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The use of low temperature and coatings to maintain storage quality of breadfruit, *Artocarpus altilis* (Parks.) Fosb.

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Abstract

Harvested, ripening breadfruit softened synchronously throughout the depth of the fruit. Postharvest life was optimally extended at 12–13 °C while chilling injury was evident at 7 °C. Peak CO_2 production of fruit at ambient temperature (24–30 °C) was 300 ml kg^{-1} h^{-1}, but was one fifth this value for fruit stored at 13 °C and occurred 5–10 days later. Peak C_2H_4 production was similarly delayed at 13 °C, but was instead depressed eightfold. Semperfresh F, Nutri-Save, Sta-Fresh MP and chitosan coatings all retarded fruit softening, more so at ambient temperature than at 13 °C. All coatings resulted in lower internal O_2 concentrations and higher internal CO_2 concentrations. Unlike the carbohydrate-based coatings, Sta-Fresh MP reduced water loss and markedly retarded skin browning, a cosmetic problem in refrigerated storage of breadfruit. Starch breakdown and sugar production were comparable in coated and uncoated fruit at ambient temperature, but fruit at 13 °C exhibited low temperature sweetening with sugar accumulation and no accompanying starch degradation. Any advantage afforded by delayed ripening with the coatings was out-weighed by the development of off-odours and flesh discoloration in the coated fruit.

Keywords: Artocarpus altilis; Breadfruit; Coatings; Ripening; Refrigerated storage

1. Introduction

Breadfruit, *Artocarpus altilis* (Park.) Fosb., is a seedless, starchy tropical fruit native to the Pacific Islands. It exhibits great morphological variability with numerous cultivars locally recognised (Ragone, 1997). The crop is cultivated throughout the tropics with the mature but unripe fruit being cooked and consumed in much the same way as root and tuber crops (Worrell and Carrington, 1997). Breadfruit are mainly consumed locally with virtually no postharvest treatment, but a growing export trade from the Caribbean to Europe and North America has stimulated research into postharvest handling procedures for this per-

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ishable fruit, which has a very high respiratory rate (Worrell et al., 1998). Previous investigators have shown that refrigerated storage above 12 °C could extend the postharvest life of this fruit (Thompson et al., 1974; Maharaj and Sankat, 1990), but much remains to be known about the postharvest biology of this starchy staple. In particular, application of semipermeable coatings have been shown to improve the storage life of other perishable tropical fruit, such as litchee (Zhang and Quantick, 1997) and mango (Baldwin et al., 1999).

In this study, we examine the effect of temperature on postharvest fruit quality and the respiratory climacteric of breadfruit and evaluate the possible use of chemical coatings as an adjuvant to refrigerated storage.

2. Materials and methods

2.1. Plant material

Mature breadfruit (*A. altilis* [Parks.] Fosb.) were harvested from trees of unknown age in backyard orchards in St. Michael and St. James, Barbados. The fruit were of the seedless, 'white flesh' (uncooked flesh colour) cultivar most common in Barbados and were harvested at the early mature stage, as defined previously (Worrell et al., 1998). Fruit were briefly washed in running water and allowed to air-dry prior to use.

2.2. Measurement of fruit softening

Ninety-six freshly harvested fruit were stored at ambient temperature (25–30 °C) and each day a random sample of 16 fruit was assessed for softening by three methods. Firstly, fruit were rated subjectively by finger pressure using a three-point scale where '1' represented incompressible fruit, '2' represented spongy (reversibly compressible) fruit and '3' represented fully soft fruit (showing permanent deformation on being compressed). Secondly, fruit were peeled and penetrated to a depth of 25 mm at three locations around the equatorial diameter, using a FT327 penetrometer with tapered 7 mm tip (David Bishop Instruments Ltd., Heathfield, E. Sussex, UK). Finally, fruit were bisected polarly and firmness of the exposed flesh measured with the same penetrometer in outer (just below the skin), middle (midway between skin and core), and inner (just outside the core) regions.

2.3. Temperature treatments

Replicates of eight freshly harvested breadfruit were individually weighed, then stored at either 7, 12, 13, 14, 15, 16, 17, 22 °C or ambient temperature (25–30 °C) for up to 11 days. Temperature control was provided by 0.34 m^3 low temperature incubators (Precision Scientific Inc., Chicago, USA). Each day fruit were weighed and softening was assessed nondestructively by finger pressure.

2.4. Characterisation of the climacteric

Six fruit were placed in individual 25 l plastic bell-jars and ventilated with C_2H_4-scrubbed, humidified air (1.5 l min^{-1}). Three fruit were kept at ambient temperature (24–30 °C) while the other three were enclosed in a 13 °C incubator. Fruit texture, respiration and C_2H_4 production were monitored twice daily, as previously described (Worrell et al., 1998).

2.5. Coatings and storage life

Three replicates of ten fruit each per treatment were brush coated with 1.5% (w/v) Semperfresh F, 3% (w/v) Nutri-Save$^{(R)}$ (Nova Chem Limited, Nova Scotia, Canada), full strength Sta-Fresh MP (FMC Corporation, Lakeland, FL), 1.5% chitosan (Sigma Chemical Company, St. Louis, MO) or left uncoated. Manufacturers' recommendations were followed for all coatings except for chitosan, which was dissolved overnight in warm 0.2 M acetic acid and subsequently neutralised with 0.5 M sodium acetate. Fruit were air dried, then stored at ambient temperature (24–30 °C) and were monitored every 2 days for weight loss, texture (finger pressure), skin discoloration and microbial contamination. The percentage of the fruit surface showing the latter two features was estimated using a clear vinyl sheet with a 1 × 1 cm

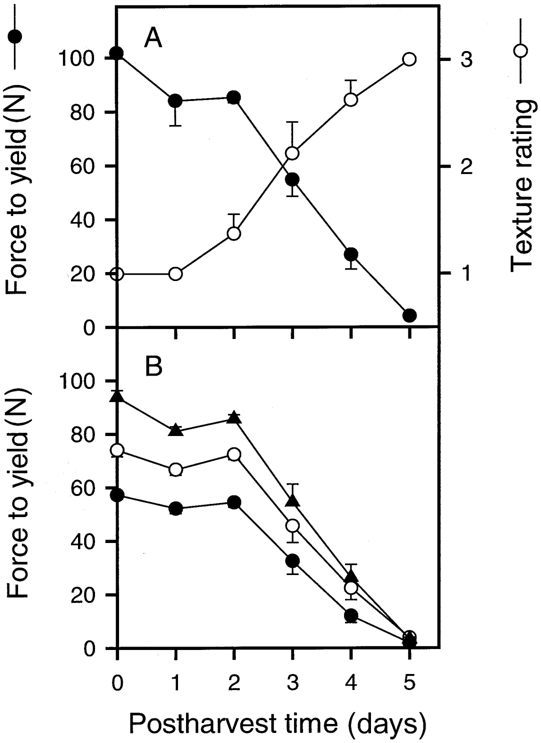

Fig. 1. Textural changes in breadfruit during ripening at ambient temperatures, as measured by three methods. (A) External penetrometer puncture test (closed circles) and texture rating by finger pressure (open circles). (B) Penetrometer puncture tests of internal flesh at the inner (●), middle (○) and outer (▲) regions (mean of 16 fruit ± SD).

dot grid. The experiment was repeated with storage at 13 °C.

2.6. Internal gas compositions in coated fruit

A 4 cm deep hole was bored in the equatorial region of each of 90 fruit using aluminium wire (1 mm OD). An 18-gauge 38-mm needle was inserted in each hole up to its hub and sealed in place with silicone dental impression material (Reprosil; Dentsply Intl., Milford, USA). A 5 ml plastic syringe (without plunger) was attached to each needle hub and the open end plugged with a self-sealing rubber septum. The fruit surface was then left uncoated or painted with one of the four coatings described above, using 18 fruit per treatment, nine of these being stored at ambient temperature and nine at 13 °C. Gas samples (1 ml) were withdrawn daily from each syringe chamber. CO_2 was measured using an infra-red gas analyser (ADC, Hoddesdon, UK). O_2 was analysed using a Protox oxygen meter (Gow-Max Instrument Company, Gillingham, Kent, UK) by sampling directly from the syringe chambers for 20 s before recording the displayed concentration. Volumetric measurements are reported at 101 kPa total pressure and ambient temperature.

2.7. Analysis of carbohydrate levels in coated fruit

Thirty breadfruit were divided into five groups of six fruit each. One group was left uncoated, while each of the others was coated with one of the coatings previously described. For each treatment, three fruit were stored at ambient temperature and the remaining three fruit at 13 °C. An internal portion of fruit tissue (about 100 g) was removed from three fruit initially and from the remainder after 7 days for the assay of starch, reducing sugar and total sugars, as previously described (Worrell et al., 1998). Assays were reported with respect to fresh weight.

3. Results and discussion

3.1. Measurement of fruit softening

Fig. 1 compares three methods of measuring softening in ripening breadfruit. By all three methods the kinetics of softening were quite similar with a decline in firmness detectable by the 2nd day after harvest. In contrast to the finger pressure method, the penetrometor-based measurements revealed a slight decline in firmness after 1 days of storage. The comparable results obtained by monitoring fruit softening destructively using a penetrometer and subjectively using finger pressure, validated the use of the second approach throughout this study. This was important as breadfruit is a large, bulky fruit and a

Table 1
Mean texture rating (firm = 1; soft = 3) and weight loss of breadfruit stored at various temperatures for 5 and 10 d (mean of eight fruit ± SE)

Storage temperature (°C)	Texture rating		% Initial weight	
	At 5 days	At 10 days	At 5 days	At 10 days
7	1.0 ± 0.0	1.0 ± 0.0	87.9 ± 1.05	79.7 ± 1.95
12	1.0 ± 0.0	1.1 ± 0.0	82.9 ± 0.45	72.2 ± 0.84
13	1.0 ± 0.0	1.0 ± 0.0	81.6 ± 0.96	70.7 ± 1.02
14	1.3 ± 0.1	2.5 ± 0.3	82.0 ± 0.95	69.2 ± 1.11
15	1.8 ± 0.2	2.8 ± 0.2	85.6 ± 0.56	76.1 ± 0.21
16	2.8 ± 0.2	3.0 ± 0.0	84.3 ± 0.40	76.0 ± 0.65
17	2.1 ± 0.3	2.6 ± 0.0	85.4 ± 0.64	78.8 ± 1.79
22	2.9 ± 0.1	[a]	74.9 ± 0.78	[a]
Ambient	3.0 ± 0.0	[a]	75.6 ± 0.96	[a]

[a] Fruit discarded.

destructive approach to measuring softening would have presented serious difficulties in terms of replication and provision of adequate refrigerated space. Comparison of textural changes in outer, middle and inner zones of the fruit (Fig. 1B) suggests softening began simultaneously throughout the fruit, further justifying the monitoring of softening at the fruit surface.

3.2. Optimal storage temperature

Table 1 summarises the response of breadfruit to a wide range of storage temperatures with respect to weight loss and softening. Softening was particularly rapid at temperatures of 16 °C and above. Fig. 2 gives a detailed view over a narrower temperature range. At 12 and 13 °C, no softening was detectable even after 9-days storage, while softening was evident after 2 days at ambient temperature (25–30 °C) and after 5 days at 14 °C (Fig. 2A). This confirms previous reports of an optimal storage temperature for breadfruit of between 12 and 13 °C (Thompson et al., 1974; Maharaj and Sankat, 1990). While fruit stored at 7 °C also remained firm during the experimental period (Table 1), unlike fruit stored at 12 and 13 °C, these did not ripen normally on transfer to ambient temperature following refrigeration and displayed water-soaked tissue and flesh browning. This was interpreted as symptoms of chilling injury and confirms previous observations made by Thompson et al. (1974). To minimise the likelihood of chilling injury, 13 °C rather than 12 °C was used as the storage temperature in all subsequent work. While preliminary experiments revealed that cooling time for this bulky commodity could be reduced from 9 to 3 h when room cooling was replaced by hydrocooling, pre-cooling did not extend storage life at 13 °C (data not shown) and so was not incorporated into the postharvest handling protocol. Maharaj and Sankat (1990) have, however, reported a positive response to immediate precooling of the fruit in chipped ice in the field.

Fruit at the lower temperatures (12, 13, 14 °C) showed a 20% loss in fresh weight over the first 6 days of storage compared to 32% weight loss at ambient temperatures for the same period (Fig. 2A). The lower rate of weight loss, and hence water loss, at lower storage temperatures is expected, reflecting lower vapour pressure differences between fruit and surroundings as temperature is lowered. Experiments tracing dye entry in submerged breadfruit and comparing drying rates of fruit partially covered in vaseline (data not shown) revealed that water entered submerged fruit primarily through the peduncle rather than the skin, but that the skin was the main route for water loss. This water loss may be facilitated by the numerous latex ducts permeating the fruit and opening at the fruit surface (Reeve, 1974).

3.3. Effect of refrigeration on respiration and C_2H_4 production

Breadfruit showed a comparatively high basal CO_2 production rate of 20–50 ml kg^{-1} h^{-1} as might be expected for such a perishable commodity. When fruit were stored at 13 °C, peak CO_2 production (300 ml kg^{-1} h^{-1}) was reduced to one fifth its value at ambient temperature and occurred between 10–16 days postharvest compared to 5–6 days postharvest at ambient temperature (Fig. 3A and 3B). Since the peaks for CO_2 and C_2H_4 production coincide, the same delay was seen in C_2H_4 production at 13 °C as for CO_2 but the lower temperature depressed peak C_2H_4 production (1.5 µl kg^{-1} h^{-1}) about eightfold (Fig. 3C and 3D). The initiation of softening was also markedly delayed at the lower storage temperature, commencing after 9–13 days at 13 °C, compared with after 5–6 days at ambient temperature (Fig. 3E and 3F), coincident with the corresponding onset of the respiratory climacteric. Storage at 13 °C, compared with ambient storage, doubled or tripled the time required for fruit to soften and reach the climacteric peak. Thus, despite the complexity of the ripening process, breadfruit, like many other types of produce, exhibits a Q_{10} in the region of 2 (Thompson, 1996).

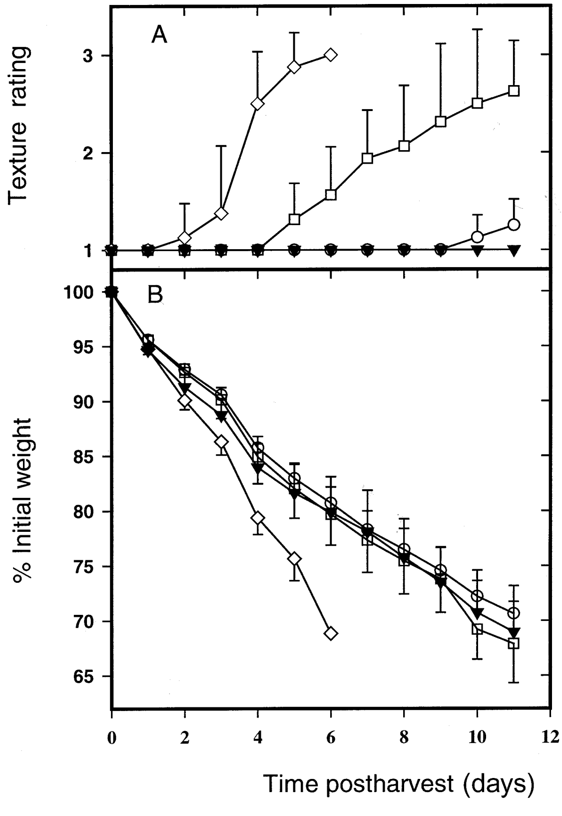

Fig. 2. Weight loss (A) and texture rating by finger pressure (B) of breadfruit stored at 12 (○), 13 (▼), 14 °C (□) and ambient temperature (◇). Mean of eight fruit ± SD.

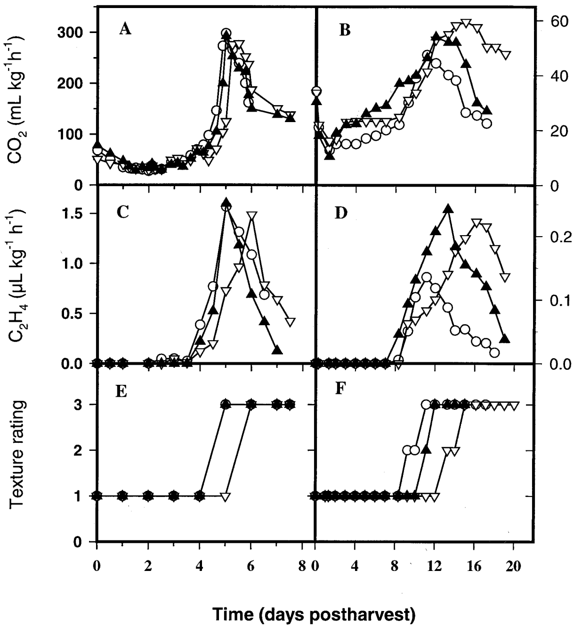

Fig. 3. Postharvest changes in respiration (A,B), ethylene evolution (C, D), and texture (E, F) in breadfruit stored at ambient temperature (A, C, E) or 13 °C (B, D, F). Each symbol represents a single fruit.

3.4. Effect of coatings on fruit quality

At ambient temperature, all of the coatings examined slowed down fruit softening, on average doubling the time taken for all fruit to become fully soft (Fig. 4A). This is in marked contrast to a previous study in which an oxidised polyethylene emulsion coating failed to extend breadfruit postharvest life (Thompson et al., 1974). At 13 °C, the effect of coatings on softening was less marked, with uncoated fruit beginning to soften after 9 days and coated fruit after 2 weeks of storage (Fig. 4B). While coated fruit outwardly appeared normal, bisection revealed internal flesh discoloration after 1 week at ambient temperature and after 2 weeks at 13 °C and this was often accompanied by the development of an alcoholic odour. A similar observation was made on coated mangoes where elevated levels of ethanol and methanol were measured compared to uncoated fruit (Baldwin et al., 1999).

Coatings had little effect on reducing water loss except in the case of Sta-Fresh, which reduced the rate of weight loss both at ambient temperature and 13 °C (Fig. 4C and 4D). These results are to be expected in that Sta-Fresh is a wax-based coating while all the others are carbohydrate-based. Unlike wax- and oil-based coatings, carbohydrate coatings have proven ineffective barriers to water loss (Smith et al., 1987). Along with its effect on reducing water loss, Sta-Fresh helped maintain green skin colour at both ambient temperature and 13 °C (Fig. 4E and 4F). Skin browning of breadfruit in storage is a problem, more so at low temperature (Maharaj and Sankat, 1990). Like skin browning in lychee (Underhill, 1992) and rambutan (Landrigan et al., 1996) it may be caused by skin dessication in that, firstly, the Sta-Fresh treatment reduced water loss and, secondly, submergence of fruit, a traditional method of postharvest storage of breadfruit in Jamaica, also maintains bright green skin colour (Thompson et al., 1974).

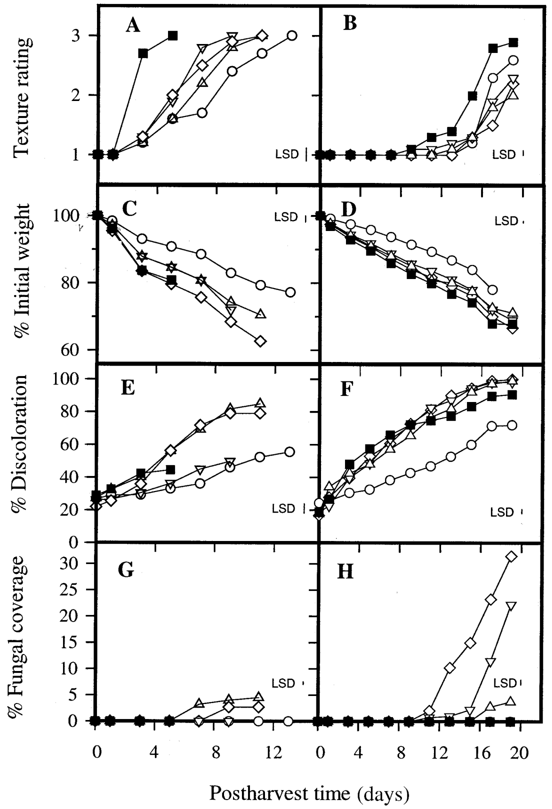

Fig. 4. Postharvest changes in texture (A,B), fresh weight (C, D), skin discoloration (E, F) and fungal coverage (G, H) in coated and uncoated breadfruit stored at ambient temperature (A, C, E, G) or 13 °C (B, D, F, H). Mean of 30 fruit.■ Uncoated control○ Sta-Freshv Semperfresh◇ NutrisaveΔ Chitosan

With the exception of Sta-Fresh, coatings promoted fungal growth on the fruit surface after prolonged storage, a problem not evident in uncoated fruit (Fig. 4G and 4H). Fungal proliferation was more marked at 13 °C and with fruit coated with Nutrisave and Semperfresh. In contrast to these results with breadfruit, Semperfresh has been shown to inhibit fungal growth on bananas (Al Zaemey et al., 1993), while chitosan exhibited similar antimicrobial effects on tomato (El Ghaouth et al., 1992) and lychee (Zhang and Quantick, 1997).

3.5. Internal atmosphere of coated fruit

Uncoated fruit showed internal O_2 levels slightly lower than that of ambient O_2 concentration and these did not change substantially during the postharvest life of the fruit at either storage temperature (Fig. 5A and 5B). In contrast, coating the fruit had an immediate effect of reducing the internal O_2 concentration, which continued to decline during storage. Differences between the coatings were not consistent. Internal CO_2 levels fluctuated dramatically during storage and, at least under ambient conditions, seemed to pass through a maximum, typical of a climacteric (Fig. 5C). The rise in internal CO_2 and fall in internal

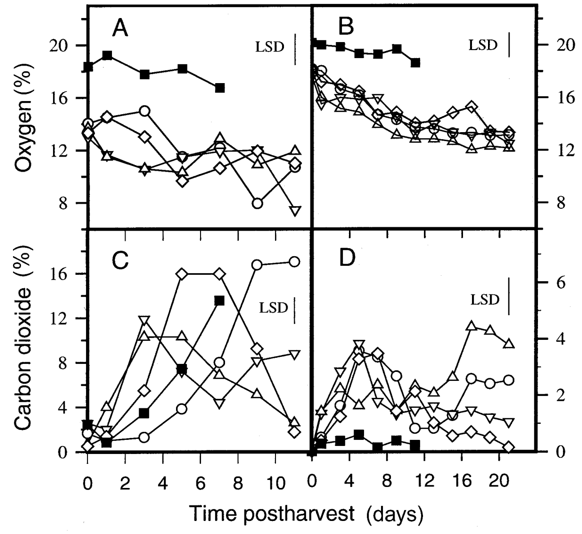

Fig. 5. Internal oxygen (A, B) and carbon dioxide (C,D) concentration in coated and uncoated breadfruit stored at ambient (A, C) or 13 °C (B, D). Mean of nine fruit. ■ Uncoated control ○ Sta-Fresh ▽ Semperfresh ◇ Nutrisave △ Chitosan

O_2 was less at 13 °C than at ambient temperature (Fig. 5A–D), reflecting the decreased rate of respiration at the lower temperature. Variability of internal gas concentrations, such as seen here, is a well recognised problem encountered with fruit coatings and probably arises from uneveness of the coating and a tendency of the latter to exaggerate variations in skin permeability (Smith et al., 1987). Despite this variability, it is clear that coatings resulted in lower internal O_2 and higher internal CO_2 concentrations and this may explain why coated fruit generally ripened slower (Fig. 4A, B). In support of this, Ramlochan (1991) was able to maintain breadfruit in a marketable state for 3 weeks at 12 °C in an atmosphere of 2–5% O_2 plus 5% CO_2.

3.6. Carbohydrate levels during storage

After 1 week of storage at ambient temperature, total and reducing sugar concentrations rose considerably (Fig. 6A,C) and starch reserves declined (Fig. 6E). Fruit coated with StaFresh and Semperfresh showed the largest rise in total sugars and the largest fall in starch content (Fig. 6C,E). In contrast, while fruit at 13 °C showed increases in total and reducing sugars, as was the case at ambient temperature, starch levels were unchanged (Fig. 6B,D,F). At both ambient and 13 °C, Nutrisave-coated fruit had the highest starch content and tended to show the smallest increases in reducing and total sugars. The rise in sugars at ambient temperature is consistent with reported increases in soluble solids during breadfruit ripening (Thompson et al., 1974; Maharaj and Sankat, 1990) as are the declines in starch seen here. The rise in sugars at 13 °C without starch breakdown appears to be unrelated to ripening. Fruit at this stage had not begun to ripen and this sugar accumulation appears to be another example of the phenomenon of low temperature sweetening exhibited by a wide range of higher plants and plant organs (ap Rees et al., 1981).

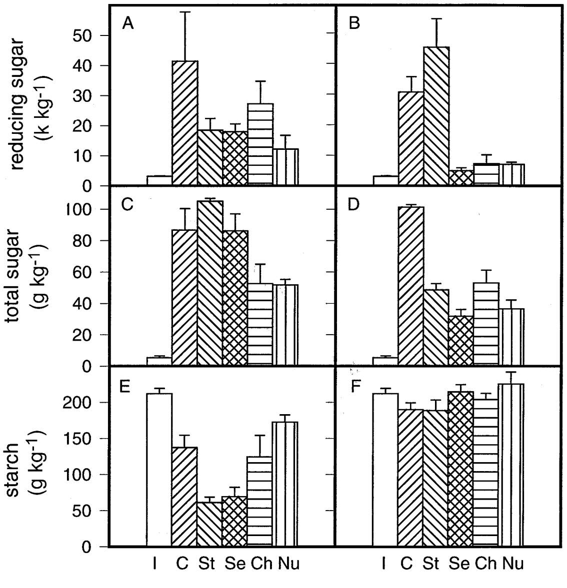

Fig. 6. Reducing sugar (A, B), total sugar (C, D) and starch (E, F) levels measured in coated and uncoated breadfruit flesh initially and after 1 week of storage at ambient (A, C, E) or 13 °C (B, D, F). Mean of three fruit ± SD.I = initialC = uncoated control (1 week)St = Stafresh (1 week)Se = Semperfresh (1 week)Ch = Chitosan (1 week)Nu = Nutrisave (1 week)

4. Conclusion

Low temperature storage of breadfruit at 13 °C doubled the shelf-life of this starchy staple to about 10 days by delaying the onset of the climacteric. All the coatings investigated delayed fruit softening slightly at both ambient temperature and 13 °C, possibly by depressing internal O_2 and increasing internal CO_2 concentrations. Coatings, however, resulted in unacceptable discoloration of the internal flesh and development of off-odours and for these reasons their use in breadfruit postharvest storage cannot be recommended. Plastic films may prove a more useful surface barrier in the refrigerated storage of harvested breadfruit.

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