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QUALITY ATTRIBUTES OF BANANA FRUIT AS AFFECTED BY CHILLING AND NON-CHILLING TEMPERATURES

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ABSTRACT

Preclimacteric banana fruits were held for 8 days at chilling temperatures (5°C or 10°C) followed by storage at 16°C; or held continuously at a non-chilling temperature (16°C). Yellow colour development of the banana peel was severely retarded in fruits held for 8 days at either 5°C or 10°C. After transfer to 16°C, abnormal colours developed in the form of grey, brown and black hues. Total soluble solids (TSS), titratable acidity (TA), and pulp to peel ratio were lower in fruits held at either 5°C or 10°C than in fruits held at 16°C. After transfer to 16°C, the TA of fruits previously held at 5°C increased rapidly and remained significantly higher than that of unchilled fruits. The TA of fruits previously held at 10°C did not increase significantly until the 14th day. Pulp to peel ratios of chill-injured fruits eventually attained values which were typical of normal ripened fruits but by that time the appearance of the peel was unprepossessing. The development of chilling symptoms appeared to be greater in fruits held at 10°C than at 5°C. However, after the increase in temperature, fruits previously held at 5°C sustained a higher chilling index than fruits previously held at 10°C.

RESUMEN

Se almacenó unos frutos de banano preclimatéricos a unas temperaturas frigoríficas (5° o 10°C) por 8 días para trasladarios después a 16°C; otros fueron almacenados contínuamente a una temperatura no frigorífica (16°C). Se observó un grave retraso en el desarrollo del color amarillo en la piel en los frutos almacenados a 5°C y 10°C por 8 días. La temperatura fue elevada hasta 16°C, y la piel de los frutos dañados por frío presentaron un desarrollo anormal de color, es decir, hubo tonos de gris, marrón, y negro. El total de sólidos solubles (TSS), la acidez valorable (TA), y la coeficiente pulpa-piel fueron más bajos en los frutos almacenados a 5°C y a 10°C que en los almacenados a 16°C. Tras el traslado a 16°C, se aumentó rápidamente la TA de los frutos anteriormente almacenados a 5°C y se mantuvo a un nivel significativamente más alto que la de los frutos no refrigerados. En los frutos anteriormente almacenados a 10°C, la TA no sufrió ningún cambio significativo hasta el decimocuarto día. La coeficiente pulpa-piel de los frutos dañados por frío terminaron por alcanzar unos valores típicos de frutos normalmente madurados, pero a esas alturas, la piel presentaba un aspecto poco atractivo. La evolución de los síntomas de congelación parecía más intensa en los frutos almacenados a 10°C que en los almacenados a 5°C. Sin embargo, tras un aumento de la temperatura, los frutos anteriormente almacenados a 5°C presentaron un índice de congelación mas alto que los anteriormente almacenados a 10°C.

Keywords: Banana; Chilling, Quality

Most horticultural crops of tropical and subtropical origin, when exposed to low, non-freezing temperatures, undergo a marked physiological dysfunction referred to as chilling injury. Although the phenomenon of chilling sensitivity has been recognized for centuries, most of the impetus for the study of chilling injury has resulted from the economic problems associated with handling, marketing and storage of horticultural products. As a result, most of the research has been concerned with time – temperature responses, temperature tolerances and external characteristics of injury. Despite more recent efforts to investigate the cellular mechanism for chilling injury, there exists still an incomplete understanding of what constitutes low temperature resistance and just how low temperatures result in injury.

Bananas, the edible fruit of the genus *Musa* are sensitive to chilling injury. The cultivation of bananas is limited to tropical and subtropical regions, hence fruits must be transported over long distances before they are available for consumption in temperate areas of the world. The commercial acceptability of fruits depends in part on the absence of ship ripe fruits and the absence of rots and blemishes; both of which may be considerably reduced by low temperature storage of fruits in transit. However exposure of fruits to temperatures below 12°C (Wilkinson, 1970) result in chilling injury, hence temperatures during transit must be maintained above 12°C.

Chilling injury poses a serious problem to the banana industry because of its effect on quality and wastage. Chilling injury of green bananas is characterized by delayed ripening and when severe enough by the complete failure of pulp ripening (Wardlaw, 1972). Haard and Timbie (1979) suggested that there is a discoordination of the biochemical events characteristic of normal ripening when banana fruits are chilled. The present research was initiated in order to investigate how this abnormality in ripening affects some important quality attributes of banana fruit when subject to severe (5°C) and marginal (10°C) chilling temperatures compared to fruits stored at a non-chilling temperature (16°C).

Materials and methods

Preparation and treatment of fruits

Non-ethylene treated, preclimacteric fruits of *Musa* (AAA Group) with a colour index of 2, according to the scheme of von Loesecke (1950) were used. Fruit hands were divided into individual fingers which were randomly assigned to the following storage treatments: (a) 5°C for 8 days followed by storage at 16°C; (b) 10°C for 8 days followed by storage at 16°C and (c) continuous storage at 16°C. Throughout the experimental period, chamber temperature fluctuated no more than 1°C. Relative humidity was maintained between 95–100% by including petri dishes containing moist filter paper in each chamber and was monitored with an Abbean model AB167B dial hygrometer. Fruits from each treatment were sampled at 2-day intervals to assess the following quality attributes:-

Fruit colour development

The development of fruit colour was assessed by visual comparison with the description of fruit colour given by von Loesecke (1950) and modified by Abou-Aziz *et al.* (1976) to include colour development by chilled fruit (Appendix I). A numerical color index which corresponded to the peel colour of uninjured or chill-injured fruits was ascribed to fruits at each 2-day interval and is reported as the mean ± S.E. of 5 replicates of one fruit each.

Development of chilling injury symptoms

The development of chilling injury symptoms was quantified using the scale adapted from Poland and Wilson (1933) (Appendix II). A numerical chilling index (0 to 4) which corresponded to the injury symptoms of chill-injured fruits was ascribed to fruits at each 2-day interval and is reported as the mean ± S.E. of five replicates of one fruit each.

Total soluble solids (TSS)

A drop of banana pulp juice was squeezed through a nylon sieve onto the lens of a Fisher hand refractometer and the % TTS was read directly. TSS is reported as the mean ± S.E. of four replicates of one fruit each.

Titratable Acidity (TA)

Forty-five g of banana pulp were homogenized with 90 g distilled H_2O and 30 g of the homogenate were titrated to an endpoint of pH 8.1 with 0.1N NaOH. Titratable acidity is expressed as mg malic acid per gram of banana pulp and is reported as the mean ± S.E. of 4 replicates of one fruit each.

Determination of pulp: peel ratio

Whole and peeled banana fruits were weighed to obtain gross and pulp wieght. Peel weight was derived by the difference between gross and pulp weight and the pulp to peel ratio was calculated as a quotient of the pulp and peel weights. Each value of pulp: peel ratio represents the mean ± S.E. of 6 replicates of one fruit each.

Results and discussion

Fruit colour development

Yellow colour development was significantly retarded in fruits held at both chilling temperatures (5°C and 10°C) compared to fruits held at the non-chilling temperature (16°C). The development of brown and black colours was observed in chill-injured fruits on the 12th day and this became progressively greater with time. Unchilled fruits attained a colour index of 6 (Figure 1), the stage of consumer preference (Peacock, 1980) by the 14th day. Chill-injured fruits never attained this stage of consumer preference.

Desai and Deshpande (1975) suggested that yellow colour development in the banana fruit is probably influenced by the activity of chlorophyllase enzyme which breaks down chloroplasts with the formation of compounds such as chloroplast pigments which are rapidly destroyed by unspecified oxidases (Goodwin and Mercer, 1972). During the ripening process as chloroplasts are destoryed, the appearance of carotenoids is substantially enhanced accounting for the yellow colour.

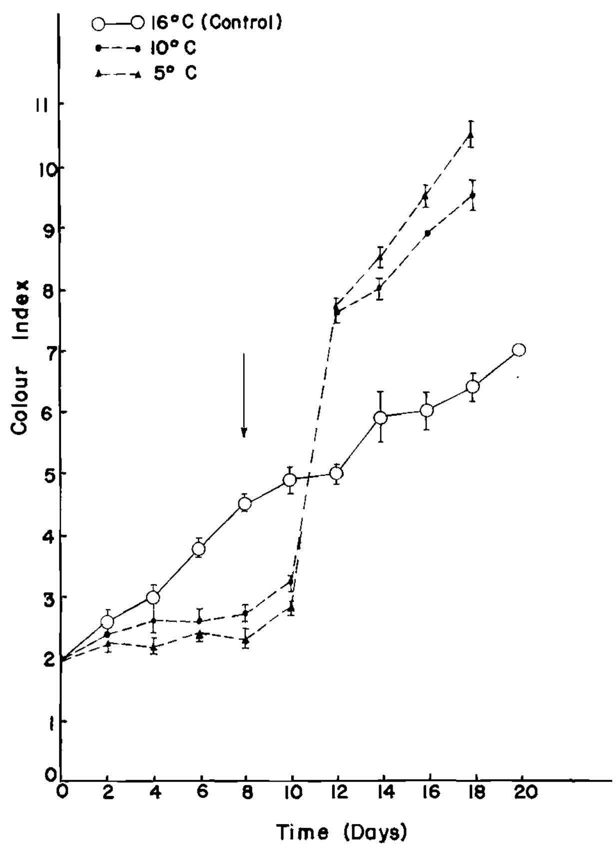

Figure 1 Colour development of banana fruit held at chilling and non-chilling temperatures. Arrow (↓) indicates time at which chilling temperatures (5° and 10°C) were raised to 16°C.

Murata and Ku (1966) suggested that since low temperatures reduced tissue content of ascorbic acid which inactivates oxidative browning reactions, it is possible that quinones accumulate in chilled fruit and undergo secondary reactions to give the brown colouration associated with chill-injured fruit. Abd El-Wahab and Nawwar (1977) identified 3, 4-dihydroxyphenylethylamine as the major phenolic constituent in banana peel and suggested that it may be oxidized to dark coloured substances more readily at low temperatures.

The retardation of yellow colour development in the banana fruit as a result of exposure to chilling temperatures may be due then, to the masking of the yellow colour by the dark coloured substances which are formed at low temperatures. Alternatively, low temperatures may inhibit the activity of chlorophyllase enzyme responsible for degreening so that the yellow colour of the carotenoids is not unmasked.

Development of chilling injury symptoms

There was no incidence of chilling injury at 16℃ since this temperature is above the critical threshold temperature for injury of the banan fruit. Incidence of injury became apparent on the 4th day for fruits held at 5℃ and 10℃ (Figure 2). The degree of injury became progressively more acute with time and the severity of injury was greater at 10℃ than at 5℃ over the 8-day storage period at chilling temperatures. After the storage temperature was increased to 16°C, the rate of symptom development increased more rapidly in fruits previously held at 5℃ than at 10℃. By the 20th day, fruits from both chilling treatments were entirely brown/black and were indistinguishable.

The apparent increased severity of injury symptoms sustained by fruits held at the higher chilling temperature is similar to the phenomenon observed with peaches and plums by van der Plank and Davies (1937), who suggested that the incidence of chilling injury was related to the interaction of 2 opposing factors: an equilibrium factor by which lowering the temperature increased the disposition towards injury and a kinetic factor by which higher temperatures promoted the manifestation of injury symptoms. Fidler (1968) suggested that visible results of low temperature injury arise from the disturbance of metabolism, hence there may be latent injury which is more severe at lower temperatures and a secondary visible effect which develops less rapidly at low temperatures.

Total soluble solids (TSS)

The TSS content of fruits held at 5℃ and 10℃ was significantly lower than that of fruits held at 16℃ (Figure 3). Despite the rapid increase in TSS content of chill-injured fruits observed 4 days after the temperatures were increased to 16℃, the maximum TSS values for chilled fruit remained significantly lower than that of unchilled fruit.

In as much as total soluble solids are essentially sugars, it would be expected that increases in TSS values are accounted for by the process of starch hydrolysis. Madamba *et al.* (1977) found that the regression coefficient between total sugars and TSS was highly significant and in the order of 0.992. The significantly lower TSS values of banana fruit pulp during storage at 5℃ and 10℃ compared to 16℃ suggests that there is considerable retardation of starch hydrolysis at low temperatures. Even when chill-injured fruits reach the senescent stage which occured by the 16th day (Figure 1), the starch content was higher and sugar content lower than unchilled fruit. The lower the chilling temperature, the more severely retarded was the process of starch hydrolysis.

Titratable acidity (TA)

The TA of pulp tissue from fruits stored continuously at 16℃ increased rapidly over the first 4 days, remained relatively constant over the next 4 days and then declined steadily (Figure 4). During the 8-day storage period that fruits were held at either 5℃ or 10℃, the increase in TA was significantly lower than that of fruits held continuously at 16℃. Following the increase in storage temperature to 16℃, the TA of fruits previously held at 5℃ increased rapidly for 4 days and then remained relatively constant, whereas in fruits previously held at 10℃, there was no significant increase in TA until the 14th day, after which TA values declined steadily.

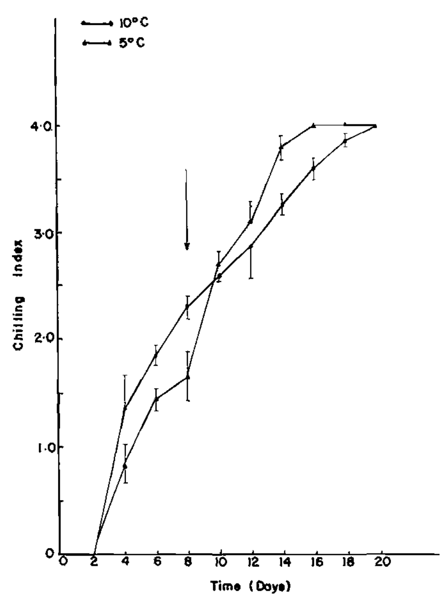

Figure 2 Development of chilling symptoms in banana fruit held at chilling temperatures. Arrow (↓) indicates time at which chilling temperatures (5° and 10°C) were raised to 16°C.

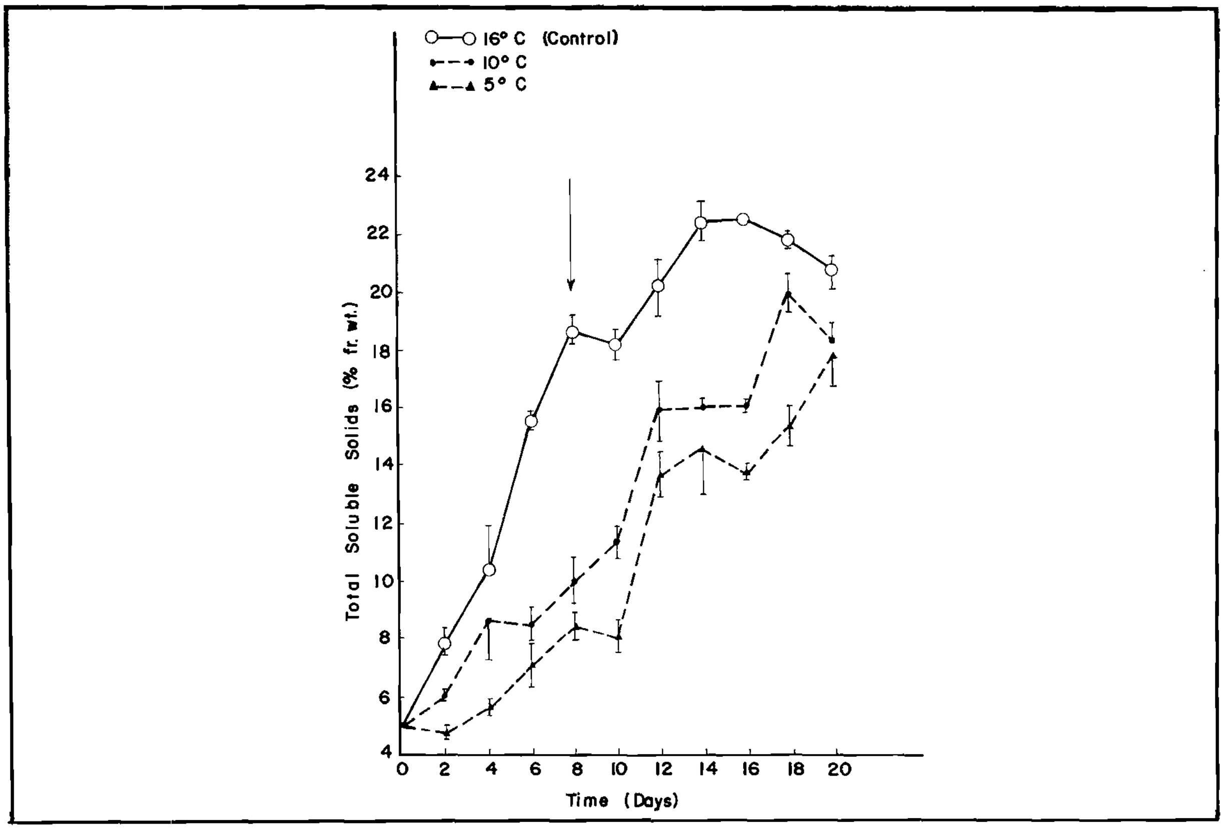

Figure 3 Total soluble solids of pulp tissue from banana fruits held at chilling and non-chilling temperatures. Arrow (↓) indicates time at which chilling temperatures (5° and 10°C) were raised to 16°C.

Changes in TA have been explained in terms of starch hydrolysis by Madamba *et al.* (1977), who suggested that sugars formed from starch hydrolysis underwent further conversion to organic acids during the early stages of ripening which account for the increase in TA. When the TA attains its maximum value, the conversion of sugars to acids slows down. TA decreases when starch reserves have been depleted by continuous hydrolysis and acids continue to undergo further metabolic transformation to CO_2 and H_2O (von Loesecke, 1950).

Desai and Deshpande (1975) related acidity changes to changes in the mechanism of the respiratory process. These authors explained the increased acidity observed in banana fruit during ripening as being due to an obstruction in the proton transfer process. Due to increasing water content in the pulp as a result of osmotic transfer (von Loesecke, 1950; Charles and Tung, 1973), the gas exchange process becomes inefficient providing little or no O_2 required in the final phase of proton transfer, thus protons accumulate and due to the limited buffering capacity of banana pulp, this is manifested as increased acidity.

Results obtained in the present investigation may be explained using both of the above hypotheses. The lower rate of increase in TA of banana fruits held at 5°C and 10°C may be due to a possible retardation of the rate of conversion of starch to sugars, hence less sugars would be available for organic acid transformation at the chilling temperatures. In addition, the lower concentration of sugars in chill-injured banana fruit pulp would reduce the osmotic transfer of H_2O from peel to pulp, hence sufficient O_2 may be present in the pulp tissue to avoid proton accumulation. The increased TA values observed after the temperatures were increased to 16°C may be explained by increased rates of starch to sugar conversion and increased osmotic transfer of water from peel to pulp. The significantly higher TA values for chill-injured fruits compared to unchilled fruits at the end of the storage period may be due to larger starch reserves in the chill-injured fruit pulp which would prevent metabolic transformation of organic acids to CO_2 and H_2O.

Oxalic acid in bananas is completely water soluble and represents about 50% of the total acidity of unripe 'Gros Michel' pulp but decreases during ripening to 60% of its original value, suggesting that the ripening banana is capable of metabolizing this acid (Wyman and Palmer, 1964). Feeding of oxalate-^{14}C to banana slices confirmed that it is metabolized (Palmer and Wyman, unpublished, as quoted by Palmer, 1971). The higher TA observed in chill-injured banana fruit observed at the end of the experimental period suggests the possibility that chill-injured fruits may have a reduced ability to metabolize oxalic acid.

Pulp: peel ratio

After the first 8 days, the pulp: peel ratio of fruits held at 5°C and 10°C was significantly lower than that of fruits held continuously at 16°C, (Figure 5). After all storage temperatures were adjusted to 16°C, the pulp: peel ratio of fruits previously held at 5°C and 10°C remained significantly lower than that of unchilled fruit until the 22nd and 18th day, respectively.

The pulp: peel ratio of banana fruits is related to the osmotic transfer of water from the peel to the pulp due to the accumulation of sugars in the pulp during ripening, (von Loesecke, 1950). The lower pulp: peel ratio of fruits stored at chilling temperatures may be due to retardation of starch to sugar conversion at lower temperatures (Barnell, 1940),

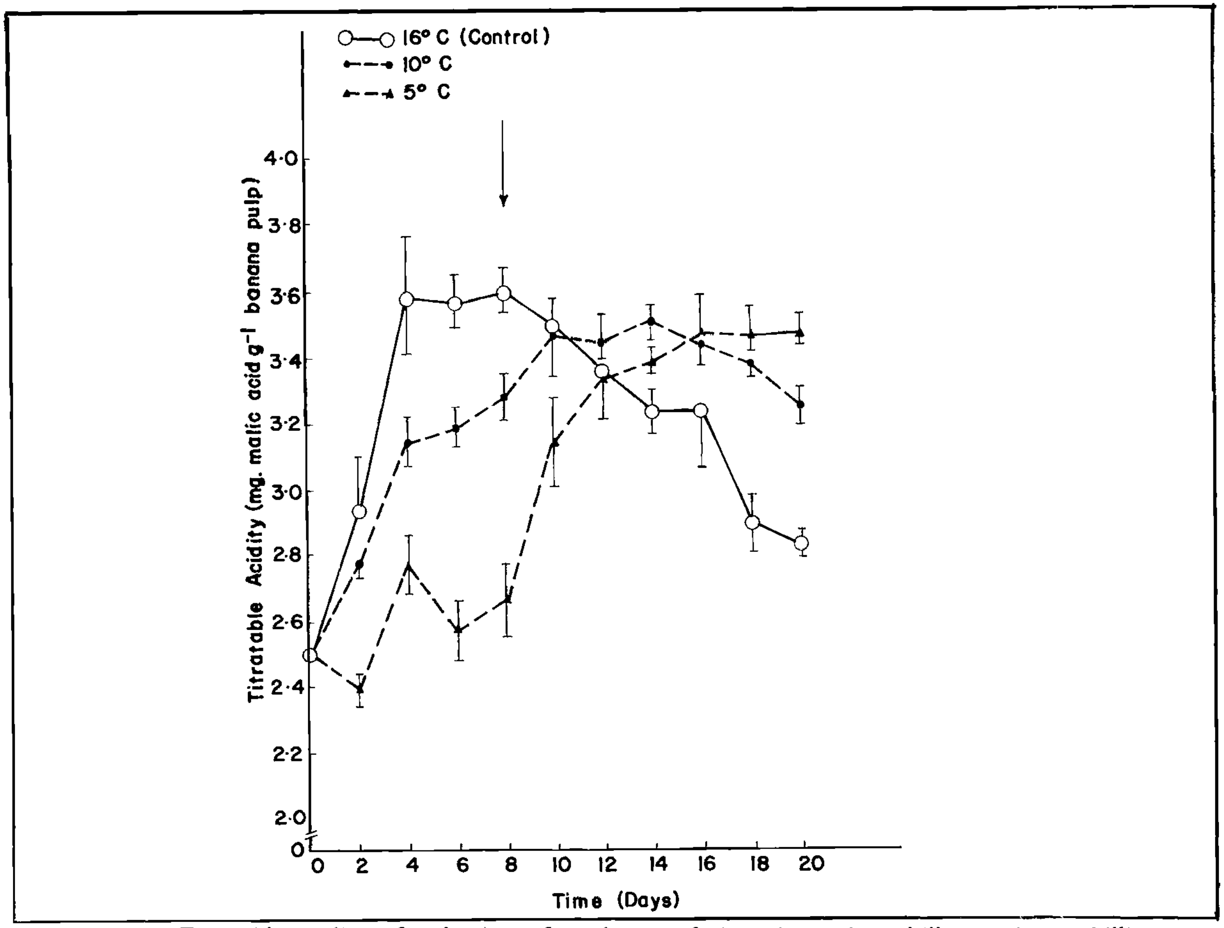

Figure 4 Titratable acidity of pulp tissue from banana fruits subjected to chilling and non-chilling temperatures. Arrow (↓) indicates time at which chilling temperatures (5° and 10°C) were raised to 16°C.

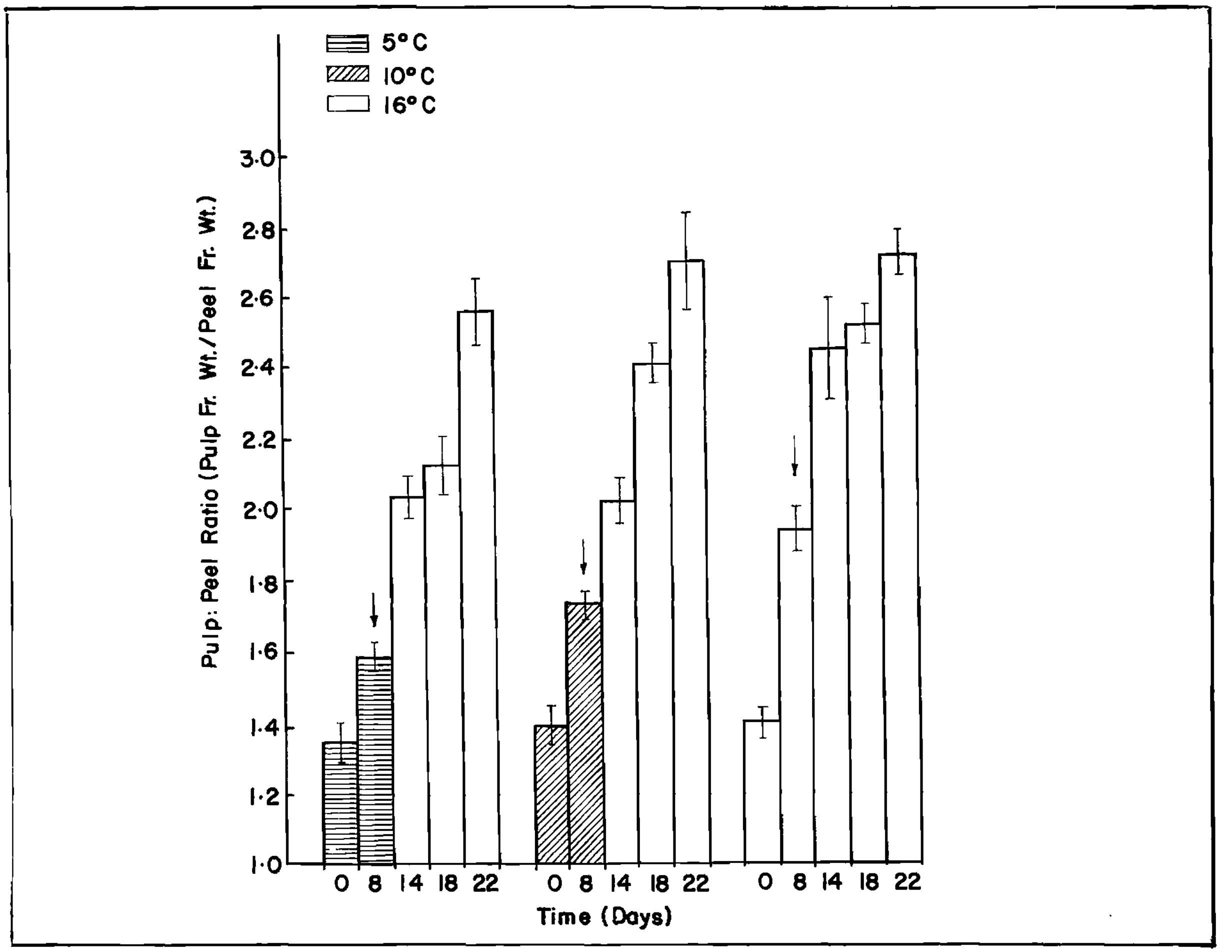

Figure 5 Pulp: peel ratio of banana fruits at various stages during storage at chilling and non-chilling temperatures. Arrow (↓) indicates time at which chilling temperatures (5° and 10°C) were raised to 16°C.

which would result in a lower concentration of sugars in chilled fruit pulp compared to unchilled fruit pulp. The increase in pulp: peel ratio observed in chilled fruit after storage temperatures were adjusted to 16°C may be accounted for by more rapid conversion of starch to sugars resulting in greater osmotic transfer of water from peel to pulp.

The range of values for pulp: peel ratio that is typical of normally ripened bananas at the eating-ripe stage is between 2.2 and 2.7 (von Loesecke, 1950). Unchilled fruit attained a pulp: peel ratio within this range after 14 days (Figure 5). Despite the previous chilling treatments at 5°C and 10°C, chill-injured fruits eventually attained a pulp: peel ratio within the acceptable range after 18 and 22 days respectively. By this time colour indices were 10.6 and 9.5 for fruits chilled at 5°C and 10°C respectively (Figure 1), values indicative of abnormal colour development (Appendix 1). The chilling index of fruits from both 5°C and 10°C approached 4 at this time indicative of severe injury (Figure 2). Therefore, by the time that the pulp: peel ratio of chill-injured fruits had attained values within the range that is acceptable for consumption the appearance of the fruits was unacceptable.

Summary

Exposure of green banana fruits to a severe (5°C) and marginal (10°C) chilling temperature for an 8-day period followed by storage at a non-chilling temperature (16°C) caused substantial deterioration of fruit quality resulting in commercially unacceptable fruit. Both chilling temperatures had retarding effects on the development of fruit colour, and on the increases in TSS, TA and pulp: peel ratio, with the degree of retardation being more acute at the more severe chilling temperature (5°C). An anomalous relationship between chilling temperature and the development of chilling injury symptoms was observed, where fruits held at the marginal chilling temperature sustained a higher chilling index than fruits held at the severe chilling temperature. This phenomenon is similar to that observed with peaches and plums by van der Plank and Davies (1937). After the increase in storage temperature, the rate of symptom development increased more rapidly in fruits previously held at 5°C than at 10°C.

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APPENDIX I - Colour index of banana fruits in relation to development of peel colour during ripening (1–7) and as a result of chilling injury (8--11). After von Loesecke (1950) and modified by Abou-Aziz *et al.*, (1976).

Colour Index	Peel Colour
1	green
2	green – trace of yellow
3	more green than yellow
4	more yellow than green
5	green tip
6	all yellow
7	yellow flecked with brown
8	dull green with large brown areas
9	more than 50% brown or dull green
10	almost all brown or smoky grey
11	black

APPENDIX II - Chilling index as a function of symptom development in bananb fruits. Adapted from Poland and Wilson (1933).

Chilling Index	Symptom Description
0	no abnormality
1	slight dullness -- trace when compared to unchilled fruit
2	medium dullness – fruit may be saleable but not attractive
3	severe dullness -- peel is dull grey or brown
4	All brown – peel may be entirely brown, often black green