.95	1.48

[a] RT, RC, HDr are room temperature, rapid precooling and hydrocooling respectively.
NS – not significant.

Table 4. Mean values for ascorbic acid, titratable acidity (TA), total soluble solids (TSS), pH, and ratio of TSS:TA of carambola variety B_{10}

Main effect[a]	Ascorbic acid (mg/100 g)	Titratable acidity (TA) (%)	pH	Total soluble solids (TSS) (°Brix)	Ratio of TSS:TA (%)
Precooling method (PM)					
RT	28.29	6.04	3.78	8.15	1.43
RC	29.90	5.53	3.79	8.12	1.68
HDr	27.08	5.10	3.79	7.85	1.55
$LSD_{0.05}$	1.28	0.26	0.01	0.12	0.08
Precooling time (PT)					
0 hours	27.51	5.98	3.81	8.20	1.49
12 hours	29.39	5.65	3.75	8.10	1.52
24 hours	28.31	5.33	3.78	7.87	1.56
36 hours	28.67	5.52	3.81	8.04	1.58
48 hours	28.24	5.29	3.80	7.98	1.62
$LSD_{0.05}$	NS	0.33	0.01	0.15	NS
Storage time (ST)					
0 days	24.78	7.05	3.72	7.91	1.13
10 days	27.28	6.73	3.74	8.02	1.22
20 days	31.75	5.30	3.79	8.06	1.62
30 days	32.24	4.23	3.85	8.17	1.98
40 days	26.08	4.46	3.84	8.04	1.82
$LSD_{0.05}$	1.65	0.33	0.01	0.15	0.10
Grand mean	28.42	5.56	3.79	8.04	1.55

[a] RT, RC, HDr are room temperature, rapid precooling and hydrocooling respectively.
NS – not significant.

Generally, HDr gave the lowest value, followed by RC and RT. Precooling times of more than 24 hours showed a deteriorating effect on the storage quality. Although the three precooling methods affect the storage quality differently, all the fruits were unacceptable by day 40.

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Effect of Maturity, Damage, and Humidity on the Ripening of Plantain and Cooking Banana

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PLANTAIN and banana *(Musa* spp.) are major staple crops grown throughout the humid tropical zone. They provide both a primary source of carbohydrate and revenue for small-scale farmers. In sub-Saharan Africa, *Musa* crops provide more than 25% of the carbohydrates in the diet of more than 70 million people (IITA 1992).

Estimates of postharvest loss of *Musa* crops in the traditional marketing systems range from 20–80%. (FAO 1977; Olorunda and Aworth 1984). The causes of such high levels of loss remain unclear but Karikari et al. (1980), suggested that damage caused during harvesting and marketing was a major factor contributing to postharvest loss of plantain. A link between mechanical damage, early ripening, and economic loss of banana fruit suggested by Rippon (1974) and Littmann (1972), established that moisture loss from preclimacteric fruit hastened ripening. The experiments in this study investigated the effects of damage, fruit maturity, and storage humidity on the ripening and climacteric response of *Musa* fruit. The treatments simulated the types of damage and storage conditions experienced by fruit in the traditional, tropical marketing process.

Materials and Methods

The experiments in this study were carried out at Kade Agricultural Research Station (Ghana), Silsoe College (U.K.), and the University of the Philippines at Los Baños.

Three Ghanaian plantain cultivars were used in experiment 1 to determine the effect of damage and maturity on ripening. The plantain cultivars were harvested at three maturity stages based on days after flowering, viz: fully mature, mature, and immature. After harvest, fruit were systematically treated using four damage treatments: control (no damage), impaction, abrasion, and quasi-static loading (Ferris 1992). Rate of fruit ripening was assessed by recording changes in peel colour until stage 8 — yellow peel with large coalescing black spots (Von Loeseke 1949). Fruit moisture loss was measured by weighing fruit at regular intervals.

Experiments 2 and 3 were conducted in controlled environment rooms at Silsoe College. These experiments aimed to determine the effect of damage and humidity on fruit ripening. The plantain for these experiments were airfreighted from the West Indies by the St Lucian Ministry of Agriculture. In experiment 2, fruit were treated using three damage techniques: control (no damage), impaction, and abrasion. The fruit were then stored at low and high humidity: 55–65% RH and 96–100% RH, respectively.

In experiment 3, fruit were abraded at four levels: control (no abrasion), 10% of the peel abraded, 25% of peel abraded, and 50% of the peel abraded. Temperature was controlled at 20°C and relative humidity ranged from 70 to 85% RH. A porometer (Mk 2, Delta T Devices, Cambridge, U.K.) was used to compare the rate of water loss of control and abraded banana peel.

Experiment 4 was conducted at Los Baños. This experiment was to determine the effect of damage and humidity on the preclimacteric period of cooking banana. Ethylene produced by cooking banana fruit was measured in a static system using a Shimadzu gas chromatograph series GC–8A, fitted with a flame ionisation detector.

Results and Discussion

The results from experiment 1 (Table 1) confirmed that the more mature the fruit was at harvest, the more rapid was the rate of ripening (George and Marriott 1983). These data also showed that the largest reduction in ripening period was caused by abrasion to least mature fruit (Table 1). Abrasion also caused a significant increase ($P \leq 0.05$) in weight loss (Fig. 1). The effect of impaction on fruit ripening was inconsistent and only impaction of immature fruit caused a significant, though limited, reduction in ripening period.

Quasi-static loading had no effect on ripening. In a similar study by Maxie et al. (1968), involving compression damage of banana fruit, which are physiologically and morphologically similar to plantain and cooking banana, there was a substantial reduction in the preclimacteric period. The difference in results from these two compression studies may be explained by the severity of damage. The compression treatment used by

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Maxie et al. (1968) involved a loading treatment which disrupted the peel membrane. In contrast, although quasi-static loading caused a consistent pulp injury, the peel remained intact. This difference in response related to peel integrity is clearly an important factor in terms of ripening time and suggests that preclimateric green fruit are a highly robust storage unit that can withstand considerable pressure without loss of quality or ripening period, providing the peel is not corrupted.

Table 1. The effect of fruit maturity and damage on the ripening period of plantain

Fruit maturity	Types of damage				
	Control	Impact	Abrasion	QS loading[a]	Mean
Immature	22.3	20.2	13.7	22.1	19.7
Mature	15.1	15.2	11.1	15.1	14.1
Fully mature	11.9	12.0	10.0	11.3	11.3
Mean	16.4	15.8	11.6	16.3	

C.V. = 21.5% [a] Quasi-static loading
LSD (P≤0.05) for comparison of any mean in main table = 3.28.
LSD (P≤0.05) for comparison of mean at same level of maturity = 2.03

Experiments by Peacock (1973), found that a drop impact treatment and a 10% peel abrasion treatment reduced the 'green life' of bananas by only 11.5% in the most extreme case. Peacock considered this reduction was of no commercial significance. The results in experiment 1 confirmed that impact had a minor effect on ripening. However, abrasion caused a significant, ($P \leq 0.05$), 39% reduction in the ripening period of least mature fruit. Abraded fruit ripened 9 days earlier than the control. This considerable difference between the two experiments may be explained by the interaction between damage and storage humidity.

When the effect of abrasion on fruit ripening was studied at high and low humidity (experiment 2), it was revealed that abrasion and impaction had no effect on ripening of fruit stored at high humidity (100% RH). However, at 55% RH, abrasion caused a significant reduction in the ripening period (Ferris 1992). Evidently the accelerated ripening caused by abrasion is a passive effect dependent on humidity. Abrasion caused a reduction in the 'green life' of only fruit stored at a humidity of less than 100% RH.

Further investigation of abrasion at increasing levels of severity, on fruit stored at 75–85% RH, showed a power relation between abrasion and fruit weight loss (Fig. 2). The data in Figure 3 also show a power relation between level of abrasion and ripening period. These data sets show that, over the initial ranges, i.e. from 2–4% daily weight loss and 0–5% peel area abraded respectively, there was a dramatic reduction in ripening period. The significant change in weight loss and early ripening of abraded fruit may be explained by an increase in peel permeability to water. Figure 4 shows data obtained from porometric observations from sec-

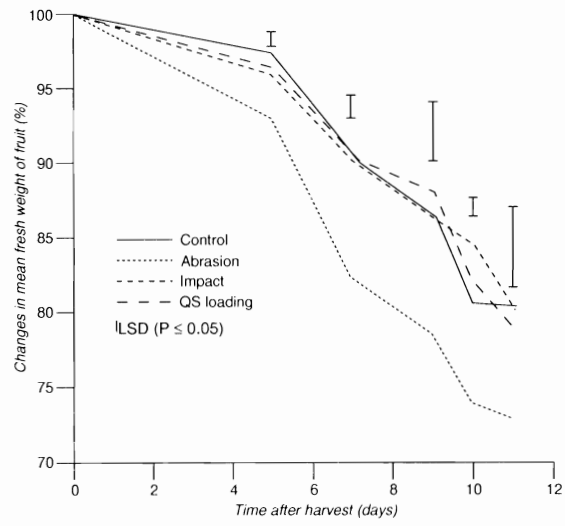

Figure 1. The effect of damage treatments on percent change in weight of French plantain stored at ambient tropical temperature and humidity: recorded temperature range, 26–31°C; recorded relative humidity range, 70–96%.

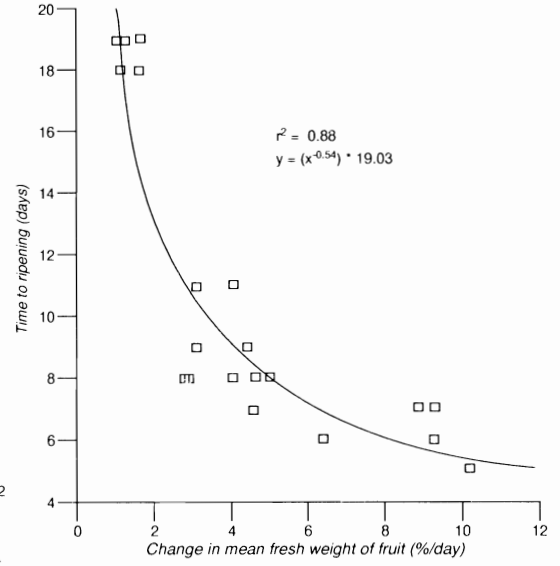

Figure 2. The power relation between average percent change in weight per day and time to ripening of bananas stored at 70–80% relative humidity and 20°C.

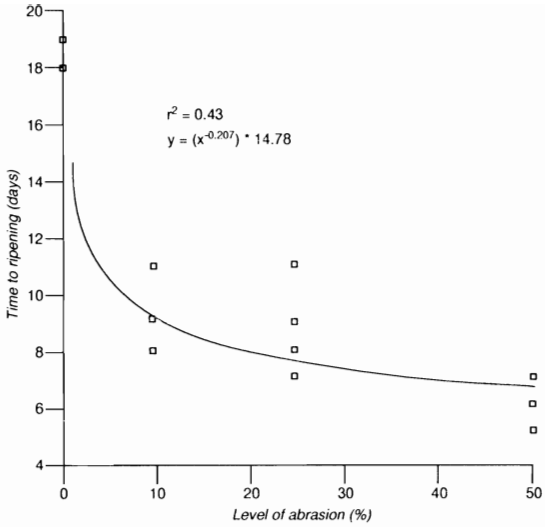

Figure 3. The power relation between percent abrasion and the time to ripening of bananas stored at 70–85% relative humidity and 20°C.

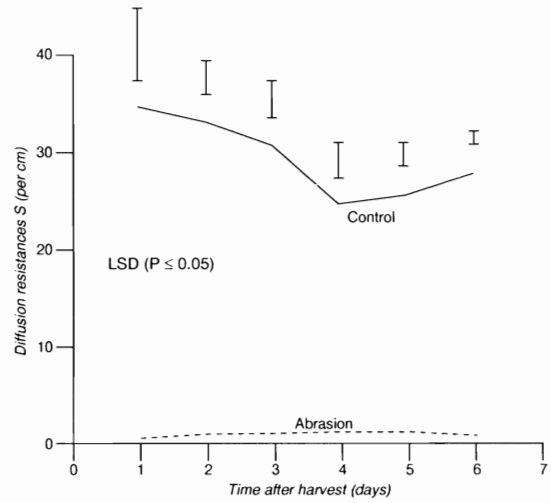

Figure 4. The effect of abrasion on the moisture diffusion resistance of banana peel stored at 70–85% relative humidity and 20°C.

tions of undamaged and abraded peel. The abraded peel shows a significant ($P \leq 0.05$) increase in peel permeability to water which is indicated in Figure 4 as a significant ($P \leq 0.05$) reduction in diffusion resistance, compared with the control peel.

When the effect of abrasion and humidity were studied in terms of ethylene production and climacteric response, it was found that abrasion caused a consistent increase in ethylene production. Fruit stored at 100% RH produced a stress ethylene peak in response to damage but, after this, ethylene produced by damaged fruit returned to near control levels after 2–3 days. Consequently, both damaged and control fruit stored at 100% RH entered the climacteric almost simultaneously after approximately 15 days (Thompson et al. 1992). In contrast, damaged fruit stored at low humidity reached peak climacteric ethylene production after 7 days and control fruit stored at low humidity reached peak ethylene production after approximately 10 days.

Conclusion

The results from this study have important commercial implications, as ripening determines the 'green life' or 'marketable period' of *Musa* fruit in the transport and marketing chain. Abrasion caused the most significant reduction in ripening period and it was considered that the accelerated ripening was caused by increase in peel permeability to water vapour. This water loss induced a water stress which triggered the climacteric response and hastened ripening. However, abrasion is not an active mechanism, because it does not induce the climacteric response independently. Banana fruit progressively lose water as humidity is reduced from 100%, and the rate of water stress is merely exacerbated by abrasion. The results also showed that although abrasion was a serious form of damage, a simple manipulation of ripening environment, i.e. high humidity storage, could enable a retailer to avoid the detrimental effects of peel damage. When high humidity storage is not feasible, it is of practical importance for the harvester and retailer to be aware that small changes in the level of abrasion, i.e. from 0–5%, may cause dramatic reductions in ripening period. Hence, working practices should aim to avoid or minimise damage when a long market life is desired.

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