was held in the dump-tank for 5 min; then the tomatoes were spray-washed and waxed with a petroleum-based commercial tomato wax. Tomatoes were exposed to 500 ppm ethylene for 3 days to promote color development and held at 70°F (21°C) for 3 weeks to simulate ripening and marketing.

Table 1. Average incidence of bacterial soft rot in tomatoes after 3 weeks at 70°F (21°C) as influenced by the temperature and bacterial contamination of water in the dump-tank (average from 5 packinghouses).

Bacterial concn (cells/ml)	Incidence of decay[z] 60°F (15.6°C) (%)	90°F (32.2°C) (%)
0.0	3.6	2.8
3.5 x 10^2	8.0	13.2
7.0 x 10^2	14.4	20.0
1.4 x 10^3	20.4	21.6
2.8 x 10^3	16.4	27.2

[z]Decay incidences at different water temperatures and bacterial concns were significant at the 5% and 1% levels, respectively.

Twice a week, the tomatoes were inspected and the decayed fruit removed to prevent secondary infection. Data were recorded as percentage of fruit decayed during the holding period.

Results and Discussion

The incidence of bacterial soft rot in tomatoes exposed to contaminated water was higher than in controls, which were exposed to uncontaminated tapwater only (Table 1). The level of contamination also influenced the incidence of soft rot, ranging from 13.2% when tomatoes were exposed to 90°F (32.2°C) water contaminated with 3.5 x 10^2 cells/ml to 27.2% when the bacterial suspension was 8 times as high.

Maintaining the dump-tank water at 90°F (32.2°C) did not prevent the development of bacterial soft rot. In fact, at all levels of water contamination, incidence of soft rot was greater at 90°F than at 60°F (Table 1). Also, examination of tomatoes exposed to 60°F (15.6°C) water revealed no skin cracks or other detrimental effects after the 3-week holding period.

These data show that heating the dump-tank water above the temp of the tomatoes does not help prevent decay and may actually be detrimental if the water is not otherwise treated to reduce bacterial contamination. This unnecessary heating also increases the cost of operation.

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EFFECT OF REFRIGERATED TEMPERATURES ON THE INCIDENCE OF CHILLING INJURY AND RIPENING QUALITY OF MANGO FRUIT

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Abstract. Kent **mango fruits harvested at physiological maturity were stored at 8, 10 and 13°C and 85-90% RH for 10, 16 and 22 days and subsequently transferred to ripening at 25°C and 85-90% RH. Physiological loss in weight was less in fruits stored at lower temp and higher in those stored at higher temp. Respiratory trend of refrigerated fruits showed an extended preclimacteric trough lasting throughout the storage period until they were transferred to conditions for ripening. Chilling injury of fruits occurred in all temp tested regardless of the length of storage, the manifestation of the injury being more severe when transferred to ripening conditions. Refrigerated storage prior to ripening reduced the rate of ripening followed by inhibited formation of sugars, carotenoids and flavor as corroborated by chemical analysis and organoleptic evaluation. It was concluded that temp below 13°C were critical in the development of chilling injury in** Kent **mango fruit.**

One of the methods commonly used to extend the storage life of fresh fruits and vegetables is to employ refrigeration which retards the metabolic processes controlling the post harvest changes in respiration and ripening. In the case of mango however, there is a controversy regarding the benefits of refrigeration in extending the storage life. Mango is a highly perishable tropical fruit and use of refrigeration to extend its short storage life presents serious problems. Movement of fruits to distant markets is therefore achieved by costly air transport.

Cool storage of mangos has been the subject of study all over the world since the turn of the century. Several workers have reported the advantages or disadvantages of refrigeration in extending the storage life of mangos (2, 8, 10, 16, 19, 23, 24) grown in India and other tropical countries. Unfortunately, the existing literature on the refrigerated storage of mango cultivars from Florida and Mexico is very scanty. The most serious disadvantage of refrigeration in extending the storage life of mangos is the incidence of chilling injury caused even at the so-called optimum temp (7, 17). Symptoms of chilling injury

in mango appear as discolored, pitted regions on the skin, followed by non-uniform ripening, poor color and flavor and increased susceptibility to microbial spoilage. It is also attended by reduced sugar content and poor starch breakdown due to reduced amylase activity (4). Alcohols and aldehydes are formed as breakdown products due to fermentative decarboxylation in chill injured mangos, particularly when the storage atmosphere is charged with a high concn of CO_2 (12). The need to eliminate the accumulation of CO_2 beyond the tolerance level has been demonstrated (13). Several physical and chemical treatments have been tested on mangos at different stages of maturity, in an attempt to reduce chilling injury; these have not had any significant benefits (21). It has also been recently reported that the best ripening temp of 'Alphonso' mango is 25°C (22). Several other methods such as controlled atmosphere storage, hypobaric storage and use of skin coatings have been suggested as possible methods for extending the storage life. However, they are not yet commercially applied and therefore, remain of academic interest.

Due to their high perishability, the high cost of air transport and the lack of research data on the use of refrigeration for the preservation of mango, the growers and shippers in Mexico are facing serious problems. The object of this work was to determine the critical temp which cause chilling injury in mangos grown in Mexico with special reference to physiological and biochemical changes in order to establish optimum conditions for their storage and transportation.

Materials and Methods

1000 mango (Cv. 'Kent') fruits were harvested at physiological maturity from a commercial orchard in Esquinapa, Sinaloa state, on the Pacific coast and transported to the laboratory at Chapingo (State of Mexico) in ventilated plastic boxes within 24 hr after harvest. They were washed in ordinary tap water to remove dust and dried in a blast of air. They were divided into 4 lots of 250 fruits, each of which was subdivided into five replicates of 50 fruits. One lot of 250 fruits, consisting 5 replicates, was exposed directly to 25°C and 85-90% RH for ripening; this was considered the control treatment. The remaining three lots of 250 fruits were separately stored at 8, 10 and 13°C and 85-90% RH respectively (Table 1). From each one of these storage temperatures one replicate of 50 fruits was removed periodically every 10th, 16th and 22nd day of storage and exposed at 25°C and 85-90% RH for ripening.

Table 1. Description of treatments.

Treatment	Storage conditions			Ripening conditions		
	Temp. (°C)	RH (°C)	Time (days)	Temp. (%)	RH (%)	Time (days)
Control	—	—	—	25	85-90	10
T-1	8	85-90	10	〃	〃	6
T-2	〃	〃	16	〃	〃	8
T-3	〃	〃	22	〃	〃	6
T-4	10	〃	10	〃	〃	4
T-5	〃	〃	16	〃	〃	8
T-6	〃	〃	22	〃	〃	6
T-7	13	〃	10	〃	〃	4
T-8	〃	〃	16	〃	〃	6
T-9	〃	〃	22	〃	〃	4

Physiological loss in weight (PLW) of control and cold stored fruits was determined daily during holding periods of 10, 16 and 22 days at each temperature and subsequently during ripening at 25°C until the majority reached edible ripeness.

Respiration of whole fruits was determined using three individual fruits for each treatment under simulated conditions of storage by the modified continuous current method (11) and a mean for these 3 replicates calculated. In the case of the control fruits respiration rates were taken daily whilst refrigerated fruits were measured on every second day.

Fruit ripening, assessed by recording changes in softness (by touch), color (visual observation) and aroma (by smell) was noted every 3 days during the entire period of storage and ripening.

Symptoms of chilling injury on fruit surface appeared as greyish pinheads with characteristic depressions; fruits having 5 or more such patches were classified as chill injured. Chilling injury was assessed immediately after removal from storage for 10, 16 and 22 days and subsequently after ripening of the fruits at 25°C.

In order to establish the stage of maturity chemical analyses of the fruit pulp were conducted initially after harvest, later after removal from storage and finally when the fruits reached edible ripeness. The analyses included determination of water content, total acidity, pH, and vitamin C by AOAC methods (3), sugars by the modified Somogyi micro method described by Hodge and Davis (9) and carotenoids by column chromatography (1). The analyses were done with quadruplicate samples and their average values expressed on a fresh basis.

Results and Discussion

Physiological loss in weight. Table 2 gives the cumulative physiological loss in wt of mangos stored under different conditions for various periods and subsequently during ripening at 25°C. It was observed that control fruits ripened at 25°C lost 8.1% wt during a ten days ripening period. The weight loss in cold stored fruits was proportional to the temperature and duration of storage, in that fruits stored at 8°C lost less wt than those stored at 10 and 13°C for the same period of storage. Thus the lower refrigeration temp significantly reduced wt loss. These observations are in agreement with those already reported for mango 'Manila' (18). The physiological loss in wt during refrigerated storage was minimal, ranging from 1.0-2.0%, in all the storage temp regardless of the duration of storage. However, when the fruits were transferred to ripening conditions the loss in weight increased considerably within the 4-8 days ripening period.

Table 2. Cumulative physiological loss in weight (%) in mango 'Kent' during storage and ripening.

Treatment	At the end of storage		At the end of ripening		Cumu. physiol. loss in wt	
	Time	PLW	Time	PLW	Time	PLW
Control	—	—	10	8.1	10	8.1
T-1	10	1.0	6	5.0	16	6.0
T-2	16	1.4	8	6.0	24	7.4
T-3	22	1.8	6	7.6	28	9.4
T-4	10	1.0	4	6.7	14	7.7
T-5	16	1.5	8	8.5	24	9.9
T-6	22	2.0	6	9.6	28	11.6
T-7	10	1.0	4	8.6	14	9.6
T-8	16	1.6	6	10.5	22	12.1
T-9	22	2.1	4	13.3	26	15.4

Effect of temp on the respiration of mangos. Figs. 1-4 show the respiration of mangos stored at different temp for various periods. It can be observed that when mangos were directly ripened at 25°C (Fig. 1), the respiratory rate reached a minimum within 3 days, then increased, reach-

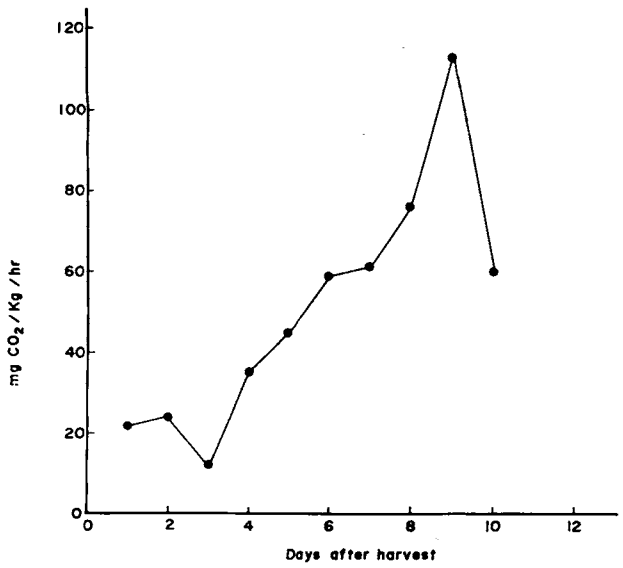

Fig. 1. Respiratory pattern of mangos ripened at 25°C and 85-90% RH soon after harvest.

ing the climacteric maximum on the ninth day and subsequently declined at the stage of edible ripeness. In contrast, the fruits stored under all the refrigerated temperatures showed an extended trough of preclimacteric minimum lasting throughout the period of storage. Subsequently when the fruits were transferred to ripening conditions a rapid increase in respiratory activity occurred. This sudden increase in the evolution of CO_2 (Figs. 2-4) would normally be considered to be the respiratory climacteric associated with ripening. However, the increase occurred well before the fruits were considered ripe by visual examination and chemical analysis (see below) and therefore attributable to the effect of the refrigerated storage treatments.

Ripening. The ripening indices of mangos stored at different temp for various periods are given in Table 3. Fruits which were ripened at 25°C immediately after harvest

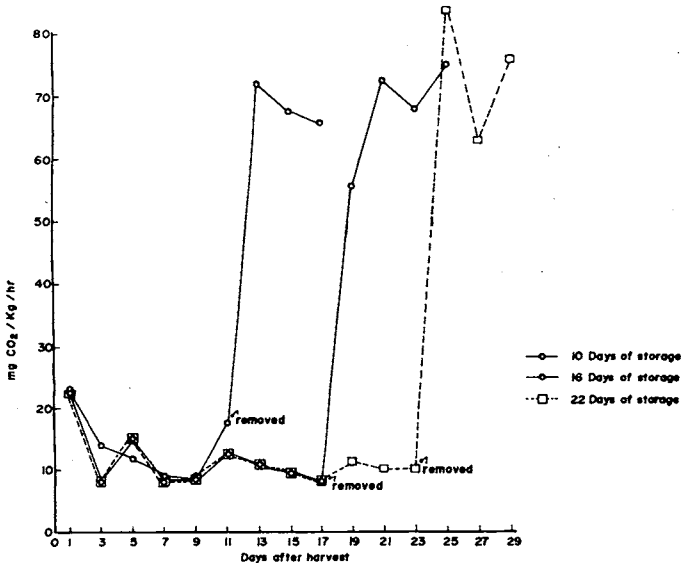

Fig. 2. Respiratory pattern of mangos stored at 8°C and 85-90% RH for various periods and then ripened at 25°C.

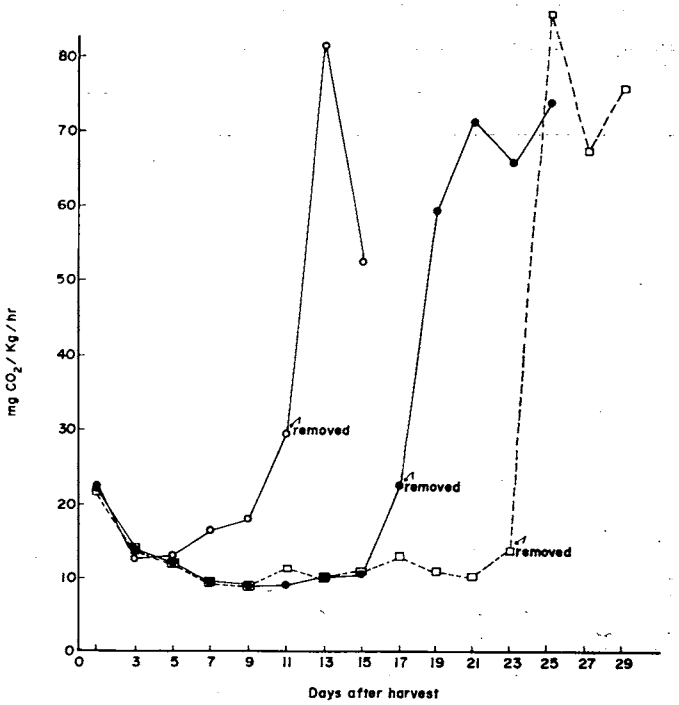

Fig. 3. Respiratory pattern of mangos stored at 10°C and 85-90% RH for various periods and then ripened at 25°C.

showed 82% ripe fruits at the end of 10 days, while those stored at 8°C for 10, 16 and 22 days and subsequently ripened at 25°C showed only 64, 56 and 52% ripe fruits at the end of 16, 24 and 30 days respectively. As the storage temp increased there was a slight increase in the percentage of ripe fruits. Among all the storage temp, T-7 and T-8 showed a maximum of 76% ripe fruits. Generally, after removal to conditions of ripening, the refrigerated mangos developed chilling injury symptoms, failed to ripen

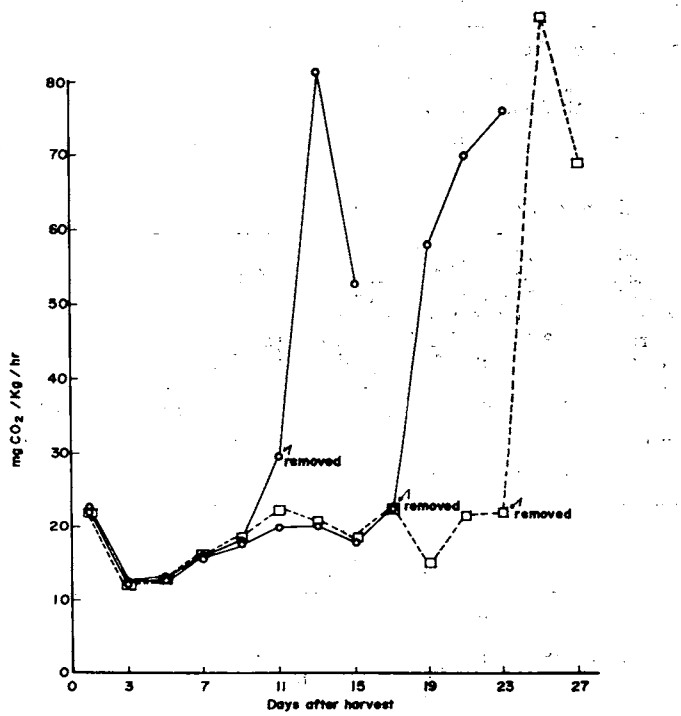

Fig. 4. Respiratory pattern of mangos stored at 13°C and 85-90% RH for various periods and then ripened at 25°C.

Table 3. Ripening (%) index of mango 'Kent' stored at different temperatures for various periods and subsequently ripened at 25°C.

Treatment	10 days			14 days			16 days			22 days			24 days			28 days			30 days		
	GF	T	R	GF	T	R	GF	T	R	GF	T	R	GF	T	R	GF	T	R	GF	T	R
Control	9	9	82	observation terminated																	
T-1	71	29	0	22	50	28	16	20	64												
T-2							69	31	0	20	44	36	8	28	56						
T-3													54	46	0	30	55	15	16	32	52
T-4	70	30	0	12	52	36	4	28	68												
T-5							63	37	0	12	52	36	8	32	60						
T-6													52	48	0	24	50	26	9	34	57
T-7	66	34	0	0	24	76															
T-8							62	38	0	8	16	76									
T-9													35	65	0	10	28	62			

[z]Average of three replicates of 50 fruits each. GF = green, firm; T = turning; R = ripe.

uniformly and became over soft resulting in spoilage within 3-4 days. These ripe fruits were substandard in quality compared with those which were ripened directly at 25°C and were not suitable for either table use or processing.

Effect of refrigerated storage on chemical constituents. Mango fruits subjected to ripening at 25°C soon after harvest showed a well balanced acid : sugar relation (0.18 and 14.62% respectively) and an excellent external color with a bright orange yellow pulp color due to a high concentration of carotenoids (5560 μg/100g). By comparison, mangos stored at 8°C for 10, 16 and 22 days before subsequent ripening showed higher acidity with significantly lower sugars and carotenoid levels and increased Vitamin C contents. Similar changes in chemical constituents were noted in mangos stored at 10 and 13°C (Tables 4-6). A close correlation was observed between the temperature of storage and the levels of the measured chemical constituents. Thus, the lower the temp and the longer the duration of storage, the higher the acidity and the lower the levels of sugars and carotenoids. These fruits were dull both externally and internally, poor in flavor and in other organoleptic qualities.

Table 4. Changes in chemical constituents[z] in mango 'Kent' during storage for various periods at 8°C; 85-90% RH and subsequently ripened at 25°C; 85-90% RH.

Conditions of storage and ripening	Moisture (%)	Tot. acid (%)	pH	Vit. C (mg/100g)	Sugars (%)		Carotenoids (μg/100g)
					Red.	Tot.	
Initial analysis (1 day after harvest)	81.9	0.33	4.6	18.6	3.68	5.24	308
Same ripened at 25°C & analyzed after 10 days	79.7	0.18	5.2	21.8	2.76	14.62	5560
Stored at 8°C & analyzed after 10 days	81.8	0.49	4.5	25.1	3.12	6.75	557
Same ripened at 25°C & analyzed after 6 days	80.9	0.30	4.7	76.6	2.83	11.45	2285
Stored at 8°C & analyzed after 16 days	81.6	0.35	4.6	56.7	4.93	6.25	482
Same ripened at 25°C & analyzed after 8 days	81.2	0.30	4.7	80.0	3.12	10.90	1942
Stored at 8°C & analyzed after 22 days	81.2	0.81	4.3	60.0	3.75	6.20	374
Same ripened at 25°C & analyzed after 6 days	79.5	0.96	4.2	80.0	3.19	8.94	1428

[z]Analysis of the pulp of mango 'Kent' expressed as averages of four replicates on fresh weight basis.

Table 5. Changes in chemical constituents[z] in mango 'Kent' during storage for various periods at 10°C; 85-90% RH and subsequently ripened at 25°C; 85-90% RH.

Conditions of storage and ripening	Moisture (%)	Tot. acid (%)	pH	Vit. C (mg/100g)	Sugars (%)		Carotenoids (μg/100g)
					Redu.	Tot.	
Stored at 10°C & analyzed after 10 days	81.0	0.54	4.4	32.4	3.15	7.56	631
Same ripened at 25°C & analyzed after 4 days	76.6	0.27	4.7	102.7	3.08	11.10	2806
Stored at 10°C & analyzed after 16 days	81.6	0.40	4.5	92.9	4.90	6.85	549
Same ripened at 25°C & analyzed after 8 days	79.8	0.34	4.6	70.0	3.44	10.73	2680
Stored at 10°C & analyzed after 22 days	81.2	0.98	4.2	65.0	4.74	6.56	284
Same ripened at 25°C & analyzed after 6 days	80.1	0.68	4.3	88.0	4.23	9.35	2113

[z]Analysis of the pulp of mango 'Kent' expressed as averages of 4 replicates on fresh wt basis.

Table 6. Changes in chemical constituents[z] in mango 'Kent' during storage for various periods at 13°C; 85-90% RH and subsequently ripened at 25°C; 85-90% RH.

Conditions of storage and ripening	Moisture (%)	Tot. acid (%)	pH	Vit. C (mg/100g)	Sugars (%)		Carotenoids (μg/100g)
					Redu.	Tot.	
Stored at 13°C & analyzed after 10 days	81.6	0.54	4.4	40.6	4.36	9.25	1277
Same ripened at 25°C & analyzed after 4 days	80.1	0.43	4.5	72.8	4.01	12.68	3760
Stored at 13°C & analyzed after 16 days	81.8	0.54	4.4	111.1	4.14	9.21	825
Same ripened at 25°C & analyzed after 6 days	79.7	0.47	4.5	80.0	3.13	12.32	3195
Stored at 13°C & analyzed after 22 days	79.3	1.03	4.1	60.0	4.14	8.79	390
Same ripened at 25°C & analysed after 4 days	80.9	0.55	4.4	65.0	3.97	9.56	2314

[z]Analysis of the pulp of mango 'Kent' expressed as averages of 4 replicates on fresh wt basis.

Chilling injury. Fig. 5 shows graphically the development of damage through chilling injury after storage for 10, 16 and 24 days at each temp. On the tenth day of observation, chilling injury to fruits was negligible in all of the refrigerated temps. When these fruits were transferred to ripening conditions, chilling injury symptoms developed to a level of almost 50% within 6 days. Mangos stored for 16 days at 8, 10 and 13°C and then ripened showed, respectively, 76, 74 and 72% chilling injury after 6 days. Finally, mangos refrigerated at 8, 10 and 13°C for 22 days when transferred to ripening showed, respectively, 98, 90 and 85% chilling injury. In other words, the incidence of chilling injury increased proportionately with a decrease in the temp of storage and an increase in the length of the storage period.

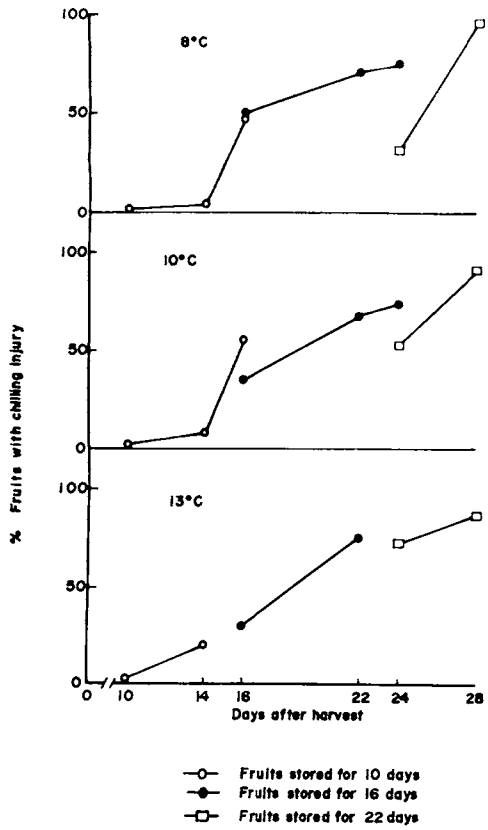

Fig. 5. Extent of chilling injury in mango fruits stored at different temp for varying periods and then ripened at 25°C.

Chilling injury in the fruits was observed as greyish depressed spots which later coalesced to form black patches (Fig. 6). In most cases although the injured areas did not penetrate deep into the pulp (Fig. 7) its color was considerably affected.

Several theories have been proposed for the mechanism of chilling injury in fruits and vegetables (5, 6, 14, 15, 19, 20) and 2 of them are worth mentioning in this context. One theory suggests that it is the production of certain toxins under critical conditions of storage which on accumulation induce irreversible changes in metabolism. The other proposes that the physical effect of exposure to refrigerated temperatures triggers some abnormal reactions which influence adversely protoplasmic consistency and cellular or mitochondrial membrane permeability resulting in irreparable damage to the ripening mechanism. At present, it is not yet clear in mango whether the physical effect of exposure to chilling temp preceeds or follows the toxin formation and accumulation.

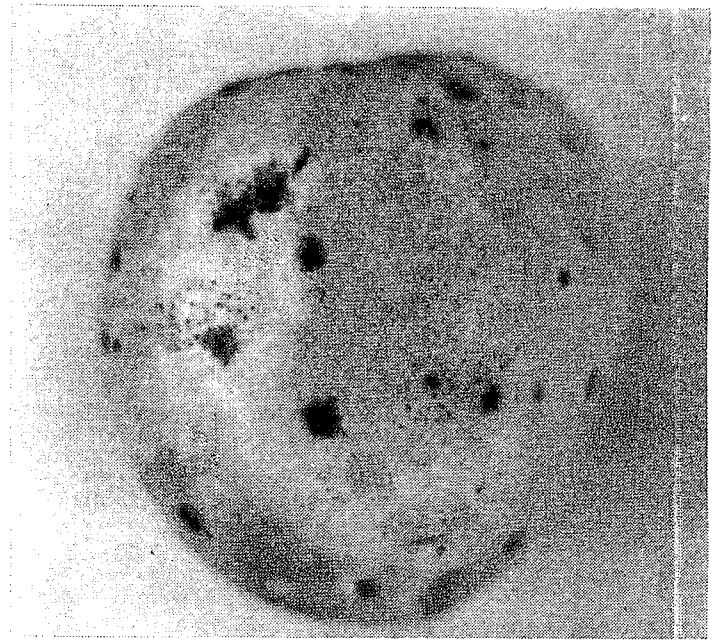

Fig. 6. Appearance of chilling injury in cold stored 'Kent' mango during ripening at 25°C.

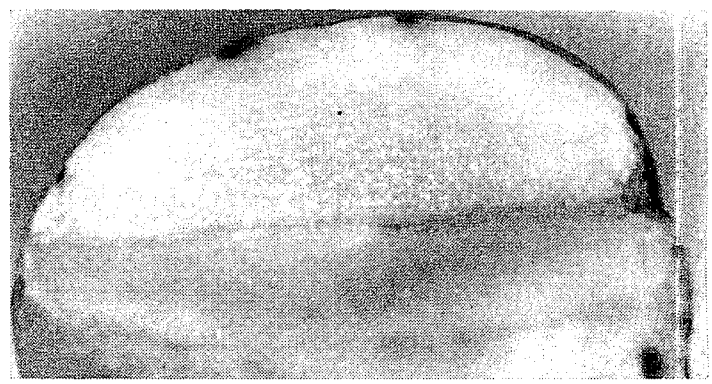

Fig. 7. A section of a chill injured 'Kent' mango showing depth of tissue damage.

Clearly then, all of the refrigerated temp chosen here resulted in chilling injury to the mangos irrespective of the duration of storage. The critical temp was probably close to 13°C. Further experiments are contemplated utilizing temperatures above 15°C to determine optimum storage conditions for enhanced storage life whilst avoiding chilling injury.

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