International Journal of Research in Applied, Natural and Social Sciences (IJRANSS)
Vol. 1, Issue 2, July 2013, 31-42

MANGO FRUIT PRECOOLING TECHNIQUES

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ABSTRACT

Due to the short post harvest life of tropical fruits like mangoes, precooling is an important post harvest unit operationr. There are several techniques commercially employed such as hydrocooling, mechanical cooling augmented by liquid nitrogen, air cooling. The precooling process should be as fast as possible, but the cooling should not result in any chilling injury to the fruit. Liquid nitrogen has high cooling capacity and due to the inertness of the vaporized nitrogen gas, is very much applicable for preccoling purposes. Its boiling point is – 195.6 ^{o}C. This severe cold temperature raises concerns on the possibility of chilling injury to the fruit. Hence, the present study was undertaken to establish different cooling systems where liquid nitrogen can be employed to augment the air cooling process. Other common precooling techniques for mangoes are hydrocooling and air cooling with mechanical refrigeration. It has been observed that all the commercial cooling techniques, such as hydrocooling, air cooling have comparable effect on the overall quality as measured through some of the physicochemical parameters such as firmness, aroma. However, it has also been observed that liquid nitrogen augmented air cooling technique has some edge over other conventional commercial cooling in terms of time required for cooling.

KEYWORDS: Precooling Techniques, Mango, Fruits

INTRODUCTION

Fruit Material

Mango (*Mangifera indica* Linn.), a commercially important tropical fruit, belonging to the family *Anacardiaceae*, believed to have originated in the Indo-Burmese region. Mango is known to be the most important tropical fruit of Asia, grown commercially in more than 87 countries. This contributes to nearly 50% of the worldwide production of tropical fruits (Stefan et al 2003). The production of mango has been increasing over the years and so has been its demand. FAO (2012) estimates have indicated the annual production of mango at over 24 million metric tonnes in 2010 with nearly 50 % produced in India. Other countries like Mexico and Thailand follow India (Table 1).

Table 1: Production and Trade of Mango for the Year 2010 (x1000 Tonnes)

	World	**India**	**Thailand**	**Mexico**
Production	30714	12289	1812	1951
Export	1632	305	259	---
	World	**USA**	**EC**	**UAE**
Import	1452	367	193	72

Source: FAO 2012

The state-wise distribution of mango cultivation in India given in Table 2 shows that Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu and Bihar are the leading states for mango production in India. However, about 98% of this production is consumed locally in the producing countries with very little participation in the global trade. Over 90% of exports are directed to seven countries viz., UAE, Saudi Arabia, Kuwait, UK, Singapore, Netherlands, and Bangladesh. Countries in the European Union (EU) and USA are potential markets with an existing demand for fresh mangoes that can be tapped, provided the quality of the produce is assured at the consumers end (FAO 2012).

Most of the Indian varieties are reported to possess strong aroma and intense peel coloration, characterized by attractive fragrance, delicious taste, and high nutrition value. About 30 varieties are grown on a commercial scale in different states in India. The most important mango varieties cultivated are *Alphonso, Banganapalli, Bangalora Chousa Dashehari Fajri, Gulabkhas, Himsagar, Kesar, Krishnabhog, Langra Mulgoa Neelam, Pairi and Rajapuri.* .In recent times, some mango hybrid varieties like *Mallika, Amrapali, manjeera, Ratna, Arka Aruna, Arka Puneet, Arka Anmol, Neeleshan, Neeluddin, Neelgoa* (NHB, 2006) have also been gaining popularity. Of these, the cultivar amrapali a hybrid scion cultivar, Dashehari (F) x Neelum (M) developed by IARI. New Delhi, and is particularly appealing as it is a distinctly dwarf variety, highly regular and prolific in fruit bearing and having excellent fruit quality (Ara et al 2000).

Since India is the richest source of quality mango varieties in the world, India could potentially increase its export of mangoes through proper storage, packaging, and marketing practices. Mango being a perishable commodity, proper care and attention is needed to the post harvest handling of the fruits to ensure that the quality of the fruit is preserved till the point of consumption. As a living biological entity, mango respires and transpires (Kader, 1987). Before harvest, when they are attached to the parent plant, losses due to respiration and transpiration are replenished by water, photosynthates and minerals from the plant. After harvest, losses of respirable substrates and moisture are not replenished; therefore, deterioration occurs soon followed by senescence or total death. The physiological and biochemical changes during respiration and transpiration are influenced by environmental factors like temperature, ethylene, O_2 and CO_2 concentration (Kader, 1980) and in general these biological activities causes decline in quality of the produce and limit its shelf life.

Mango being a tropical fruit is also susceptible to chilling injury (Abou Aziz *et al.*, 1976). This means that at lower than threshold temperatures, storage could induce stress resultant symptoms in the fruit manifested as brown patches on the skin, and as the severity of the injury progresses, as discolouration of the pulp and stone. Exposure to harsh temperatures also leads to poor ripening and loss of flavour and texture of the fruit (Chaplin et al 1991, Nair et al 2003). Since LN_2 is a refrigerant of very low temperature, while using a system with LN_2 for cooling of mango fruits, it is necessary to ensure that the fruit is not overtly stressed and liable to chilling injury.

MATERIALS AND METHODS

Table 2: Area under Cultivation and Production of Mango in Different States in India

State	Area (in 000'ha)		Production in 000'MT	
	2003-04	2004-05	2003-04	2004-05
Andaman & Nicobar	39.1	42.4	149.2	158.1
Andhra Pradesh	1498.6	1506.1	12525.1	13668.8
Arunachal Pradesh	78.3	80.8	218.9	218.8
Assam	415.4	410.1	3158.2	3189.6
Bihar	1222.1	1192.6	16822.2	16189.0
Chhattisgarh	135.0	232.2	1979.2	1636.2
Delhi	48.3	48.3	652.8	652.8
Goa	99.8	99.8	313.2	313.2
Gujarat	887.4	1023.3	6981.3	9402.6
Haryana	239.8	236.6	3018.8	3268.2
Himachal Pradesh	271.8	277.2	1470.3	1739.7
Jammu & Kashmir	281.3	308.8	1752.7	2170.7
Jharkhand	142.4	256.8	1493.5	3798.3
Karnataka	1491.4	1508.1	10147.9	10569.9
Kerala	1680.9	1689.1	9453.1	9323.3
Lakshadweep	3.2	3.2	54.3	54.3
Madhya Pradesh	714.6	737.6	3653.4	4129.5
Maharashtra	1926.8	2010.8	14460.7	15192.8
Manipur	79.1	79.1	417.0	417.0

Table 2: Contd.,

Meghalaya	85.2	85.2	555.8	555.8
Mizoram	35.8	35.8	107.1	107.1
Nagaland	29.8	29.8	163.7	163.7
Orissa	1298.0	1304.9	9915.3	9997.7
Pondicherry	25.8	25.9	139.9	142.6
Punjab	208.2	217.3	3249.5	3390.2
Rajasthan	2589.7	2599.2	2878.6	3019.2
Sikkim	58.2	57.4	112.7	118.3
Tamilnadu	1026.3	1061.1	11252.2	13681.6
Tripura	74.0	76.2	871.1	908.3
Uttar Pradesh	1144.5	1173.1	17325.3	18850.6
Uttranchal	130.9	285.5	1130.0	1778.5
West Bengal	1484.8	1501.9	21115.2	20725.6
Total	**19449.0**	**20198.9**	**157834.9**	**169828.8**

Source: Indian Horticulture Database, National Horticulture Board, 2006

Precooling Treatments

All precooling treatments were conducted in triplicate and each lot comprised of 5 fruits. As a control, one lot of fruits was ripened without any precooling. All fruits were ripened for a week at 21 $\pm$ 1 ^{o}C.

Hydrocooling

Two treatments of hydrocooling were attempted using a cold-water bath having internal recirculation facility (Model No.F32, Julabo, Germany; Figure 1).

Figure 1: Pictorial View of the Cold Water Bath

One lot was cooled with water at 10 ^{o}C and the second lot with water at 5 ^{o}C. Since the fruits were mature, they were completely submerged in the cold-water bath. Thermocouples (Copper – Constantan) were inserted into the flesh of two fruits in each lot and the temperature near the centre of the fruit was monitored. In each case, after the center of the fruit reached 12 ^{o}C, the mangoes were withdrawn from the water bath, wiped dry and then left for further examination and ripening.

Liquid Nitrogen Augmented (Initial Cool Down) Air cooling

Precooling of mangoes with liquid nitrogen was carried out in the setup as shown in Figure 2. In this study, liquid nitrogen was employed as the cooling medium only for the initial cool down of the system i.e. till the temperature for storage was achieved (12 ^{o}C). Once this temperature was attained, flushing of liquid nitrogen into the chamber was stopped and the storage temperature was thereafter maintained using a mechanical refrigeration system till the end of the storage period.

Air Cooling

The same setup described in section 3.3.2 was employed to study the precooling of mangoes using air cooling at 10 ^{o}C employing only the mechanical refrigeration system. This means that liquid nitrogen flushing for the initial cool down was not carried out for this case. After the center temperature of mango reached a steady state, the lot was withdrawn from the chamber and was examined for any visual changes in colour and thereafter left for ripening. The change on air temperature was also recorded with time using a temperature indicator (Model no. 52 K/J, FLUKE Co. USA, figure 3).

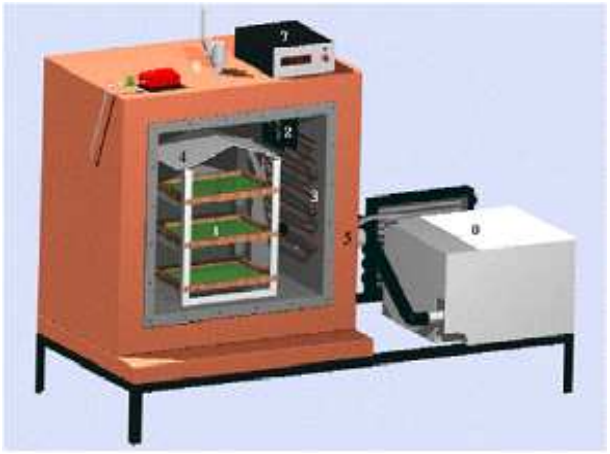

Figure 2: Pictorial View of the Lab Scale CA Chamber (Mahajan, 2001) (1 – Fruit Tray, 2 – Evaporator Fan, 3 – Evaporator Coil, 4 – Protection Cover, 5 – Outlet Valve, 6 – LN_2 Inlet, 7 – Temperature Controller and 8 – Refrigeration System)

In each case, copper - constantan thermocouple (32 gauge) was inserted to the centre of a mango in the lot and the rate of change in temperature was recorded till it reached a steady state of 12 ^{o}C. This temperature was arrived at as an end point for precooling as 10 - 15 ^{o}C is the most widely recommended range of temperature for low temperature storage of green mature mangoes (Bender *et et al.,* 2000, Kader, 2002, Lalel *et al.,*. 2003b)

Figure 3: Pictorial View of a Temperature Indicator (Model No. 52 K/J, FLUKE Co. USA)

Physico Chemical Characteristics

Firmness

Firmness of mango fruit was measured destructively using a texture analyzer (Model TA- XT2i, Stable Microsystems Ltd. UK) fitted with a standard penetrometer probe (SS, 5 mm diameter)as shown in Figure 4. The analyzer was linked to a computer that recorded the data via a software programme XTRA.Dimension (Version 3.7h, Texture Technologies Corp., and Scarsdale, NY).

Figure 4: Pictorial View of a Texture Analyser (Model TA- XT2i, Stable Microsystems Ltd. UK)

The variety used for this study had a skin of about 2mm thickness (Mannan *et al.*, 2003) was peeled off the fruit using a knife .The probe was pushed in to the fruit flesh to a distance of 8mm at two locations along the equator of the fruit and the average values were reported. The operating conditions were:

Pre-test speed 1.5 mm/s

Test speed 0.5 mm/s

Post test speed 10 mm/s

The maximum force encountered by the fruit tissue was recorded as its firmness (Jha *et al.*, 2006).

Analysis for Aroma Volatiles

Lalel *et al.,* (2003a) in their investigation on the distribution of aroma volatiles in different parts of the mango fruit concluded that most volatiles are concentrated in the peel and outer pulp. Hence the whole fruit as such was sampled for determining the aroma volatiles in this study.

The fruit samples were analyzed for aroma volatiles using dynamic headspace sampling with a CDS Model 8000 Universal Sample Concentrator interfaced to a Chemito 1000 gas chromatograph which was equipped with a FID as the detector as shown in Figure 5. Dynamic headspace sampling is a simple, solvent-free way to analyze materials for volatile organic compounds. The CDS Analytical Model 8000 Sample Concentrator was equipped with a headspace sampler, 95 mm in diameter and 110 mm deep, permitting the analysis of large objects intact, eliminating requirement of sample preparation. A single whole fruit (ripe or raw) was sealed in the temperature-controlled vessel programmed for 40 °C for 30 minutes. In this vessel, the analytes were collected, as in a purge and trap analysis, while the carrier gas was vented. The headspace atmosphere was constantly purged out of the sample vessel and through a Tenax trap. After the collection step, the trap was heated and back-flushed to transfer the adsorbed compounds to the GC for analysis.

Figure 5: Pictorial View of the Headspace Sampler and GC – FID Used for Aroma Analysis

Since no solvents were used to prepare the sample for the GC, there was no solvent peak, no dilution of the compounds of interest, and no waste solvent to discard. Separation of the compounds was achieved on a BPX - 5 capillary column (50 m x 0.22mm id; SGE Australia). The concentrator and GC conditions were as outlined in Table 3.

Volatile compounds were identified by comparing their retention times with standard pure compounds. Concentrations of volatile compounds were calculated using regression equations fitted to peak height calibration curves. The calibration curve for a volatile compound was plotted after determination of the peak heights obtained when standards of known concentrations were analyzed for headspace composition.

Table 3: GC Conditions for Analysis of Aroma Volatiles

Sample Concentrator Conditions	GC Conditions
Valve Oven: 225 °C	Carrier: Nitrogen
Transfer Line: 250 °C	Column: BPX -5 (50m x 0.22 mm dia)
Temperature: 40 °C	Detector: FID
Time: 30 minutes	**GC Program:** Detector temperature: 300 ^{o}C
Trap: Tenax	Injector temperature: 290 ^{o}C
Trap Desorb: 225 °C for 5 minutes	Oven Temeprature Initial: 50 °C for 3 minutes
	Intermediate: 90 ^{o}C, Heating rate: 5 °C/min.
	Final: 290 °C, Heating rate: 5 ^{o}C/ min Hold for 5 minutes

Chemicals

Pure reference standards α pinene, β pinene, β caryophyllene, ocimene, β myrcene, limonene, α gurjunene, α humulene, terpinolene, 2- phenethyl acetate, ethyl acetate, butyl buterate, ethyl decanoate, linalool, α terpineol, dodecanol, tetra decan 1-ol, gamma dodecalactone, gamma octalactone, delta decalactone, furfural were purchased from Sigma Aldrich, Germany. The choice of these standards was based on literature reports on common volatile compounds in mangoes (Macleod & Snyder, 1985, Idstein, H., Schreier, 1985, Engel & Tressl 1983, Andrade *et al.,* 2000, Lalel *et al.,* 2003c)

RESULTS AND DISCUSSIONS

Precooling of Mango

Cooling of mangoes to the storage temperature of 12 ^{o}C using LN_2 augmented air cooling was compared to other common methods of precooling of mangoes as described in section 3.3 and the findings are reported below.

Precooling Rate

The total time taken for the fruit to achieve the desired temperature and the relative savings in cooling time for each of the precooling technique studied is outlined in Table 4 results are mean of 6 measurements for each treatment

Table 4: Cooling Time for the Different Precooling Techniques

Precooling Technique	Total Cooling Time, Min	% Relative Saving in Cooling Time Compared to Air Cooling Using Mechanical Refrigeration
Hydrocooling at 5 ^{o}C	36	84
Hydrocooling at 10 ^{o}C	60	73
Air cooling using only mechanical refrigeration	225	-
Liquid nitrogen augmented air cooling (20.85 kg/ h)	180	20

While the LN_2 augmented air cooling system of precooling was almost instantaneous in its action, with the desired air temperature being achieved in less than 4 minutes, the same air temperature in case of air cooling (without the liquid nitrogen flushing) was reached only after about 36 minutes of cooling time.

This resulted in nearly 89% saving in the initial cooling time for the air by initial cool down with liquid nitrogen. As a result, the overall precooling time for mango to reach the desired temperature was also reduced by 20% when the mechanical refrigeration was combined with initial flushing of liquid nitrogen for air cooling.

The cooling coefficient (equation (1) and (2)), which is the rate of change in temperature of the fruit per unit change in temperature difference between the product and the medium was used as a uniform basis to compare the four methods.

The values of cooling coefficients calculated for the precooling techniques compared in this study are given in Table 5 along with the respective regression coefficients. It was observed that all the four methods resulted in high regression coefficients (>0.96) showing that the experimental data fitted well in the equation.

Table 5: Cooling Coefficients for the Different Precooling Techniques Studied for Mango

Precooling Technique	Cooling Coefficient* min^{-1}	R^2
Hydrocooling at 5 ^oC	0.0762	0.9878
Hydrocooling at 10 ^oC	0.0475	0.9696
Air cooling using only mechanical refrigeration	0.010	0.9863
Liquid nitrogen augmented air cooling	0.014	0.9754

* The cooling coefficient was calculated as given below (Dincer, 1997)

$$C = \frac{\ln Y}{t} \quad (1)$$

where, C = cooling coefficient, $^oC/(min.\ ^oC)$

$$Y = \frac{(T-T_m)}{(T_i-T_m)} \quad (2)$$

where, t = time elapsed during cooling, min

T = temperature at any time, ^oC , m and i denotes media and initial condition.

It was found that the cooling coefficient was influenced by the cooling method employed (Table 5). Hydrocooling performed better than air cooling as it had higher cooling coefficients. This could be due to two reasons. Firstly, the better heat transfer coefficient of the cooling medium i.e. water in comparison to that of air, resulted in faster cooling of the fruit. Secondly, for hydrocooling, the medium temperature was at the desired level (5 or 10 ^oC) from the beginning of the cooling process. While for air cooling, the air temperature was reduced from the initial ambient conditions to the final medium temperature over a period of 4 minutes when air was cooled using liquid nitrogen augmented air cooling and 36 minutes (Table 4) when air was cooled using only mechanical refrigeration system. Due to this, the value of medium temperature was initially on the higher side for the air cooling processes resulting in poorer cooling coefficients as compared to that of hydrocooling.

The liquid nitrogen augmented air cooling system yielded a cooling coefficient of 0.014 min^{-1} as against the cooling coefficient of 0.010 min^{-1} for air cooling using only mechanical refrigeration. Thus, the faster initial cool down using liquid nitrogen flushing resulted in improvement in the cooling coefficient by nearly 40 %.The peel color indices of the ripened fruit calculated using the equations given by Ravindra and Goswami (2008) after the different precooling

techniques were studied. The calculated indices were observed to be in close agreement with the objective color values. Also, except for the hydrocooled sample at 5 ^{o}C, all the samples scored nil for chilling injury symptoms.Even for the injured sample, the scores were low at a level of 2.11, implying a little over 10 % injury or discoloration of the peel. The pulp of the ripened fruits was also objectively evaluated for its color. The results indicated that none of the precooling techniques adversely affected the color development in the pulp of the fruit. The peel and pulp of the studied variety are reported to have a deep yellow color (Mannan *et al.*, 2003) and the hue values of the sample fell in this region.

Considering that the temperature of liquid nitrogen at the point of flushing into the storage chamber was in the vicinity of -85 ^{o}C and the flow rate was high at 20.85 kg/h, it was expected to cause some chilling injury to the fruit. However, no such effect was observed in this study. This could be because of the absence of any direct contact between the liquid nitrogen stream and the fruit surface during the whole precooling process due to the overhead shield provided within the chamber (Figure 2).In the case of hydrocooling, it was observed that the mango fruits attained its core temperature of 12 ^{o}C at about 36 minutes when hydrocooled at 5 ^{o}C while the same temperature was reached in 60 minutes when hydrocooled at 10 ^{o}C. This indicated that increasing the cooling water temperature from 5 to 10 ^{o}C resulted in nearly 40 % increase in hydrocooling time.This could be due to the obvious decrease in the temperature gradient between the fruit and the cooling medium when the water temperature was increased. For the two cases of air cooling viz., mechanical refrigeration and LN_2 augmented air cooling (i.e. initial cool down with LN_2 followed by mechanical refrigeration); the desired temperature was achieved later than that of hydrocooling. This increase in cooling time was expected due to lower heat transfer coefficient of air as compared to that of water.

Firmness

The firmness index was calculated by equation given by Ravindra and Goswami (2008) and the firmness of the fruit measured objectively is depicted in Figure 6. It was observed that all the four precooling techniques compared in the study resulted in a loss of firmness of the ripened fruit as compared to that of the control sample. The sample exposed to 5 ^{o}C suffered the maximum loss of firmness.This is expected as the fruit was directly in contact with a very cold fluid (5 ^{o}C) for about 36 minutes. Hydrocooling at 10 ^{o}C and air cooling using LN_2 augmented air cooling system yielded similar scores of firmness index for the fruit at 5.0 and 5.3 respectively, which was lower than the index value of 6.78 of the air cooled ripened fruit.

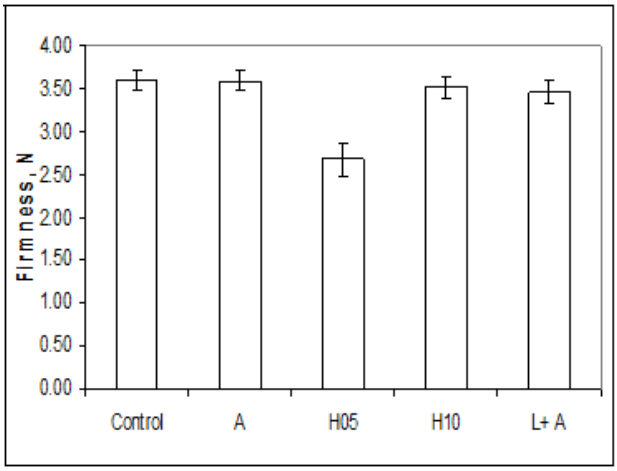

Figure 6: Firmness Values for Ripe Mango after Different Precooling Treatments H05 Stands for Hydrocooling at 5 ^{o}C, H10 Stands for Hydrocooling at 10 ^{o}C, MR Stands for Air Cooling Using Only Mechanical Refrigeration and LN_2 + MR Stands for LN_2 Augmented Air Cooling. Results are Mean of 9 Values, Error Bars Indicate Standard Deviation

The objective measurement (Figure 6) also reflected this trend. This implied that no adverse impact on the fruit firmness was observed owing to liquid nitrogen for initial cool down of the storage chamber when the fruit was not directly exposed to the liquid nitrogen spray.

Aroma of the Fruit

The aroma volatiles; as selected terpene hydrocarbons, esters, alcohols, lactones and aldehydes produced by the whole fruit in the raw (freshly turned out of RCA storage) and post ripening were analysed by headspace sampling and quantified using a GC FID and the results were evaluated for the effect of RCA on mango fruit aroma. A typical aroma chromatogram is shown in Figure 7, wherein it is seen that the aroma components such as Terpenes, Esters, Alcohols, Lactones, Aldehydes were identified and quantified with the help of gas chromatography.

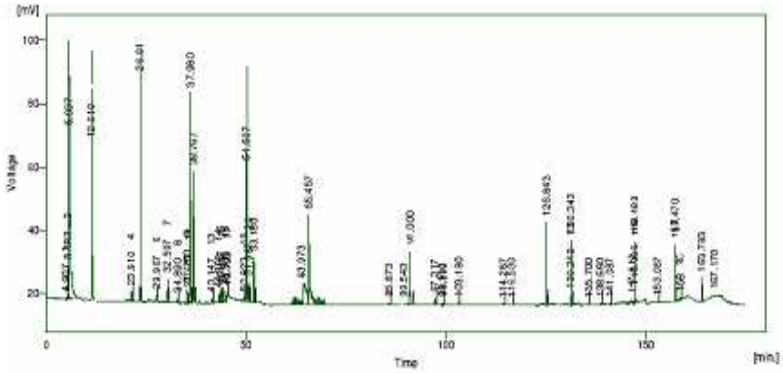

Figure 7: GC – FID Chromatogram for Aroma Volatiles

CONCLUSIONS

Mangoes or similar fruits can be precooled with different techniques such as liquid nitrogen augmentation of a mechanical refrigeration system, hydrocooling, or air cooling. These are unique commonly employed precooling techniques. It was observed that hydrocooling was a faster technique than air cooling, however liquid nitrogen augmentation helped to reduce the time required for air cooling by 20%. Chilling injury symptoms in the treated fruits indicated that even though liquid nitrogen has a very low temperature, judicious control of the exposure time and the absence of direct contact with the fruit surface prevented any chilling injury to the fruit. Low temperature such as use of hydrocooling at 5 ^{o}C did resulted in some chilling injury to the fruit, albeit very minimal. The ripening indices like colour development and firmness of the ripened fruit indicated that the liquid nitrogen augmented precooling system employed did not adversely affect the ripening of the fruit.

The physicochemical studies such as firmness, retention of aroma indicated that the precooled fruits were comparable as far as the technique employed was concerned. It could be concluded from this study that liquid nitrogen systems can be successfully used for precooling of mangoes if the design of the system ensures no direct contact between the fruit and the cryogenic liquid.

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