JOINT PROCEEDINGS

TROPICAL REGION

21st Annual Meeting
of the Caribbean Food Crops Society
and
32nd Annual Meeting of the American Society for Horticultural Science — Tropical Region

technology for agricultural development

Hilton Hotel, Port of Spain, Trinidad
8 - 13 September 1985

Host Institutions
— Caribbean Agricultural Research and Development Institute

— Ministry of Agriculture, Lands and Food Production, Trinidad & Tobago

— Faculty of Agriculture, University of the West Indies

Published by the Caribbean Food Crops Society, Box 506, Isabela, Puerto Rico 00662

THE POTENTIAL FOR CONTROLLED ATMOSPHERE STORAGE OF SOME CARIBBEAN CROPS

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ABSTRACT

Modified atmosphere storage can increase the storage life of certain perishable crops beyond what is normally expected in refrigerated storage. This involves a change in the gaseous composition of the atmosphere surrounding the crop, with carbon dioxide and oxygen being principally affected. This technique may have potential for extending the storage life of tropical crops and avoiding the effects of chilling injury.

This paper reviews the state of research and examines the potential for controlled atmosphere storage of avocado, *(Persea americana)*, breadfruit *(Artocarpus altilis)*, cabbage *(Brassica oleracea)* and mango *(Mangifera indica)*, crops which are important to the Caribbean region.

RESUMEN

Almacenamiento en atmósfera modificada puede aumentar la vida poscosecha de ciertos cultivos de caracter perecedero a mas de lo que normalmente se espera en almacenamiento refrigerado. La modificación en atmósfera se trata de un cambio en la composición gaseosa de la atmósfera alrededor del producto, con dióxido de carbón y oxígeno siendo los principalmente afectados. Esta técnica puede tener éxito en extender la vida poscosecha de cultivos tropicales y en evitar los efectos de daño por el frío.

Este informe revisa el estado de investigación hasta hoy en día y examina la posibilidad de almacenamiento en atomósfera modificada para el aguacate *(Persea americana)*, fruta de pan *(Artocarpus altilis)*, repollo *(Brassica oleracea)* y mango *(Mangifera indica)*, cultivos de importancia a la region del Caribe.

The importance of fresh fruits and vegetables has resulted in considerable trade in these commodities which provide essential nutrients in the human diet. There are considerable postharvest losses, however, in these fresh fruits and vegetables. Figures varying from 25 to 80% have been reported for loss of these commodities (19, 39).

In the Caribbean Islands, the need to reduce such losses cannot be over-emphasised. A Commonwealth Secretariat Report (61) provided the following summary with respect to the perishable crop storage:

"(i) All the islands are engaged in the production of perishable commodities which are seasonally produced.

(ii) Agriculture is export oriented and the bulk of the unexported fruit is thrown away. At times they are simply left in the field to rot.

(iii) Postharvest losses are extremely high, rising to about 50%.

(iv) Research, training programmes and on going projects are generally minimal or non-existent, so that the position in a number of territories today is as it was many years ago with little being done to reduce postharvest losses. In one or two instances where research has been finalised in specific areas, there has been no follow up action and losses continue unabated."

To date, the above position remains unchanged. It has been suggested that for many countries, increased availability of food crops can be achieved through improved conservation and storage techniques rather than efforts only aimed at increasing production levels. The development of improved storage methods for Caribbean crops could impact on the economics of many islands as follows:-

(i) A reduction in the importation of perishable commodities that are seasonally produced in the Caribbean, and hence a savings in foreign exchange.

(ii) Increased exports of Caribbean crops to overseas markets particularly to North America and Europe.

This paper reviews the state of the art with respect to research on storage of some selected Caribbean crops, viz; avocado, breadfruit, cabbage and mango. Emphasis is given to storage techniques which employ modification of the atmosphere.

Avocado *(Persea americana)*

Refrigerated storage

Numerous recommendations have been made with respect to temperature ranges for the storage of different varieties of avocados. These are usually related to production sites, duration of storage, and transportation demands.

Reports on cold storage of avocados date as far back as 1907 when Higgins (29) reported a successful export of Hawaiian avocados to San Francisco. Later, Harold (24), reported that Hawaiian avocados may be stored green at 2.2°C for 6 to 8 weeks thereafter ripening in 2 to 5 days.

Overholser (38) found that a temperature of 4.5°C was satisfactory for all California avacado varieties tested except the 'Fuerte' which required 7.2°C to prevent blackening of the skin. In general, a temperature of 0°C was found to be too low since it led to skin discolouration. However, it was mentioned that some varieties may be satisfactorily stored at 0-2°C for up to two months while others kept for 4–6 weeks.

The first reports of cold storage of West Indian varieties were made by Wardlaw (63) and Wardlaw and Leonard (64). The preliminary observations suggested that of the 33 varieties tested, 22 were not sufficiently cold-resistant to withstand a temperature of 5–12°C for a period of 15 – 20 days without developing characteristic discolouration. The remaining varieties, for example the 'Pollock', ripened normally at 21°C after being held for 15–20 days at 4.5°C. An additional storage period of 10 days at 4.5°C caused slight abnormal changes to gradually be developed. These results were confirmed by Smith (50) and Ward (67). In addition, Ward (67) reported that contrary to expectations, a pure Guatemalan type, 'Panchoy', grown in Trinidad was found to be subject to chilling injury in storage.

Many recommendations have since been made for the cold storage of different cultivars of avocado. For 'Taylor', Lyle (36) reported a storage temperature of 5–6°C without indicating the length of storage time. In Florida, Hatton *et al*, (26), found that the best storage temperature for the locally grown fruit was 15°C. Erickson and Tadaaki (18) found that 'Hass' was in acceptable condition after being kept for 32 days at 9°C.

In Israel, workers studied the behaviour of 'Etinger', 'Fuerte' and 'Nabal' stored for 1, 2, 3 and 6 weeks at 0, 2, 4 and 6°C. They found 'Nabal' from Guatemalan stock, to be most tolerant to the storage conditions tested.

In Egypt, Abou Aziz *et al* (1) reported that 10°C was the best temperature for storing the Mexican variety 'Duke' for periods of up to two weeks.

Arriola *et al* , (4) reported that among the varieties stored in Guatemala, 'Hass' can be stored for three weeks at 12°C, wheras 'Azteca', 'Guatenca' and 'Fuerte' withstood slightly shorter storage periods. When these varieties were stored at 7°C, ripening was retarded by 4 to 6 days.

It appears that the Mexican and Guatemalan varieties and their hybirds such as 'Hass' and 'Fuerte' are more resistant to cold than the West Indian varieties.

Modified atmosphere storage

In an effort to extend the shelf life of avocados, a fair amount of research has been reported with modified atmosphere storage. A wide range of recommendations, dependent upon variety, are put forward.

In Israel, Aharoni (2) stored 'Fuerte' at 8°C and 12°C in polyethylene bags for 23 days and 'Nabal' for 46 days. Fruits stored at 14, 15 and 17°C softened and many rotted.

In Grenada, Halkon (23) investigated the use of packing treatments. He reported that sealed polyethylene bags prolonged storage life more than any other treatment. In one trial, polyethylene wrapped avocados required an average of 20 days to soften, whereas the unwrapped fruit took 12 days. Although no definite conclusions were drawn nor recommendations it was noted that fruit stored below 12.7°C for more than one week generally showed some form of chilling injury.

Audit and Scott (5) working in Australia packed 'Hass' avocados individually in sealed polyethylene bags and experimented with potassium permanganate as an ethylene absorbent. The fruits were then stored at 10°C and ripened at 20°C after they began to soften. Packing fruit in these bags markedly increased the storage life and softening was further delayed by the use of potassium permanganate. There was no apparent deterioration in the eating quality 40 to 50 days after storage, but the occurrence of anthracnose usually made it necessary to terminate storage, even though the fruits were quite firm. These results were confirmed by ICAITI (30) and Scott and Chaplin (48).

Chaplin and Hawson (13) further investigated the use of polyethylene bags at ambient temperatures for various storage times. The modified atmosphere which developed in the bags retarded ripening and helped fruit stay firm. Abnormal ripening characteristics were observed, however, when storage temperatures were high and storage time exceeded 8 days.

Several researchers have used combinations of CO_2 and O_2 in controlled atmospheres to extend the useful storage life of fruit. In Florida, Hatton and Reeder (27) investigated storage of 'Lula'. Using a constant flow system to purge the ethylene gas, they reported limited success initially with CA storage using 1% O_2 and 9% CO_2 levels at 10°C. The flow was adjusted so that fruit respiration would not reduce to O_2 level below 1 to 1.5% O_2, a condition where injury was likely to occur. One hundred per cent of 'Lula' avocados stored at 2% O_2 and 10% CO_2 at 7°C were in acceptable condition after 20 or 40 days, while all fruit decayed when stored in air. External darkening and percentage weight loss were significantly lower for fruit held in CA than in air. Vakis *et al* (59) also showed that 10% CO_2 storage atmosphere reduced the incidence of chilling injury of 'Taylor' avocados.

Spalding and Reeder (52) observed that all fruits of 'Lula' and 63% of 'Booth' were acceptable after 60 days storage under 10% CO_2 and 2% O_2 at a temperature of 7°C. Bleinroth *et al*, (10) found that among the nine varieties studied in South America at a temperature of 7°C in an atmosphere of 10% CO_2 and 6% O_2, 'Prince' and 'Wagner' had the longest storage life, 37 days in CA and subsequently, 2 days in air.

In Israel, Apelbaun *et al* (3) found that reducing the atmospheric pressure in the refrigerated storage chamber at 6 °C markedly retards avocado ripening. The effect was found to be more pronounced when the pressure was reduced below 100 mm Hg. Fruit stored at 760 and 200 mm Hg ripened in 35 and 50 days respectively, while the fruit stored at pressures below 100 mm Hg remained unripe for 70 days in storage. The best storage pressure tested for avocado was 60 mm Hg. Although ripening was markedly retarded under sub-atmospheric conditions, all fruits ripened normally several days after being transferred to normal atmospheric pressure and a temperature of 14°C. This showed that the fruit retained the ability to undergo normal ripening processes, including developing proper texture and taste.

Breadfruit *(Artocarpus altilis)*

Breadfruit has an extremely short storage life under normal conditions and is considered unpalatable as soon as it becomes soft and sweet. This factor results in difficulties with respect to marketing breadfruit locally when there is an export potential in temperate countries (9). Even transport by air is a difficult proposition.

Detached breadfruit has a high respiration rate, reaching a climacteric peak of above 3ml CO_2 per kg/hr at 20°C five days after harvest (6). Information on methods of storage and on the storage life of breadfruit is limited. Several methods for preserving breadfruit have been reported including fermentation (8). Passam *et al*, (41) reported that segments of peeled breadfruit which have been boiled for a short period and frozen at − 15°C could be stored for approximately 11 weeks. After cooking, frozen samples compared favourably in flavour, colour and texture with fresh breadfruit. Ward (62) in his investigations on ensilage in Jamaica reported that the product was unfit for human consumption. It was also mentioned that breadfruit slices in a brine solution are canned for local and export markets.

Thompson *et al* (57) studied the effect of maturity, temperature and wrapping treatments on breadfruit of the yellowheart and whiteheart types. The temperatures studied were 27.7°C, 12°C and 7°C. It was reported that storage at 25° – 28°C resulted in complete softening of the fruits in 2–4 days while at 12.5°C, softening occured in 8.3 days. At 7°C, softening was greatly delayed. When ripening eventually began, it was irregular and abnormal either because of prolonged storage or transfer to ambient conditions. They also found that soluble solids developed within 3–4 days at 28.5 °C and even more rapidly when fruits were transferred from 12.5°C to ambient temperatures. However, some fruits which were stored at 2.5 °C accumulated little soluble solids either during storage or when removed to ambient conditions. It was postulated that softening appears to be associated with the accumulation of soluble solids, a process which normally accompanies the ripening of climacteric fruits. In other experiments, 38 µm polythene bags (150 gauge) were found to significantly extend storage life at both high and low temperatures. At 24.5 ° C, the extension was from 2.8 to 14.1 days and at 12.5 ° C, from 8.3 to a maximum of 21.5 days. During storage, the fresh green appearance was maintained. When fruits ripened, they did so normally. In addition, storage life appeared to be unaffected by either the stage of maturity at harvest or harvesting method. Fungal and bacterial infections were uncommon. Additionally, when fruits were removed to ambient conditions from storage below 12°C, it was consistent with the hypothesis that chilling injury occurs under such conditions.

The increase in the storage life of breadfruits packed in polyethylene bags was further confirmed by Marriot *et al*, (37) in Jamaica. Sealed 25 um polyethylene bags (100 gauge). and 50 µm bags (200 gauge) were used. The mean time to softening for unwrapped fruits was found to be 5.2 days, whereas for polythene wraps these times were 7.1 and 18.7 days respectively. Softening was usually internal for unwrapped fruit and those in 100 gauge bags; it was usually superficial and accompanied by browning for fruit in 200 gauge bags. In addition, storage life was greater for fruits harvested partially mature (light green, closely packed fruit segments) compared to fully mature (dark green, large fruit segments) fruits.

In Trinidad, Passam *et al*, (41) reported that breadfruit of a local whiteheart type enclosed in polyethylene bags could be stored in a fresh marketable state at 14 °C for up to 10 days. Inclusion of an ethylene oxidizing agent did not improve storage significantly.

Cabbage *(Brassica oleracea)*

Storage

There has been little reported on refrigerated storage of cabbage in the Caribbean. In Trinidad, Trotman (58) reported that cabbage was placed in cold storage due to a large crop and unremunerative prices. The objectives were to avoid waste and relieve markets and also to obtain information on the possibility of storing locally grown varieties. Unwrapped cabbages were packed in crates normally used for the export of grapefruits. They were cooled by air blast. Temperatures ranged between 2.2 ° C and 5.5 ° C for the first 5 weeks and between 4.4 ° C to 15.5 ° C for 4 additional weeks. Relative humidity was practically 100% for the first two weeks and varied between 82–90% for the remainder of the storage time. As the storage was operated commercially, it was necessary to sell as much as possible, hence the removal of cabbage from storage was based on market conditions. Cabbages were first removed after five weeks and the last batch after nine weeks. Weight loss for withdrawn cabbages varied between 5% and 13% whereas trimming losses varied between 8% and 22%. It was reported that cabbages were unattractive in appearance when withdrawn from cold storage, the outer leaves being wilted and brownish, though the hearts were sound and in good condition. Taste was evaluated but it was noted that as the storage time increased, deterioration extended more deeply into the head. It was concluded that the net saleable weight declined at a rate of about 5% per week.

Outside of the Caribbean area, there has been a substantial amount of research on refrigerated and modified atmosphere storage for long term preservation of temperate cultivars of cabbage. Parsons (40), reported that cabbages were stored in crates lined with perforated and non-perforated polyethylene as well as in unlined crates. They were stored for various periods at 0 °C, 3.3 °C and 7.2 °C. Cabbages stored at 7.2 °C deteriorated more rapidly than those stored at lower temperatures. Approximately 80% of the cabbages placed in storage remained edible after 8 weeks at 0 °C, 6 weeks at 3.3 °C and 4 weeks at 7.2 °C. Moisture loss, trimming losses and fresh green colour retention were best for polyethylene lined as compared to unlined crates. The use of polyethylene liners was beneficial at all experimental temperatures for prolonging the storage life and maintaining the original quality of the cabbage.

Isenberg and Sayles (31) attempted the long term storage of Danish cabbage in New York. Tests were conducted at 0 °C ± 0.5 °C using walk-in refrigerators with individual compartments of plywood. Atmospheres were developed from bottled gas and were flushed daily. In a series of experiments over a four year period, atmospheres were tested in combinations ranging from 2.5% to 10% for both CO_2 and O_2 for periods of 125–200 days. Atmospheres containing in excess of 5% of either CO_2 or O_2 were not better than air. When tested were conducted at 4.5°C, there was a considerable increase in storage rots so that cabbage would have not been accepted commercially. Thus this treatment was eliminated after initial tests. Further observation yielded no marked internal changes in any of the treatments where CO_2 and O_2 levels were 5% or less. The cabbage stored at 2.5% O_2 and CO_2 was often abnormally sweet, but cabbage stored at 2.5% O_2 and 5% CO_2 was much more acrid to taste, similar to fresh cabbage in the field. Air stored cabbage was flavourless. Trimming was generally low. The most prominent aspect of cabbage in modified atmosphere storage was the reduction in the rate of colour loss.

Several subsequent reports were in agreement with the conditions reported above. Van Den Berg and Lentz (60) found storage life between 3.5 °C, 4.5 °C and 7.8 °C was limited to 4–5 months and 2–3 months respectively, and at 0–1 °C there was little rotting and internal growth after 7 months storage. In addition, they found the storage of cabbage at a RH near saturation (98–100%) reduced decay, moisture loss and colour loss substantially when compared to 90–95% RH. Geesen (21, 22) found storage life up to 10 months at 0–2°C, 3% O_2 and 5–6% CO_2 with remainder being nitrogen. Furry *et al* (20) summarized similar results but noted the necessity for the reduction of ethylene gas concentration to a very low level. Wang (61), found that Chinese cabbage was not saleable without extensive trimming after 3 months of storage in air at 0 °C but in 1% O_2 and at 0°C they were still saleable after 5 months of storage with only slight trimming. No off-odour, off-flavour, or other symptoms of sub-oxidation were found at the end of 5 months storage at 1% O_2 at 0°C.

Hicks and Ludford (28), reported on the effects of low ethylene levels (1 ppm) on the storage of cabbage. Ethylene was found to have a definite detrimental effect on the appearance of cabbage when added to air atmosphere but little effect on controlled atmosphere. Similarly, weight loss in storage was greatest in air plus ethylene as was the decrease in total sugars.

Mango *(Mangifera indica)*

Refrigerated storage

It was noted by Thompson (54) that the minimum temperature for the storage of West Indian mango cultivars has been given as 4–7°C (49),8.6°C (7) or 6 to 7°C and for Florida cultivars, 10°C (45). Below these temperatures in cold storage, or on subsequent removal to higher temperatures it was generally found that fruits do not ripen normally. Wardlaw and Leonard (65) reported that chilling may be manifested in several ways including the production of skin blemishes, failure to develop normal colour on ripening, failure to ripen on removal from cold storage and a notable decline in pathogenic resistance. It was further stated that susceptibility to chilling injury varies with maturity at harvest, season and the duration of exposure to low temperatures. Fungal diseases are common in stored fruits, the most important being anthracnose. Pennock and Mandonado (43) and Smooth and Segall (51) showed that hot water treatment of mango fruits reduced the incidence of anthracnose decay.

Thompson (54) investigated the storage of West Indian mangoes with respect to cultivars, wrapping, temperature, size and shape, and maturity at harvest. It was found that different cultivars harvested in the same area and stored under the same conditions showed different degrees of susceptibility to disease development. Placing fruits in polyethylene bags significantly delayed ripening but led to physiological breakdown of tissue probably caused by CO_2 toxity after prolonged storage. It was further reported that fruits stored at lower temperatures had less weight loss. No fungal lesions developed with storage temperature of 8.5°C for 6 weeks, whereas mangoes stored between 13°C and 16°C were badly rotted after 4 weeks and those stored at 21°C rotted after 2 weeks. Fruit stored at 10°C for 14 days showed excessive fungal development. Fruit stored at 7°C for 26 days, however, ripened normally when moved to a higher temperature. Generally fruit at Stage B maturity* stored best with little evidence of fungal development over a 28 day period. The flavour of the ripened fruit was consistently good. Thompson (54) concluded that no evidence of chilling could be detected in storage at 5°C and above. Immature fruits did develop chilling symptoms when stored below 10°C; Stage B proved optimum for storage over a period of three to four weeks. The optimum temperature was not specified. In addition a shorter storage life was characteristic of more mature fruits.

In further experiments, trial shipments to the United Kingdom were successful at 4°C for 2 days followed by 13°C for 10 days. A more detailed evaluation of wrapping was highlighted. West Indian cultivars 'Julie' and 'Ceylon' harvested at Stages B and C** were reported to be commercially highly acceptable (55).

Samoya de Arriola (47) reported that fruits of the 'Mamey' variety grown in Guatemala stored best at 12°C at which temperature the fruit remained in good condition for 21 days. Lower temperatures induced chilling symptoms. Passam (42) investigated the storage of some West Indian varieties in Trinidad which had the potential for export. A temperature of 14°C was selected, corresponding to the temperature used for shipping bananas to Europe. At ambient temperature, fruits of all cultivars ripened in 3–8 days; at 14°C, storage life ranged from 12 to 18 days for the 'Graham', 16 days for the 'Julie' and 13 days for the 'Hayden'. Beyond this period, fruits ripened in a further 3–8 days when removed to ambient temperature. Enclosing the fruit in polythene extended the storage life by an additional 2 days for 'Julie', 4 days for 'Graham' and 15 days for 'Hayden', but with this method occasional off flavours developed.

Controlled atmosphere storage

Banarjee *et al*, (7), reported that mangos stored in an atmosphere containing over 15% CO_2 did not develop the normal red or orange colour, but instead developed a pale yellow colour. The flavour, however, was good. Karmarkar and Joshi (35), reported that a CO_2 concentration of up to 11% had no depressing effect on the respiratory activity of mangos. Kapur, *et al* (34) found the quality of 'Alphonse' mangos unimpaired when stored in an atmosphere of 7.5% CO_2 for 35 days at 8.5°C; similarly, 'Raspuri' mangoes could be stored for 49 days at 5.5 °C to 7°C. Fruits were unimpaired and they ripened satisfactorily within 3 days of removal from CA storage.

Hatton and Reeder (27) investigated the response of 'Keitt' mangos to storage in several types of controlled atmosphere at 12.8°C. This temperature was previously noted to be the optimum one for 2 to 3 weeks cold storage of most Florida mangoes. The best condition tested for maintaining quality during storage was 5% O_2 and 5% CO_2 for 20 days. Diplodia stem-end decay was the most evident factor limiting the duration of storage. Weight loss and softening were considerably reduced compared to fruit stored in air. It was concluded, however, that the small time advantage gained by storage in controlled atmosphere precluded its practical use.

* Stage B – A stage of maturity where the shoulder is raised above the hollow where the stem end is inserted.

** Stage C – A further stage of maturity at which the fruit is at the point of becoming soft.

Bleinroth *et al* (11) working in South America had better results.

The varieties, 'Carlota', 'Hayden', 'Jasmin' and 'Soa Quiriro' were subjected to CA storage because of their susceptibility to temperatures below 8°C. Under normal refrigerated storage at 8°C with a RH of 90%, 'Carlota' and 'Hayden' lasted for 2 weeks and 'Jasmin' and 'Sao Quiriro' for 3. 'Hayden' could be stored for 30 days while 'Carlota', 'Jasmin' and 'Sao Quirior' lasted for 35 days at 8°C and 90% RH in an atmosphere containing 10% CO_2, 6% O_2 and 84% N_2.

Kane and Marcellin (33) reported 'Julie' and 'Amelie' had a storage life of approximately 4 weeks at 11 to 12°C when CO_2 levels were increased to 5% and O_2 levels decreased to 5%.

Discussion and conclusions

West Indian avocado varieties seem to be least tolerant to cold storage with a life of 15 days at 12 °C. Polyethylene wrapped fruits had a storage life of 15–20 days (23). Florida avocados subjected to controlled atmosphere storage lasted for 40 days (52). Wardlaw and Leonard (64) noted that some West Indian avocados showed surprising tolerances to gas storage, including some that were chilling sensitive. No definite conclusions were drawn however, and no further research on CA storage conditions using West Indian varieties was reported.

Breadfruit can be exported successfully as a whole fruit providing conditions for its safe storage are well defined. Storage in sealed polyethylene bags below a temperature of 12°C for over 8 days results in chilling injury (57) whereas storage in perforated bags has no effect (56). These results suggest that CA storage should be investigated.

In temperature countries, storage conditions for cabbage are well defined. Some cultivars respond favourably to long term (about 8 months) storage at 0–1°C, 2.5% O_2 and 5% CO_2 (20). There is an absence of information, however, with regards to the storage of West Indian varieties. Since this vegetable can be considered seasonal, long term storage is necessary if a year round supply for local consumption at relatively constant prices is to be maintained.

Hatton and Reeder (27), did not find controlled atmosphere storage of mangos encouraging, whereas Bleinroth (11), noted that the storage life of certain varieties doubled under CA conditions. Kane and Marcellin (33) noted that the variety 'Julie' (which has considerable export potential) showed improved storage in CA. Passam (42) indicated that for West Indian mango varieties, storage life increased for polyethylene wrapped fruits. It was also noted, however, that off-flavours and symptoms of CO_2 injury developed.

This review on the storage of avocados, breadfruit, cabbage and mangos shows that there is considerable scope for research in the Caribbean in order to obtain optimum storage conditions for, domestic varieties of these crops. While some attempt has been made to reach this goal for crop storage under normal refrigerated conditions, CA storage has been studied only superficially. This may also be true for other perishable crops growing in the Caribbean.

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