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Post-harvest heat treatment of bananas – Effect on shelf life and quality

Wärmebehandlung von erntefrischen Bananen – Effekt auf Haltbarkeit und Qualität

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Summary

Heat treatment is a potential physical treatment to eradicate or delay development of pathogens and therefore prolongs the shelf life of fruits. A study was undertaken to examine the effect of heat treatment on quality and shelf-life of bananas. A water heating chamber (20 kg/batch) with temperature controller was developed for this purpose. Banana (cv. *Cavendish*) bunches were treated at 40 and 45 °C temperature for different durations (30, 45 and 60 min). Microbial analysis just after heat treatment revealed that it is essential to heat the banana at 45 °C for at least 45 minutes to reduce the fungal count in banana to an acceptable level. Heat treatment resulted in slight decrease in firmness of raw bananas. However, the rate of decrease in firmness during ripening and storage was more pronounced in case of control sample, indicating quick softening of control samples due to ripening. The firmness value decreased from an initial value of 1.37 kgf to 0.26 kgf i. e. almost by 81 % after 7 days, whereas the same for heat treated samples ranged between 26–69 %. The Higher the temperature and duration of heat treatment, the less was the rate of ripening. Heat treatment also increased the lightness value of the banana peel. The yellowness index of treated bananas increased slowly compared to control samples. Heat treatment at 45 °C for 60 min was found to delay the ripening process and hence increase the shelf-life of bananas by 5 days.

Keywords: banana, firmness, heat treatment, microbial count, shelf-life

Zusammenfassung

Wärmebehandlung ist eine mögliche physikalische Behandlung zur Beseitigung oder zur Hemmung von Krankheitserregern und verlängert so die Haltbarkeit von Früchten. Diese Studie wurde durchgeführt, um die Wirkung der Wärmebehandlung auf die Qualität und die Haltbarkeit von Bananen zu untersuchen. Zu diesem Zweck wurde eine Wassererhitzungskammer (20 kg/Charge) mit Temperaturregler entwickelt. Bananenbüschel *(Cavendish)* wurden bei 40 °C und 45 °C für verschiedene Zeiträume (30, 45 und 60 min) behandelt. Mikrobiologische Untersuchungen unmittelbar nach der Wärmebehandlung zeigten, dass die Bananen bei 45 °C für mindestens 45 Minuten erwärmt werden müssen, um die Pilzkeimzahl auf ein akzeptables Niveau zu reduzieren. Die Wärmebehandlung führte zu einem leichten Rückgang der Festigkeit der rohen Bananen. Allerdings war die Abnahme der Festigkeit während der Reifung und Lagerung bei der Kontrollgruppe stärker ausgeprägt; dies lässt auf eine schnellere Reifung der Kontrollgruppe schließen. Der Festigkeitswert der Kontrollgruppe verringerte sich vom Anfangswert 1,37 kgf auf 0,26 kgf nach 7 Tagen; das entspricht 81 %. Der Festigkeitswert der wärmebehandelten Proben nahm zwischen 26 % und 69 % ab. Je höher die Temperatur und die Dauer der Wärmebehandlung waren, desto geringer war die Geschwindigkeit der Reifung. Die Wärmebehandlung erhöht auch den Helligkeitswert der Bananenschale. Der Vergilbungsindex der behandelten Bananen erhöhte sich langsamer im Vergleich zur Kontrollgruppe. Es wurde festgestellt, dass eine Wärmebehandlung bei 45 °C für 60 min den Reifungsprozess verzögert und somit die Haltbarkeit der Bananen um 5 Tage erhöht.

Schlüsselwörter: Bananen, Festigkeit, Wärmebehandlung, Keimzahl, Haltbarkeit

Introduction

Over the past few years, postharvest loss and food safety has become and continues to be the first concern for fresh produce industries. Fresh fruits & vegetables have high concentration of microbial contamination after harvesting, ranging from 4 to 7 log units, and therefore infections from fruit and vegetables represent an important food safety issue (Nüesch-Inderbinen and Stephan, 2016). Banana (*Musa* spp. L) is one of the cheapest, most plentiful and most consumed fruits in India as well as all over the world. Total banana and plantain production all over the world is calculated as 106.8 million metric tons (FAOSTAT, 2013). India ranks first in banana production (27.57 million MT, 28 % of total production) followed by China, Philippines, Brazil and Ecuador. Banana is popular because of its easy availability, low cost, various usage and high nutritive content. Banana is also considered a high energy food source due to elevated levels of antioxidant vitamins, vitamin A and C (ascorbic acid), and phenolics, which are related to high antioxidant capacity (Kevers et al., 2007; Thaipanit and Anprung, 2010).

Banana is among the highly perishable fruits that have a short shelf-life and suffer severe postharvest losses. One of the limiting factors for exporting bananas to distant countries is the short shelf-life mainly due to postharvest disease development during transit and storage. The major postharvest diseases are fungal diseases including anthracnose and crown rot disease caused by a fungal complex, *Colletotrichum musae, Fusarium* spp. and *Lasiodiplodia theobromae* (Kyu Kyu Win et al., 2007; Reyes et al., 1998). The quality of banana fruits is largely dependent on the varieties and various post-harvest treatments which are principally applied to increase the storability of fruits. Many postharvest treatments, such as the use of fungicides followed by low temperature storage, have been applied to prolong the shelf-life of banana. However, increased public concern over the presence of chemical residues on fruits and vegetables has led to the progressive use of heat treatment for insect disinfestations and postharvest disease control in recent years (Lurie, 1998; Paull and Chen, 2000).

Heat treatments for disinfestations of fruit have been used since 1929 when Baker and co-workers developed a vapor heat treatment against the Mediterranean fruit fly for insect control (Couey 1989). Heat treatment technologies are currently a relatively simple, non-chemical alternative to methyl bromide that can kill quarantine pests (insects and fungi) in perishable commodities, as well as control some postharvest diseases. Hot water is the best suitable medium for proper transfer of heat in the inner intracellular parts for disinfestations of pathogens. Water is preferred as the most relevant low cost medium for heat treatment without using any chemicals. Brief time for hot water treatments do not substantially increase the refrigeration load as only the surface cells are heated. Hot water treatment not only cleanses and disinfects but also prevents peel blackening of the bananas going for successive cold storage (Promyou et al., 2008). Although banana is an economically important fruit for sub-tropic areas, considerable literature dealing with the biochemical changes of heat treated bananas during storage is limited. Keeping in view of the above advantages of hot water treatment and quality enhancement of fruits, the study was undertaken to examine the effect of temperature and time combinations during heat treatment on quality and shelf-life of bananas. A heat treatment chamber was developed to study the same.

Material and methods

Raw material and heat treatment

A hot-water treatment chamber was designed and fabricated in the workshop of Central Institute of Agricultural Engineering, Bhopal, India. The chamber includes an insulated tank, electric heaters of desired capacity, magnetic contactor, digital temperature controller and RTD sensor. The chamber was designed to treat around 20 kg of banana (maximum banana bunch weight) per batch. It can be used to heat a whole bunch of banana. The size of the chamber (tank diameter: 45 cm and height: 70 cm) was determined based on the average banana bunch sizes.

Matured raw banana (var. – Cavendish) in unripe stage used in the experiment was obtained from a banana trader in Bhopal. Through inquiry it was known that the bananas reached to Bhopal around 18 hours after harvesting without any prior treatment. The whole banana bunches were purchased and bunches were cut after bringing to the Laboratory. Portable water (~ 75 liter) was filled in the heat treatment chamber. The chamber was switched on and temperature was set at the desired level. Banana bunches were placed in the perforated sample holder and dipped inside the heat treatment chamber when proper temperature was reached. Water was stirred manually for an even distribution of temperature. Power consumption for treating 1 kg of banana was found to be 0.18 kWh, the cost of which is around one Indian rupee.

Preliminary experiments were conducted to set the temperature limits for quarantine heat treatment of matured unripe banana. Banana samples were heated at different temperature ranging from 40 to 55 °C. The duration of treatment was varied between 30 and 60 min. Samples were removed from the heat treatment chamber after the specific time period and immediately dipped inside a bucket containing ethereal solution (200 ppm) (trade name: Bison; Canary Agro Chemicals Private Limited, Delhi, India) for about 10 minutes. The fruits were then dried under a fan, and kept at around 20 °C for ripening in an environmental chamber (Model : CHM – 6 plus; Remi Laboratory Instruments, India). It was observed that bananas treated at 55 °C for 15 minutes did not ripe and their skin become black after a couple of days. Similarly, samples treated at 50 °C for one hour did not ripe properly. However those treated at 45 °C produced good results. Based on this result, further experiments were planned at lower temperature i. e. between 40 and 45 °C as given in Table 1.

Analysis of different quality parameters

The firmness of bananas were determined with the help of a texture analyzer (Model TA.XT-2i, Stable Microsystems, Surrey, England) fitted with a 25 kg load cell. A 2 mm diameter cylindrical probe was used to puncture the banana,

TABLE 1: *Temperature-time combinations for banana heat treatment.*

Treatment	Temperature (°C)	Time (min)
T1	40	30
T2	40	45
T3	40	60
T4	45	30
T5	45	45
T6	45	60

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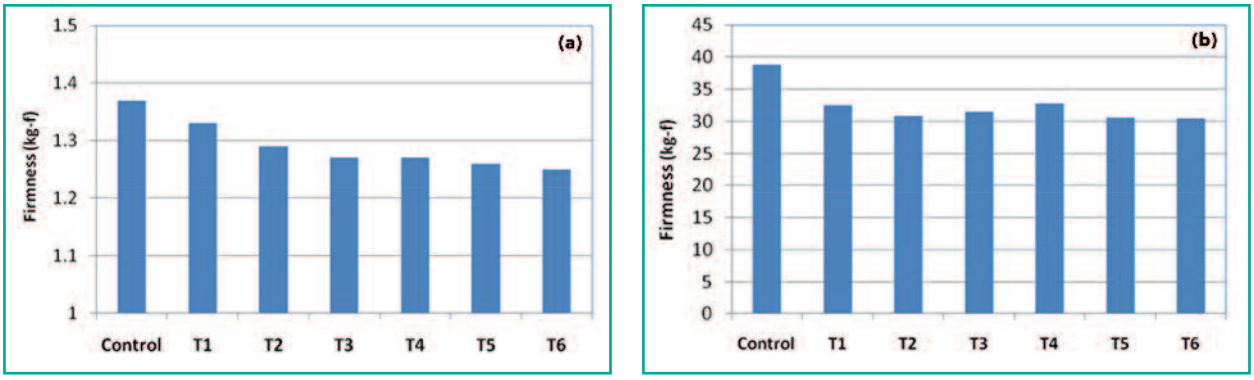

FIGURE 1: *Firmness of heat treated and untreated bananas measured by (a) 2 mm cylindrical probe and (b) flat plate compression probe(replication = 3).*

and a flat plate compression probe was used and compress the bananas to a depth of 10 mm. Banana peel color parameters were measured using a Lab Scan XE Spectrocolorimeter (Model 45/0-L, Hunter Associates Laboratory Inc., Reston, USA). Measurement of pH was done using a hand held pH/mV/Temperature meter (Model pH 323, WTW GmbH, Weilheim, Germany) attached to a stainless steel pH/temperature probe. Total acid level was determined by the titratable acidity method (AOAC, 1999) and was expressed as per cent of maleic acid. The total soluble solid of banana pulp was measured with a digital refractometer (Model: PAL-1, Atago Co. Ltd., Tokyo, Japan). The total sugar of control and treated banana samples was determined by Dubois method (Dubois, 1956), which utilizes phenol as the specific organic colour developing agent. The optical density (OD) of samples was measured at 490 nm in a Spectrophotometer (Model: UV-1800, Shimadzu, Kyoto, Japan) after setting for 100 % transmission against the blank. The standard curve was prepared by using known concentration of glucose. The quantity of sugar (mg/g of fresh banana tissues) was determined by reference to the standard curve and expressed as per cent value.

Microbiological analysis of the treated and untreated bananas was performed using serial dilution pour plate method (Downes and Ito, 2001). Briefly, 10 ml of sample was mixed with 90 mL of sterile media and serial dilutions were prepared. 1 mL of the diluted inoculums was pour plated in duplicates on different media plates. For aerobic bacterial count, the diluted sample was pour plated on nutrient agar (Himedia Laboratories, Mumbai, India) and incubated at 37 °C for 24 hours. For total fungal (Yeast and Mold) count, the sample was plated on yeast malt agar (Himedia Laboratories) and incubated for 5 days at 30 °C. After incubation, colony forming units (CFU) were counted with the help of a Colony counter (Model IMCC-01, Shambhavi Impex, Mumbai, India) and the results were expressed as $\log_{10}$ CFU mL^{-1}.

Shelf life (days) of banana fruit of each treatment was recorded during the period of storage. It was calculated from the date of harvesting to last edible stage. Edible stage of ripe banana was measured when it became very soft, observed black spot on the peel surface and detached finger from the crown.

Statistical analysis of data were carried out using SAS 9.2 (SAS Institute Inc., Cary, NC). Tukeys HSD test (One way ANOVA) and Duncan's multiple range test method was used for analysis of variance (ANOVA) to find out significance difference between different treatments and with storage period.

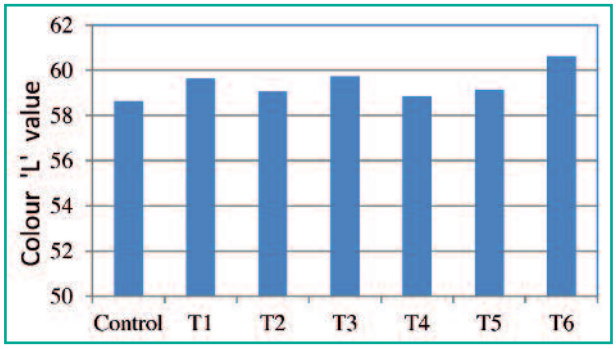

FIGURE 2: *Changes in colour parameter of banana peel with heat treatment(replication = 3).*

Results and Discussion

Physical and microbial analysis of raw banana after heat treatment

Texture (fruit firmness), peel colour, and microbial count (total bacterial count and total fungal count) of bananas just after heat treatment were measured and compared with those of untreated samples in order to assess the effect of heat treatments on these parameters.

Texture (Firmness) analysis

Raw untreated fruits had a compressive firmness of 38 kgf Heat treatment was found to decrease the initial fruit firmness. More the temperature and duration of treatment, more was the decrease in value of fruit firmness (puncture force measured by cylindrical probe (Fig. 1a). For a constant temperature, the firmness value decreased as the duration of heating increased. Statistical analysis (One way ANOVA with Tukey HSD Test) indicated significant difference ($p \leq 0.05$) in the firmness value of T5 and T6 samples compared to control. Similarly, when the compressive firmness values (Fig. 1b) were compared, significant differences were observed between control and treated sample. However there were no significant differences among the treatment.

From the literature it was found that heat treatment can either increase or decrease water loss and firmness of fruit, depending on the treatment and the commodity. The influence of hot water treatment (HWT) on citrus fruit during storage was an increased weight loss in 'Fortune' mandarins (Schirra and D'hallewin, 1997) and blood oranges (Schirra et al., 2004) but a decreased weight loss in kumquat and 'Marsh' grapefruit (Rodov et al., 1995). 'Valencia' oranges hot water dipped at 45 °C for 42 min became firmer, whereas the fruit at 53 °C for 12 min showed an in-

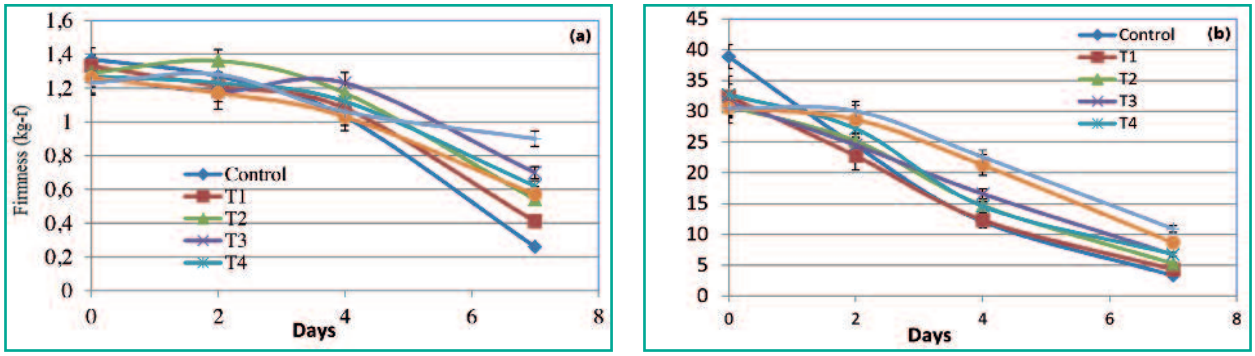

FIGURE 3: *Variation of firmness (puncture force) of treated and untreated banana with storage period (a) puncture force measured by 2 mm cylindrical probe and (b)compressive forcemeasured by flat plate compression probe.*

creased weight loss and decreased firmness (Williams et al., 1994).

Oroblanco treated with hot water at 43 °C for 30 min had higher fruit firmness than controls (Lurie et al., 2004). This inconsistency in the HWT effect on weight loss and firmness may be attributed to different fruit responses to the heat treatment. The response of a particular fruit to the heat treatment results from a combination of factors including the host, physiological age of the commodity, time and temperature of exposure, treatment methods, and storage temperature (Lydakis and Aked, 2003).

Colour analysis

The peel colour 'L' values of untreated and treated samples are depicted in Fig. 2. It can be observed that heat treatment increased the lightness value of the banana peel. Significant difference ($p \leq 0.01$) in the lightness value of T6 sample compared to other samples (except T3) was observed. This indicated that the treatment duration is responsible for increasing lightness values of banana peel. Greenness (negative 'a' value) of banana peel also increased with heat treatment.

Dipping in water might have caused removal of surface washing and removal of dirt etc., which increased the lightness and greenness values. Hong et al. (2007) also observed that HWT at 52 °C for 2 min and at 55 °C for 1 min produced cleaner and glossier mandarin fruit with bright reddish-yellow color as compared to untreated controls.

Microbial analysis

The total bacterial count (TBC) and total fungal count (TFC) of banana peel have been presented in Table 2. Raw banana peel had an initial bacterial count of 7.3 log cfu and a fungal count of 7.2 log cfu. Both the TBC and TFC decreased with heat treatment. As expected, higher the temperature and time of heat treatment, more was the decrease in TBC and TFC. There was almost 1 log reduction in TBC count and more than 3 log reduction of TFC in sample T5 and T6. Hence it is needed to heat the banana at 45 °C for at least 45 minutes to reduce the fungus present in banana to an acceptable level (Stannard, 1997). The fungus is a major cause of spoilage during ripening (Reyes et al., 1998).

HWT has been shown to destroy fungal propagules and modify the chemical environment of the fruit peel by activating antimicrobial compounds present in it (De Costa and Erabadupitiya, 2005). Win et al. (2007) have reported that HWT (45 °C for 20 min) gave useful inhibition of banana crown rot. Paull and Chen (2000) reported that hot water treatment at 50 °C for 45 min delayed softening of

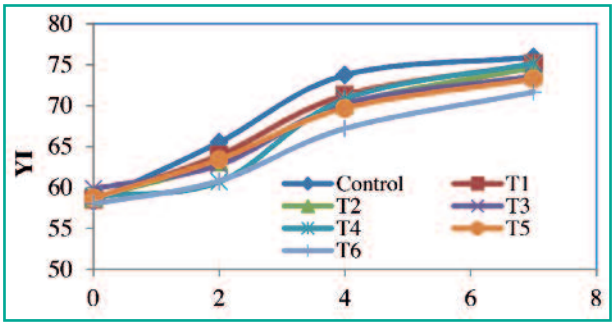

FIGURE 4: *Variation in yellowness index of treated and untreated banana with days of storage.*

green mature bananas, and treatment at 50 °C for 20 min reduced crown rot from 100 % to less than 3 % (Reyes et al. 1998).

Changes in quality parameters of banana during ripening and storage

Effects of hot water treatment on fruit firmness

The firmness values of banana were measured at regular interval of 2 days to study the changes in texture of the treated and untreated banana sample during the period of ripening and storage (Fig. 3 a+b). The firmness value decreased with days of storage due to the softening of tissues that result in softening of banana peel and pulp. The change was more in case of control sample compared to treated samples, indicating quick ripening. In case of control sample, the firmness value decreased from an initial value of 1.37 kgf to 0.26 kgf i. e. almost 81 % decrease after 7 days of storage. Similarly the compression force decreased by 92 % after 7 days in control (non-heated) bananas. The firmness values of heat treated bananas also declined with storage periods similar to the control sample. However the

TABLE 2: *TBC and TFC of control and heat treated banana.*

Treatment	Microbial count	
	TBC (Log CFU)	TFC (Log CFU)
Control	7.30	7.2
T1	7.14	6.9
T2	7.08	6.7
T3	6.78	5.4
T4	6.95	6.4
T5	6.90	4.2
T6	6.30	3.9

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rates of decrease in these samples were less than that of control. The per cent change in puncture firmness values after 7 days compared to the initial values were 69, 58, 44, 51, 54, and 26 % in case of T1, T2, T3, T4, T5, and T6 samples, respectively. This shows that the rate of respiration and softening of tissues is similar but slower in heat treated samples with respect to the control one. Treatment at 45 °C for 60 minutes (T6) resulted in highest values of firmness, as the banana did not ripe fully after 7 days. The sample was kept for another 5 days during which proper ripening took place.

Analysis of variance (Table 3) indicated significant difference in firmness value among different treatment and with storage period. When the mean values of compressive firmness of different treatment were grouped, it was observed that T5 and T6 had no significant difference (Table 4), while the control, T1, T2, T3 and T4 samples formed another group.

Softening of fruits is related to a change in cell wall component and starch degradation (Seymour et al., 1993). The starch granules, packed in the tissue of banana flesh give rise to the toughness of the unripe fruit, and are hydrolyzed to sugar while an increase of the cell wall solubility allows water and nutrients to pass in and out of the cells.

It has been reported that that the changes of the soluble solids content and the firmness of banana fruits were closely related to the ripening (Soltani et al., 2010). Flesh softening is often slowed following exposure to 38–40 °C, even if the treatment is applied for an extended period (4 days) before storage (Klein and Lurie, 1990, 1992; Lurie and Nussinovitch, 1996). Following disinfestations temperatures of 45–50 °C softening is faster (Mitcham and McDonald, 1992) or disrupted (Paull and Chen, 1990). Exposure of apples to 38 °C for 4 days resulted in fruit with less soluble and more insoluble pectin (Klein et al., 1990; Ben-Shalom et al., 1996). Tomatoes had less soluble polyuronides, and had less galactose and arabinose loss after 96 h at 40 °C (Mitcham and McDonald, 1992). Heat-injured papaya fruit that fail to soften, also show little change in soluble pectin amounts or molecular weights during ripening (Qiu et al., 1995).

Effect of hot water treatment on fruit (peel) color parameters

The peel lightness (L-value) of control and treated samples remained almost constant for initial 2 days and thereafter as the banana fruit began to ripen, the peel lightness increased and was similar for hot water treated and control fruits. The L-value increased very sharply in hot water-treated fruit but rose only slightly in control fruit. Due to the slow ripening process in treated banana sample the yellowness index (YI) of sample increased slowly than the rest samples in Fig. 4. Increase in YI with days of storage represents the ripening of bananas, changing from green to yellow color of the peel. The YI of control sample increased rapidly due to faster rate of ripening and regulation of ethylene rapidly in comparison to others. The YI of all the banana samples increased rapidly between 2nd and 4th day may be due to initiation of ripening during this period. However the increase was less in heat treated samples (especially in T5 and T6) indicating delay in ripening in these samples.

Significant differences ($p < 0.01$) were found in the yellowness index of treated and control bananas (Table 3 & 4), indicating the delay ripening of banana fruits in the hot water treatment. On day 7, control fruits turned to fully yellow and resulted in some detached fingers, whereas hot water treated fruit (T6) were still greenish-yellow. The peel color of banana changed from light green to yellow on the fourth day as the result of chlorophyll degradation that gradually unmasked carotenoid pigments lying underneath in the unripe fruit.

Total soluble solid (TSS) content

Table 5 shows the mean values of soluble solids content of control and heat treated banana fruits during ripening. TSS increased from an initial value of 5.4 °Brix at to a final

TABLE 3: *ANOVA for firmness and colour parameter of banana.*

Source	df	Sum of Squares			F-Value			Sig.		
		PF	CF	YI	PF	CF	YI	PF	CF	YI
Model	11	7.080	8477.75	3215.90	46.24	103.57	284.27	<0.0001	<0.0001	<0.0001
A: Time	3	6.870	2740.23	1037.10	164.52	368.24	1008.41	<0.0001	<0.0001	<0.0001
B: Treatment	6	0.025	42.07	16.92	2.46	5.65	16.46	0.0322	<0.0001	<0.0001
Error	72	1.002	535.78	74.05						
Corrected total	83	8.080	9013.54	3290.03						

PF: Puncture force; CF: Compressive force; YI: Yellowness index

TABLE 4: *Duncan Multiple test range for fruit firmness and colour (YI).*

Treatment	Duncan grouping									
	Firmness (Puncture force)			Firmness (Compressive force)			YI			
Control			c			c		a		
T1		b	c			c			b	
T2	a	b				c			b	c
T3	a	b				b	c		b	c
T4	a	b	c			b	c		b	c
T5		b	c		a	b				c
T6	a				a					d

Same letter within each column are not significantly different at $p < 0.05$

TABLE 5: *Physico-chemical parameters of treated and control bananas.*

Parameters	Sample	0 day	2nd day	4th day	7th day	10th day
TSS, °Bx	Control	5.2^{a}	13.4^{a}	16.8^{a}	17.6^{a}	17.6^{a}
	T1	5.2^{a}	13.2^{ab}	16.2^{b}	17.2^{ab}	17.4^{b}
	T2	5.2^{a}	13.2^{ab}	15.4^{c}	16.4^{c}	16.8^{c}
	T3	5.4^{b}	12.8^{b}	16.0^{b}	17.0^{b}	17.0^{bc}
	T4	5.8^{c}	13.2^{b}	16.2^{b}	16.8^{c}	17.2^{b}
	T5	5.6^{bc}	12.6^{c}	14.4^{d}	15.8^{d}	16.8^{c}
	T6	5.8^{c}	11.4^{c}	13.6^{e}	15.0^{e}	16.4^{d}
Titrable acidity (% malic acid)	Control	0.24^{a}	0.32^{a}	0.45^{a}	0.48^{a}	0.49^{a}
	T1	0.22^{b}	0.28^{b}	0.44^{a}	0.47^{a}	0.48^{a}
	T2	0.2^{bc}	0.29^{b}	0.37^{c}	0.45^{b}	0.47^{ab}
	T3	0.22^{b}	0.30^{b}	0.41^{b}	0.46^{ab}	0.4^{6b}
	T4	0.24^{ab}	0.32^{a}	0.44^{ab}	0.39^{d}	0.4^{6b}
	T5	0.2^{c}	0.25^{c}	0.38^{c}	0.41^{c}	0.45^{bc}
	T6	0.22^{c}	0.26^{c}	0.36^{c}	0.41^{c}	0.43^{c}

Same letter within each column are not significantly different at $p < 0.01$

TABLE 6: *ANOVA for TSS and titratable acidity(TA) of banana pulp.*

Source	df	Sum of Squares		F-Value		Sig.	
		TSS	TA	TSS	TA	TSS	TA
Model	12	1947.60	0.959	538.50	90.64	<0.0001	<0.0001
A: Time	4	1918.60	0.916	1591.44	259.51	<0.0001	<0.0001
B: Treatment	6	28.88	0.042	15.97	7.97	<0.001	<0.001
Error	92	27.73	0.081				
Corrected total	104	1957.30	1.040				

TABLE 7: *Total sugar content of treated and control banana.*

Samples	Total sugar, %	
	0 day	7 day
Control	5.6	20.4
T1	5.4	20.1
T2	5.9	19.6
T3	6.1	19.3
T4	5.7	19.7
T5	6.2	18.2
T6	6.1	17.7

value of around 17 °Brix at full ripe stage in a quadratic form. ANOVA (Table 6) indicates significant differences ($p < 0.01$) in the value of TSS with time. A change in total soluble solid followed the same pattern for all the samples, with a sharp rise in the first four days and steadily leveled of afterwards. Salvador et al. (2007) reported a similar increase in soluble solids content of Cavendish variety during ripening. They found soluble solids varied from about 5.5 Brix to 18 Brix. Marriot et al. (1981) reported that sugar content increased up to about 20 % at stage six (full ripe).

Most of the soluble solids content is sugar. During ripening, the starch of banana is converted to sugar, and hence TSS increases. Increase of TSS is an important trait of hydrolysis of starch into soluble sugars such as glucose, sucrose and fructose (Marriott et al., 1981). In the flesh more movement of water and the degradation of starch to soluble sugar within the cell contributed to the increase of TSS.

In case of control sample, the TSS increased to the maximum value in 7 days and remained almost constant up to 10th day. Similar was the case for T1, T2 and T4 samples. This indicates that these samples were fully ripe after 7 days. However TSS of T5 and T6 were significantly different from others (Table 5). The TSS values of these samples remained much lower upto 7th days and continued to increase up to 10th days. This confirmed delayed ripening and increased shelf-life heat treated T5 and T6 samples.

pH and Titratable acidity

Malic acid has been identified as the main acid in banana, with substantial quantities of oxalic and citric acid in the pulp. The malic acid increases upon ripening, whereas the oxalic acid is metabolized and decreases (Salvador et al. 2007). Mean values of titratable acidity of the samples shows that the titratable acid (% malic acid) increased gradually until the fruit reaches to full-ripe stage (Table 5). The initial value of titratable acidity was around 0.2 % that increased up to a maximum of 0.48 % in control samples after 7th day. The treated samples (T5 and T6) had lowest acid values after 7th day and it increased further up to 12th day.

Total sugar

The initial sugar content of raw banana was found to be around 5–6 %. The results on 7th day indicated a progressive increase in total sugar content during ripening (Table 7). This could be due to the hydrolysis of starch into sugar during ripening (Salunkhe and Kadam, 1995; Singh et al., 2013). Highest amount of total sugar was found in control samples as these were fully ripe on day 7. As expected, T5 and T6 samples had lower values of total sugar. These results were in accordance with those obtained by Garcia and Lajolo (2008).

Shelf-life of control and treated bananas

The maximum shelf-life of untreated (control) banana was found to be 7 days during storage at 25 °C. The treated samples (T1, T2, T3 and T4) were found to be edible up to 10th day, whereas T5 and T6 remained good and marketable for up to 12 days.

Conclusions

Heat treatment was found to delay the ripening process and increased shelf-life of banana. The life of heat treated bananas for the variety under study was increased by 3 to 5 days than those of untreated fruits, and maximum increase of 5 days shelf-life was found when treated at 45 °C for 45–60 min. It occurred due to slowing down of enzyme activity and elimination of the disease incidence by applying the heat treatment. The developed chamber was found suitable for banana heating at controlled temperature (with ± 2 °C variation). It can be scaled up for commercial applications.

Conflict of interest

We state that no conflict of interest of any kind exists in publication of this article.

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