

# Thermosonication an alternative to thermal pasteurization for Nagpur Mandarin Juice

## ABSTRACT

Nagpur mandarin is well known globally for its excellent nutritional benefits and flavor. These all characteristics gets affected due to lack of knowledge & processing techniques. Thermal pasteurization is a processing technique mostly used for juice processing before storage. Thermal pasteurization treatment leads to loss in various physicochemical qualities of juice viz. ascorbic acid content, carotenoid content. Thermal pasteurization treatment also leads to increase in limonin content and browning value of juice. Therefore, an experiment was carried out to check the effect on ascorbic acid and carotenoid content using the ultrasound combined with higher temperature known as thermosonication on Nagpur mandarin (*Citrus reticulata* Blanco) juice as compared. Treatments were also used to observe its effect on limonin, browning, total soluble solid, pH & acidity as compared to thermal pasteurization. Juice samples were thermosonicated at temperature of 50 °C, 55 °C, 60 °C, and 63 °C for 25, 20, 15 and 10 min respectively at a constant frequency of 40 kHz. Juice samples were also thermally pasteurized at 65 °C, 75 °C, 85 °C, and 95 °C for 80, 60, 40, and 20 sec. Samples were analyzed after treatment. Thermosonication treatments showed better ascorbic acid content and carotenoid content in comparison to thermally pasteurized juice samples. Limonin value and browning value were also less in thermosonicated juice samples. Both the treatments do not have any significant effect on Physicochemical characters like TSS, pH & acidity. Result indicated that thermosonication treatments performed better than thermal pasteurization treatments and can be used as an alternative technique for Nagpur mandarin juice processing.

**Key words:** Thermosonication, Thermal pasteurization, Nagpur mandarin, Juice quality

## 1. INTRODUCTION

Citrus is group of perennials, evergreen flowering trees and shrubs which belongs to family Rutaceae. Citrus fruits contain fragrance mainly due to flavonoids and limonoids contained in the rind. Citrus fruits are rich in ascorbic acid (vitamin C). Fruit juice generally contains a high quantity of citric acid providing them their characteristic sharp flavor. Citrus fruits are eaten fresh, juice pressed, or preserved as a value-added product.

Citrus is grown in more than 100 countries of the world. Among 100 countries, citrus is grown commercially in 53 countries. Nagpur mandarin occupies an area of about 480 '000 Ha of the total area of 1054 '000 Ha under citrus and total production 6368 '000 MT in the country (NHB, 2020) <sup>[8]</sup>. The area under Nagpur mandarin cultivation in Maharashtra alone is 115.003 thousand hectares, with a production of 899.58 thousand MT and productivity of 7.82 t/ha. The total area under citrus fruit in Chhattisgarh is 13.90 thousand hectares with a total production of 103.44 thousand MT with a productivity of 7.44 t/ha. The total area (in Chhattisgarh) under Nagpur mandarin 0.025 thousand hectares and production of 0.765 thousand MT.

Nagpur mandarin is well known globally for its excellent nutritional benefits and flavor (Carbonell *et al.*, 2006) <sup>[6]</sup>. These all characteristics get affected during juice processing due to lack of knowledge & processing techniques. Juices also face low ascorbic acid content & low carotene content after thermal processing. Therefore, it is necessary to develop and standardize a technology to increase and stabilize the ascorbic acid & Carotenoid content with minimum effect on the other quality parameter of juice like the color taste, etc.

Thermal pasteurization is a common method used to destroy the micro-organism and inactivate the enzymes in fruit juice. This heat treatment may cause undesirable changes in the properties of juice such as physical,

biological, chemical, and organoleptic (color, flavor, nutrients). Sonication is considered as a prominent technology and a magnificent alternative to the thermal processing for the food processing industry and the most valuable source in less energy and reduced processing time (Aadil *et al.*, 2015a)<sup>[1]</sup>. Sonication, when combined with heat is called thermo-sonication (Anaya-Esparza *et al.*, 2017)<sup>[4]</sup>. Thermosonication is a treatment that is the combination of ultrasound and heat. It is more effective as lower temperatures are used in comparison to thermal treatment (Anaya-Esparza *et al.*, 2017)<sup>[4]</sup>. Thermosonication with ultrasound is an alternative processing technique to enhance the inactivation of enzymes by the formation, growth and explosion of bubbles in liquid (Abdullah & Chin, 2014)<sup>[3]</sup>. In ultrasound, a phenomenon called cavitation occurs due to the propagation of sound waves. Cavitation leads to the formation and collapse of bubbles, which in synchronization with heat, promote cell disruption along with bacterial and enzymatic inactivation (Anaya-Esparza *et al.*, 2017)<sup>[4]</sup>. The current objective is to check the effect of thermosonication over thermal pasteurization on various physicochemical parameters viz. total soluble solid, pH, acidity, carotenoid, limonin, ascorbic acid & browning of Nagpur mandarin juice.

## 2. Materials & Method

The current experiment was conducted for examining the effect of thermosonication over thermal pasteurization on various physicochemical quality parameters of Nagpur mandarin juice at post-harvest management & processing lab under ICAR-Central Citrus Research Institute, Nagpur, Maharashtra, during the year 2019-20.

Fully matured, uniform fruits of Nagpur mandarins were harvested from the experimental field under the ICAR-CCRI, Nagpur and used for experiment. Those fruits which were free from mechanical injury were selected for the experiment and the immature, damaged and off type fruits were discarded. For extraction of juice, mandarin fruits were peeled manually. Juice was extracted from fruits using the orange juice extractor. After extraction of juice, it was filtered using sieve & muslin cloth to separate the pulp present in the juice. Juice samples were then thermosonicated & thermally pasteurized at different temperature & frequency for different time interval. Treated juice & control were studied to evaluate the effect of treatments on various physicochemical quality parameters just after treatment. The experiment comprised of 9 treatments and three replications designed under CRD at 5 per cent level of significance, includes various thermosonication treatments (50 °C/ 25 minute, 55 °C/ 20 minute, 60 °C/ 15 minute and 63 °C/ 10 minute) at 40kHz frequency and thermal treatments (65 °C/ 80 second, 75 °C/ 60 second, 85 °C/ 40 second and 95 °C/ 20 second) along with control. Data were then subjected to various statistical analysis of variance as given by Gomez & Gomez (1985)<sup>[7]</sup>. Juice samples were tested for various chemical parameters after the application of different treatment to juice.

### 2.1. Acidity

acidity of the Nagpur mandarin juice was calculated by taking 5ml of juice & diluting it with 20 ml of distilled water, after than further taking 5 ml of aliquot (from diluted juice sample) & titrating this aliquot against 0.1 N NaOH using phenolphthalein as indicator. End point is denoted by the appearance of light pink color (Ranganna, 1986)<sup>[10]</sup>. The acidity is expressed in percent (%) and was calculated using the following formulae: -

$$\text{Acidity} = \frac{\text{Titre} \times \text{Normality of alkali} \times \text{volume made up} \times \text{Equivalent Weight of anthocynin} \times \text{Equivalent Weight of anhydrous citri acid} \times 100}{\text{Volume of sample taken for estimation} \times \text{weight or volume of sample taken} \times 1000}$$

## 2.2. pH

The pH of Nagpur mandarin juice was calculated using digital pH meter. The temperature was kept constant while taking all the observations.

## 2.3. Total soluble solid (TSS)

The total soluble solid of Nagpur mandarin orange juice was directly measured using digital hand refractometer. Reading was taken at room temperature.

## 2.4. Browning Index:

Browning index was assessed after removing juice pulp by centrifuging the juice sample at 2000 rpm for 20 min. Extracted supernatant after centrifugation was mixed with an equal volume of 95% ethanol. Solution was then filtered through Whatman No. 42 filter paper to obtain fully clarified extract. Clear extract was then observed for absorbance at 420 nm with spectrophotometer (Meydav *et al*, 1977). Browning was measured in optical density (O.D.).

## 2.5. Ascorbic Acid:

L-Ascorbic acid was determined using HPLC. The methodology has two divisions for extraction and analysis of L-Ascorbic acid.

### 2.5.1. Extraction Method:

The sample juice was treated with a dilute ortho-phosphoric acid solution in the ratio of 1:1 and then the sample was centrifuged at 5 °C. The centrifuged sample was then filtered by 0.45µm nylon filters before being analyzed on HPLC.

### 2.5.2. Instrument Method:

L-Ascorbic Acid (Vitamin C) was determined by a normal phase HPLC method. The system consists of an Agilent Technologies (1260 Infinity model) system with four hydraulic pumps, an injection system, a C18 column (4.6 × 250 mm, 5µm), a C18guard column, a DAD detector, and a computerized recorder/integrator. For determination of L-Ascorbic Acid (Vitamin C), the mobile phase consisted of 20 mM Na<sub>2</sub>HPO<sub>4</sub> buffer and acetonitrile (95:5) with flow rate of 1ml/min. The injection volume of the sample was 5 µl. The detector wavelength was 220 nm.

## 2.6. Limonin:

Limonin content was determined by taking 25 ml of juice sample, which were centrifuged thrice at 3000 rpm for 10 min. Five milliliter of supernatant was collected after centrifugation. Ten milliliter of chloroform was added to the supernatant on separating funnel. Four milliliters of lower layer decant was taken from the remaining liquid from separating funnel. Six milliliters of freshly prepared Burcham reagent were added to 4 ml of separated lower layer and kept at room temperature for 30 min. After 30 min, upper layer of solution was taken up & then record observation at 503 nm. Limonin was reported in ppm (Wilson, and Crutchfield, 1968).

## 2.7. Carotenoid:

Carotenoid content was estimated by taking 10 ml of juice sample & adding 20 ml of 80% methanol with 0.5 g of celite. Filter it with Buchner funnel under vacuum pressure. Add 20 ml of acetone to the filtrate & again filter it with Buchner funnel under vacuum pressure. Take the filtrate and add 5 ml of n-hexane in separating funnel. Discard the lower acetone layer after few seconds. Collect upper n-hexane layer & make up its volume to 10 ml with n-hexane. Then observation (absorbance) was recorded at 450 nm. Carotenoid was reported in mg/100ml (Ting, and Rouseff, 1986).

## 3. RESULTS AND DISCUSSION

### 3.1. TSS, Acidity & pH: -

Results showed that the thermosonication and thermal pasteurization treatment did not influence the TSS, pH & acidity of Nagpur mandarin juice. Result revealed that acidity was statistically non-significant. These may be attributed to the energy level applied to the samples through thermosonication or thermal pasteurization, did not change the molecular structure of high molecular weight associated with acidity. These results were in collaboration with Bhat *et al.*, (2011)<sup>[5]</sup> on Kasturi lime juice, Aadil *et al.*, (2015a)<sup>[1]</sup> in grapefruit juice and Tiwari *et al.*, (2008)<sup>[11]</sup> on orange juice. Data observed for the total soluble solid after treatment with thermosonication & thermal pasteurization did not show any significant effect on total soluble solids. Different treatment of thermosonication and thermal pasteurization did not change the molecular structure of high molecular weight associated with total soluble solid (TSS) (Ordenez-santos *et al.*, 2017)<sup>[9]</sup>. These results agree with the findings of Tiwari *et al.*, (2008)<sup>[11]</sup> in orange juice. However, heat pasteurization was found to be superior over thermosonication.

**Table 1: Effect of thermosonication and Heat Pasteurization on Titrable acidity, TSS, pH of Nagpur mandarin juice**

NOTATION	TREATMENTS	TITRABLE ACIDITY	TSS (%)	pH

<b>T<sub>0</sub></b>	Control	0.543	8.67	4.06
<b>T<sub>1</sub></b>	Thermosonication at 50 °C for 25 min at 40 kHz frequency	0.577	8.57	4.19
<b>T<sub>2</sub></b>	Thermosonication at 55 °C for 20 min at 40 kHz frequency	0.593	8.55	4.19
<b>T<sub>3</sub></b>	Thermosonication at 60 °C for 15 min at 40 kHz frequency	0.521	8.83	4.11
<b>T<sub>4</sub></b>	Thermosonication at 63 °C for 10 min at 40 kHz frequency	0.561	8.6	4.11
<b>T<sub>5</sub></b>	Heat Pasteurization at 65 °C for 80 sec	0.628	8.73	4.14
<b>T<sub>6</sub></b>	Heat Pasteurization at 75 °C for 60 sec	0.566	8.77	4.13
<b>T<sub>7</sub></b>	Heat Pasteurization at 85 °C for 40 sec	0.614	8.83	4.10
<b>T<sub>8</sub></b>	Heat Pasteurization at 95 °C for 20 sec	0.552	8.93	4.06
	C.D.	N/A	N/A	N/A

### 3.2. Ascorbic Acid (Vitamin C): -

Ascorbic acid content is very important quality parameter of the juice. Data in table 2 revealed that various treatments exerted significant influence over the ascorbic acid content of juice after the treatment. Data presented in the table 2 recorded maximum ascorbic acid content (19.371 mg/100ml) under treatment T<sub>2</sub> (Thermosonication at 65°C for 20 min at 40 kHz frequency) which was statistically at par with T<sub>1</sub> (Thermosonication at 50 °C for 25 min at 40 kHz frequency) having the ascorbic acid content of 19.34 mg/100ml. The minimum ascorbic acid content (16.082 mg/100ml) of Vitamin C was recorded under treatment T<sub>8</sub> (Thermal Pasteurization at 95°C for 20 sec). In addition to these, maximum ascorbic acid content (18.014 mg/100ml) among thermally pasteurized treatment was observed under treatment T<sub>5</sub> (Heat Pasteurization at 65 °C for 80 sec).

Ascorbic acid content is primarily related to the nutritional quality of orange juice (Zerdin *et al.*, 2003). A significant reduction in the ascorbic acid content has been recorded among the thermally pasteurized juice with maximum reduction of Ascorbic acid under treatment T<sub>8</sub> (Thermal Pasteurization at 95°C for 20 sec) and minimum ascorbic acid reduction was recorded under treatment T<sub>5</sub> (Heat Pasteurization at 65 °C for 80 sec). This shows that the loss of the ascorbic acid content increased with the increase in temperature from 65 °C and 95 °C. Similar result was also observed by Saeeduddin *et al.* (2015) in pear juice. According to Saeeduddin *et al.*, 2015 this trend in loss of ascorbic acid with increase of temperature for thermal pasteurization indicates the thermo-sensitivity of ascorbic acid. Ascorbic acid is thermolabile, photosensitive and prone to degradation due to various processing condition (Vieira *et al.*, 2000). Verbeyst *et al.*, (2012), have also studied the effect of matrix on the degradation of vitamin C during pasteurization. Thermal pasteurization can also cause ascorbic acid degradation by oxidation reaction in most fruit derivatives (Leskova *et al.*, 2006).

On the other hand, significant increase in ascorbic acid content was also recorded by thermosonication treatments but these treatments also showed decrease in the ascorbic acid content with the increase of temperature from 50 °C to 63 °C. Such increase in ascorbic acid content at lower ultrasound treatment and reduction with increase of thermosonication temperature has already been observed by Abid *et al.* (2014) on apple juice, Tiwari *et al.* (2009a), Tiwari *et al.* (2009b), Walking-riberio *et al.* (2009) in orange juice, Gardner *et al.* (2000), Rawson *et al.* (2011), and Spanos and wrolstad (1992.). Thus, sonication at mild temperature helps to

preserve some important nutritional components in the product (Martinez-flores *et al.* (2015)). The increase in the ascorbic acid is supposed to be due to the removal of dissolved oxygen from the juice (Knorr, Zenker, Heeinz & Lee, 2004, Aadil *et al.*, 2013, Cheng *et al.*, 2007). Oxygen is a critical factor affecting the stability of ascorbic acid (Solomon, Svanberg, & Sahlstrom, 1995). Higher temperature may induce the chemical decomposition of ascorbic acid at higher rates (Saeeduddin *et al.*, 2015). Ultrasonication degasses any liquid and the treatment favors retention of vitamin C in juice due to the removal of dissolved oxygen responsible for vitamin C degradation (Saeeduddin *et al.*, 2015).

The data recorded under present investigation are in accordance with Saeeduddin *et al.* (2015) in pear juice, Bhat *et al.* (2011) in kasturi lime & Cheng *et al.* (2007) in guava juice. Dias *et al.* (2015) on sour soap, Aadil *et al.* (2013) in grapefruit juice, Abid *et al.* (2013) in apple juice, Santhiradegaram *et al.* (2013) in chokanan mango juice, Nayak *et al.* (2018) in star fruit juice & Guerrouj *et al.* (2014) in orange juice.

In contrast, Cao *et al.* (2019), in barbery juice, has observed a decrease in the ascorbic acid content of the ultrasound treated samples as compared to control. similar results were also observed by Adekunte *et al.* (2010) in tomato juice. The loss was attributed to sonochemical reaction and extreme physical condition occurring during sonication. It has been seen that the hydrogen ions ( $H^+$ ), free radicals ( $O^{\cdot}$ ,  $OH^{\cdot}$ ), and hydrogen peroxide ( $H_2O_2$ ) formed during the sonolysis of water molecule present in juice (Petrier, Combet, and Mason, 2007, Adekunte, *et al.*, 2010, Feril and Kondo, 2004). The degradation can also be related to oxidation reaction promoted by the interaction of hydroxyl radicals produced by cavitation during ultrasonic processing (Adekunte *et al.*, 2010).

### 3.3. Carotenoid

Carotenoid is a very important quality parameter in Nagpur Mandarin Juice. Results indicated that the carotenoid content of Nagpur mandarin juice was statistically significant. Data depicted in the table showed that the maximum carotenoid content (2.926 mg/100ml) was registered under treatment  $T_0$ , (Control), which was followed by Treatment  $T_3$  (Thermosonication at 60°C for 15 min at 40 kHz frequency), treatment  $T_2$  (Thermosonication at 55°C for 20 min at 20kHz frequency) and treatment  $T_6$  (Heat Pasteurization at 75 °C for 60 sec), having the carotenoid content 2.835, 2.721, and 2.671 mg/100 ml respectively. Whereas, the minimum carotenoid content (2.468 mg/100 ml) was registered under the treatment  $T_8$  (Heat Pasteurization at 95 °C for 20 sec). In addition to these, among thermosonication samples, the treatment  $T_3$  recorded highest carotenoid content (2.72 mg/100 ml), whereas, among thermally pasteurized samples, the treatment  $T_6$  recorded highest carotenoid content (2.671 mg/100 ml). It was observed that thermosonication samples registered higher carotenoid content after control as compared thermal pasteurization.

In the present study, significant decrease in the carotenoid content has been observed in the thermosonicated and thermally pasteurized samples of Nagpur mandarin juice as compared to control. However, it has also been observed that after control, thermosonicated samples showed higher carotene content as compared to thermal pasteurization. These might be attributed to the sonication treatment well known for extracting some components due to its disrupting effect on cell walls (Martinez-flores *et al.*, 2015). This may also be accounted to the mechanical disruption of cell wall, enhancing free carotenoid in the juice (Abid *et al.*,

2014). Similar results were also observed by Abid *et al.* (2013) in apple juice, Aadil *et al.* (2015) in grapefruit juice, Martinez-flores *et al.* (2015) in carrot juice, & Guerrouj *et al.* (2016) in orange juice where they observed higher carotene content in thermosonicated samples as compared to thermally pasteurized samples. In contrast, some other studies have also shown an increase in total carotenoid content, as in orange juice-milk beverage treated with high pressure (Barba *et al.* 2012). Similarly, increase in carotenoid content has also been seen in orange juice treated with high pressure as compared to pasteurized juice (Plaza *et al.* 2011).

### 3.4. Limonin

The data on table 2 presents limonin content as influenced by different thermosonication and thermal treatments of Nagpur mandarin juice, recorded after application of treatment. Nagpur mandarin juice treated with various treatments showed significant response to the limonin. The data presented for limonin in table 2 ranged between 7.121 ppm to 9.512 ppm. Data showed that the maximum value for limonin 9.512 ppm was record under treatment T<sub>8</sub> (Thermal Pasteurization at 95°C for 20 sec) which was found statistically at par with treatment T<sub>7</sub> (Heat Pasteurization at 85 °C for 40 sec), T<sub>6</sub> (Heat Pasteurization at 75 °C for 60 sec), T<sub>5</sub> (Thermal Pasteurization at 65°C for 80 sec) and T<sub>4</sub> (Thermosonication at 63 °C for 10 min at 40 kHz frequency) having the limonin 9.062 ppm, 9.046 ppm, 8.639 ppm and 8.465 ppm respectively. The minimum limonin content (7.121) was recorded under the treatment T<sub>1</sub> (Thermosonication at 50°C for 25 min at 40 kHz frequency).

Significant increase in limonin content in the thermally pasteurized juice samples has been observed as compared to untreated juice (Control). The increase in limonin content was more pronounced in treatment with higher processing temperature which may be attributed to its low solubility in water. Heating increases its concentration (Kefford 1959) and accelerate the conversion of non-bitter precursor,  $\alpha$ -limonin monolactone to limonin (Maier and Beverly 1968). Whereas low limonin content at low processing temperature may be attribute to the inhibition of oxidation of D-ring lactone into limonin It has also been studied that heat treatment and acidification of juice speedup the formation of limonin to the maximum level but does not change the maximum constant value (Zhang *et al.*, 2018).

### 3.5. Browning

The data obtained on Table 2 represented the significant influence of different treatments on the browning of Nagpur mandarin juice. The data depicted for browning of juice on table 2 ranged between 0.277 to 0.539. The data recorded maximum browning value (0.539) under treatment T<sub>8</sub> (Thermal Pasteurization at 95°C for 20 sec). Treatment T<sub>8</sub> was statistically at par with T<sub>4</sub> (Thermosonication at 63 °C for 10 min at 40 kHz frequency) and T<sub>3</sub> (Thermosonication at 60 °C for 15 min at 40 kHz frequency) having the browning value of 0.527 and 0.494 respectively. The minimum browning value 0.277 was recorded under treatment T<sub>0</sub> (Control).

Significant increase in browning has been observed in the thermosonicated as well as thermally pasteurized juice samples as compared to untreated juice sample (Control). It might be due to the increase in browning reaction with the increase in temperature because browning depends on ascorbic acid, reducing sugar and enzyme activity. similar findings were reported by (Ajandouz and puigserver, 1999, Quitao-Teixeira *et al.* 2008). Increase in NEB is due to sonication which may be attributed to the breakdown of the carotenoid

pigment. similar changes were also reported by Ugarte-Romero *et al.* (2006). Marcy *et al.* (1984) has observed that ascorbic acid degradation is also responsible for browning of citrus juices. This degradation of ascorbic acid has been observed due to application of thermal pasteurization under the present experiment. This has already been depicted in the table 2. Destruction of ascorbic acid provides reactive carbonyl groups, which can be precursor to non-enzymatic browning (Joslyn, 1951). Furfural formation resulting from the decomposition of ascorbic acid causes non enzymatic browning. Non enzymatic browning in orange juice has already been reported due to particulate fraction (Zarate-Rodriguez *et al.*, 2000).

The enzymatic discoloration is also responsible for the browning of juice which is caused by action of enzymatic browning, caused by the action of polyphenol oxidase (PPO) which catalyzes the oxidation of phenolic compounds (Joslyn *et al.*, 1951) and pectin methylesterase (PME). As thermal pasteurization inactivates the PME activity, browning in thermally pasteurized sample is not due to enzyme, but due to non-enzymatic biochemical reaction like millard condensation, pigment destruction and caramelization of sugar (Ibarz *et al.* 2000, & Landl *et al.* 2010). Similar process may also be related to the sonication treatment under present investigation which also inactivates the PME activity.

Various browning related studies based on  $A_{420nm}$  measurement in different juice like citrus juice (Saguy *et al.*, 1978), apple juice (Burdurlu & Karadeniz, 2003), pear juice (Ibarz, Pagan and Garza, 1999), and pear juice concentrate (Beveridge and Harision., 1984) have indicated that the non-enzymatic browning predominates over pigment destruction. The result recorded under the present experiment was in agreement with Tiwari *et al.* (2009) in orange juice, Aadil *et al.* (2015) in grapefruit juice, Lagnika *et al.* (2017) in pineapple juice, Cruz-casino *et al.* (2015) in purple cactus pear juice and Tiwari *et al.* (2008) in orange juice.

**Table 2: Effect of thermosonication on ascorbic acid, carotene, limonin & browning of Nagpur mandarin juice**

NOTATION	TREATMENTS	ASCORBIC ACID (mg/100ml)	CAROTENE (mg/100ml)	LIMONIN (ppm)	BROWNING (OD)
T <sub>0</sub>	Control	18.010	2.926	8.020	0.277
T <sub>1</sub>	Thermosonication at 50 °C for 25 min at 40 kHz frequency	19.349	2.651	7.121	0.413
T <sub>2</sub>	Thermosonication at 55 °C for 20 min at 40 kHz frequency	19.371	2.721	7.419	0.461
T <sub>3</sub>	Thermosonication at 60 °C for 15 min at 40 kHz frequency	18.610	2.835	7.641	0.494
T <sub>4</sub>	Thermosonication at 63 °C for 10 min at 40 kHz frequency	18.325	2.505	8.465	0.527
T <sub>5</sub>	Heat Pasteurization at	18.014	2.590	8.639	0.395

	65 °C for 80 sec				
<b>T<sub>6</sub></b>	Heat Pasteurization at 75 °C for 60 sec	17.222	2.671	9.046	0.424
<b>T<sub>7</sub></b>	Heat Pasteurization at 85 °C for 40 sec	16.741	2.546	9.062	0.464
<b>T<sub>8</sub></b>	Heat Pasteurization at 95 °C for 20 sec	16.082	2.468	9.512	0.539
	C.D.	0.676	0.139	1.218	0.049
	SE(m)	0.226	0.046	0.407	0.016

#### 4. CONCLUSION

Based on the results obtained in the present study, it is inferred that the application of thermosonication for the processing of Nagpur mandarin showed better physicochemical & biochemical quality characters as compared to thermal pasteurization. It can be concluded from the observation that thermosonication technique can be used as an alternative technique to thermal pasteurization for the processing of Nagpur mandarin juice to obtain a better physicochemical quality parameter. However, the behavior of different physicochemical parameter must be compared with thermally pasteurized juice during storage. These parameters need to be explored during the storage for production of a high-end value-added Nagpur mandarin juice.

#### REFERENCES

1. Aadil, R. M., Zeng, X., Abbasi, M. S., Khan, M. S., Khalid, S., Jabbar, S., and Abid, M. 2015. Influence of power ultrasound on the quality parameters of grapefruit juice during storage. *Science letters*, 3: 6-12.
2. Aadil, R. M., Zeng, X., Zhang, Z., Wang, M., Han, Z., Jing, H., and Jabbar, S. 2015. Thermosonication: a potential technique that influence the quality of grapefruit juice. *International Journal of Food Science and Technology*, 50: 1275-1282.
3. Abdullah, N., and Chin, N. L. 2014. Application of Thermosonication Treatment in Processing and Production of High Quality and Safe-to-Drink Fruit Juices. *Agriculture and Agricultural Science Procedia*, 2:320–327.
4. Abid, M., Jabbar, S., Hu, B., Hashim, M. M., Wu, T., Lei, S., Khan, M. A., and Zeng, X. 2014. Thermosonication as a potential quality enhancement technique of apple juice. *Ultrasonics Sonochemistry*, 21(3): 984–990.
5. Abid, M., Jabbar, S., Tao, W., Hashim, M. M., Hu, B., Lei, S., and Zeng, X. 2013. Sonication enhances polyphenolic compounds, sugars, carotenoids, and mineral elements of apple juice. *Ultrasonic Sonochemistry*, 21(1):93-97.

6. Adekunle, A.O., Tiwari, B. K., Cullen, P. J., Scannell, A. G. M., & Donell, C. P. O. 2010. Effect of sonication on color, ascorbic acid and yeast inactivation in tomato juice. *Food Chemistry*, 122: 500-507.
7. Ajandouz, E.H. and Puigserver, A. 1999. Nonenzymatic browning reaction of essential amino acids: effect of pH on caramelization and Maillard reaction kinetics. *Journal of Agricultural and Food Chemistry*, 47(5): 1786-1793.
8. Anaya-Esparza, L. M., Velázquez-Estrada, R. M., Roig, A. X., García-Galindo, H. S., Sayago-Ayerdi, S. G., & Montalvo-González, E. 2017. Thermosonication: An alternative processing for fruit and vegetable juices. *Trends in Food Science & Technology*, 61:26–37.
9. Barba, J. F., Cortés, C., Esteve, A. F. 2012. Study of antioxidant capacity and quality parameters in an orange juice–milk beverage after high-pressure processing treatment, *Food Bioprocess Technol*, 5: 2222–2232.
10. Beveridge, T. and Harrison, J.E., 1984. Nonenzymatic browning in pear juice concentrate at elevated temperatures. *Journal of Food Science*, 49(5): 1335-1336.
11. Bhat, R., Kamaruddin, N. S. B. C., Min-Tze, L., and Karim, A.A. 2011. Sonication improves kasturi lime (*Citrus microcarpa*) juice quality. *Ultrasonics sonochemistry*, 18:1295-1300.
12. Burdurlu, H.S. and Karadeniz, F., 2003. Effect of storage on nonenzymatic browning of apple juice concentrates. *Food chemistry*, 80(1): 91-97.
13. Cao, X., Cai, C., Wang, Y., & Zheng, X. 2019. Effect of ultrasound processing on physicochemical parameter, antioxidant, and color quality of barberry juice. *Journal of Food Quality*, 1 (1):12.
14. Carbonell, J. V., Contreras, P., Carbonell, L., & Navarro, J. L. 2006. Pectin methylesterase activity in juices from mandarins, oranges and hybrids. *European Food Research and Technology*, 222(1–2): 83–87.
15. Cheng, L.H., Soh, C.Y., Liew, S.C. and Teh, F.F., 2007. Effects of sonication and carbonation on guava juice quality. *Food chemistry*, 104(4): 1396-1401.
16. Cruz-Casino, N. D. S., Ramirez-Moreno, E., Leon-Rivera, J. E., Delgado-Olivares, L., Alanis-Garcia, E. Ariza-ortega, J. A., Manriquez-torres, J. D. J., and Jaramillo-Bustos, D. P. 2015. Shelf life, physicochemical, microbiological and antioxidant properties of purple cactus pear (*Opuntia ficus indica*) juice after thermoultrasound treatment. *Ultrasonics sonochemistry*, 27: 277-286.
17. Dias, D. D. R. C., Barros, Z. M. P., Carvalho, C. B. O. D., Honorato, F. A., Guerra, N. B., and Azoubel, P. M. 2015. “Effect of sonication on soursop juice quality,” *LWT—Food Science and Technology*, 1: 883– 889.
18. Feril, L.B. and Kondo, T. 2004. Biological effects of low intensity ultrasound: the mechanism involved, and its implications on therapy and on biosafety of ultrasound. *Journal of radiation research*, 45(4): 479-489.
19. Gardner, P.T., White, T.A., McPhail, D.B. and Duthie, G.G. 2000. The relative contributions of vitamin C, carotenoids and phenolics to the antioxidant potential of fruit juices. *Food chemistry*, 68(4): 471-474.
20. Gomez, K. A. and Gomez A. A. 1984. Statistical procedure for agricultural Research. Edn 2, John Wiley & sons Newyork : 241-271.

21. Guerrouj, K., Sanchez-Rubio, M., Taboada-Rodriguez, A., Cava-Roda, R. M., and Marin-Iniesta, F. 2016. Sonication at mid temperature enhances bioactive compound and microbiological quality of orange juice. *Food and Bioproducts processing*, 99:20-28.
22. Ibarz, A., Pagan, J. and Garza, S. 2000. Kinetic models of non- enzymatic browning in apple puree. *Journal of the Science of Food and Agriculture*, 80(8): 1162-1168.
23. Joslyn, M.A. and Ponting, J.D. 1951. Enzyme-catalyzed oxidative browning of fruit products. *Advances in Food Research*, 3: 1-44.
24. Kefford J. F. 1959. The chemical constituents of citrus fruits. *Advances in Food Research*, 9:351–352.
25. Lešková, E., Kubíková, J., Kováčíková, E., Košická, M., Porubská, J., & Holčíková, K. 2006. Vitamin losses: Retention during heat treatment and continual changes expressed by mathematical models. *Journal of Food Composition and analysis*, 19 (4): 252–276.
26. Maier V. P., Beverly G. D. 1968. Limonin monolactone, the non-bitter precursor responsible for delayed bitterness in certain citrus juices. *J Food Sci*, 33:488–492.
27. Marcy, J.E., Graumlich, T.R., Crandall, P.G. and Marshall, M.R. 1984. Factors affecting storage of orange concentrate. *Journal of food science*, 49(6), 1628-1629.
28. Martinez-flores, H. E., Garnica-Romo, M. G., Bermudez-Aguirre, D., Pokhrel, P. R., & Barbosa-canovas, G. V. 2015. Physico-chemical parameter, bioactive compounds and microbial quality of thermo-sonicated carrot juice during storage. *Food chemistry*, 172:650-656.
29. Nayak, P. K., Chandrasekar, C. M., & Kesavan, R. K. 2018. Effect of thermosonication on the quality attributes of star fruit juice. *Journal of Food Process Engineering*. e12857.
30. Ordonez-Santos, L. E., Martinez-Giron, J., & Arias-Jaramilo, M. E. 2017. Effect of ultrasound treatment on visual color, vitamin C, total phenols, and carotenoids content in cape gooseberry juice. *Food Chemistry*, 233: 96-100.
31. Plaza, L., Sanchez-Moreno, C., Ancos, B. D., Elez-Martinez, P., Martin-Belloso, O., and Cano, M. P. 2011. Carotenoid and flavanone content during refrigerated storage of orange juice processed by high-pressure, pulsed electric fields and low pasteurization, 44: 834-839.
32. Quitão-Teixeira, L.J., Aguiló-Aguayo, I., Ramos, A.M. and Martín-Belloso, O. 2008. Inactivation of oxidative enzymes by high-intensity pulsed electric field for retention of color in carrot juice. *Food and Bioprocess Technology*, 1(4): 364-373.
33. Rangana, S. 1986. *Handbook of analysis and quality control for fruit and vegetable products*. Tata McGraw Hills Pub, New Delhi, 23(1):346-369.
34. Rawson, A., Tiwari, B.K., Patras, A., Brunton, N., Brennan, C., Cullen, P.J. and O'donnell, C. 2011. Effect of thermosonication on bioactive compounds in watermelon juice. *Food Research International*, 44(5): 1168-1173.
35. Saeeduddin, M., Abid, M., Jabbar, S., Wu, T., Hashim, M. M., Awad, F. N., Hu, B., Lei, S., and Zeng, X. 2015. Quality assessment of pear juice under ultrasound and commercial pasteurization processing conditions. *Food Science and Technology*, 64:452-458.

36. Saguy, I., Kopelman, I.J. and Mizrahi, S. 1978. Extent of nonenzymatic browning in grapefruit juice during thermal and concentration processes: kinetics and prediction. *Journal of Food Processing and Preservation*, 2(3): 175-184.
37. Santhiradegaram, V., Razali, Z., and Somasundram, C. 2013. Effect of thermal treatment and sonication on quality attributes of chokanan mango (*Mangifera indica*) juice. *Ultrasonic sonochemistry*, 20: 1276-1282.
38. Spanos, G.A. and Wrolstad, R.E. 1992. Phenolics of apple, pear, and white grape juices and their changes with processing and storage. A review. *Journal of Agricultural and Food Chemistry*, 40(9): 1478-1487.
39. Ting, S.V. and Rouseff, R. L. 1986. Citrus Fruit and their products, analysis and technology. Florida Market Deccar. Chapter 5: 73-78.
40. Tiwari, B. K., Donnell, C. P. O., Muthukumarappan, K., and Cullen, P. J. 2009. Effect of sonication on orange juice quality parameters during storage. *International Journal of Food Science and Technology*, 44: 586-595.
41. Tiwari, B. K., Muthukumarappan, K., Donnell, C. P. O., & Cullen, P. J. 2008. Effect of sonication on the kinetics of orange juice quality parameters. *Journal of agricultural and food chemistry*, 56: 2423-2428.
42. Ugarte- Romero, E., Feng, H., Martin, S.E., Cadwallader, K.R. and Robinson, S.J. 2006. Inactivation of *Escherichia coli* with power ultrasound in apple cider. *Journal of food science*, 71(2): E102-E108.
43. Verbeyst, L., Bogaerts, R., Van der Plancken, I., Hendrickx, M. and Van Loey, A. 2013. Modelling of vitamin C degradation during thermal and high-pressure treatments of red fruit. *Food and Bioprocess Technology*, 6(4): 1015-1023.
44. Vieira, M. C., Teixeira, A. A., and Silva, C. L. M. 2000. Mathematical modeling of the thermal degradation kinetics of vitamin C in cupuacu (*Theobroma grandiflorum*) nectar. *Journal of Food Engineering*, 43: 1-7.
45. Walkling-Ribeiro, M., Noci, F., Cronin, D.A., Lyng, J.G. and Morgan, D.J. 2009. Shelf life and sensory evaluation of orange juice after exposure to thermosonication and pulsed electric fields. *Food and Bioprocess Technology*, 87(2): 102-107.
46. Zárate- Rodríguez, E., Ortega- Rivas, E. and Barbosa- Cánovas, G.V. 2000. Quality changes in apple juice as related to nonthermal processing. *Journal of Food Quality*, 23(3): 337-349.
47. Zerdin, K., Rooney, M. L., Vermue, J. 2003. The vitamin C content of orange juice packed in an oxygen scavenger material. *Food Chem.* 82: 387-395.