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Effect of thickness on quality of tomato slices subjected to radio frequency assisted blanching

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Abstract
This study investigated the effect of thickness (3, 6 and 10 mm) on quality of tomato slices that were treated with a radio frequency (RF) radiation. Thickness, electrode gap and temperature ($P<0.05$) all had their significant effect on product quality. The 3mm thickness tomato slices had higher rates of PPO enzyme inactivation and moisture content reduction compared with 6mm and 10mm thickness. The results showed that the relative enzyme activity of PPO reduced from 43.57% to 3.17% after RF treatment at 85°C and 180mm electrode height. The colour and texture of the sample was maintained well despite the decrease in moisture content. Thickness had no significant effect on the colour and texture of the tomato slices. The lycopene and total carotenoid content were enriched twice the amount. The higher lycopene and total carotenoids content of 11.371±0.76 mg and 16±0.82 mg were observed for 3 mm thickness, 180 mm electrode height and 85°C temperature.

Keywords: Tomato; thickness; electrode height; temperature; radio frequency

1. Introduction

Tomato (*Solanum lycopersicum*) is a flowering plant widely cultivated for its edible fruit. Tomato fruits (labelled as vegetable) are berries with diameter ranging from 1.5 to 7.5 cm. In 2017, the worldwide production of tomatoes was 170.8 million tons. China as the leading producer followed by India and the United States with the second and third highest production of tomatoes in the world. Tomatoes are the fourth most widely consumed vegetable worldwide with India being the most frequently consumed. A large proportion of produced tomatoes are used for the day to day consumption. Another large percentage of the tomatoes are used for processing of tomato ketchup, puree, tomato juice and canned tomatoes. Both fresh and processed tomato possesses a high nutritional value, due to its content of vitamins, carotenoids, folates and phenolic compounds (Savatovic *et al.*, 2010). Lycopene is the abundant carotenoid present in the tomato and the other carotenoids α-, β-, γ-, δ-carotene, phytoene, phytofluene and lutein are also present (Savatovic *et al.*, 2010).

Usually enzymatic activity in the tomato causes quality deterioration reactions like undesirable colour and taste, bad odour, off flavour with loss of nutrients. The enzyme Polyphenol Oxidase (PPO), a metalloprotein containing copper, catalyses the enzymatic browning of damaged tissues of fruits and vegetables (Queiroz *et al.*, 2008) [17]. Naturally PPO is predominantly present in the chloroplast of thylakoid membranes and phenolic substances are found in vacuoles, upon cell damage, these enzymes readily react with substrate which leads to oxidation of phenols (Spagna *et al.*, 2005) [22]. Hence, it is important to inhibit the enzymatic activity which is the challenging task in food processing and preservation. PPO activity can be inhibited using amino acids, ascorbic acid and sulphites (Altunkaya and Gokmen, 2008; Ali *et al.*, 2016; Siddiq & Dolan., 2017) [3, 21]. As the chemicals pose a threat to human health, thermal treatment is one of the effective technique used for controlling browning reactions caused by enzymatic reactions. Other methods like hot water, steam heating and novel methods such as infrared (IR), microwave (MW), ohmic heating and radio frequency have been applied for blanching of fruits and vegetables.

Blanching is one of the important unit operation carried out prior to canning, drying and freezing in which vegetables or fruits are heated for the purpose of inactivating the biochemical enzymes, modifying the texture, preserving the colour, texture and nutritional value along with removing trapped air (Jose *et al.*, 2004). Radio frequency heating is an innovative technique used for blanching, which has the ability to provide high quality foods and is based on the electromagnetic heating. RF heating can be used in the food applications for its characteristics features like higher penetration depth, volumetric heat distribution and low energy consumption. The RF spectrum range lies in the range of 1 to 300 MHz. The industrial usage frequencies range lies between 10 – 50 MHz (Tribst *et al.*, 2016) [24]. The amount of heat generated in the product is determined by the frequency, the square of the applied voltage, dimensions of the product and the dielectric loss factor of the material, which is essentially a measure of the ease with which the material can be heated by RF. RF power is produced when electricity is applied to an RF generator whose signal is amplified and delivered to a parallel electrode system (RF cavity), in which the selected material is placed.

Radio frequency heating has the ability to modify the protein structure and inactivate the enzymes (peroxidase, polyphenolase, pectin esterase, catalase and PPO) and has been reported by different researchers (Manzocco *et al.*, 2008; Lopez and Baganis, 2010; Guo *et al.*, 2017) [13, 12, 10]. Manzocco *et al.*, (2008) [13] reported that RF had a significant quality retention in apples in comparison to conventional blanching methods. Zhang *et al.*, (2018) [28] observed reduction of relative activity of potato PPO to less than 10 % with temperature increase from 25-85ºC. Similar results of reduction in peroxidase activity in carrot was observed by Gong *et al.*, (2019) [9] with better colour, texture and vitamin C content.

Although many studies are available on the application of RF heating as blanching for different fruits and vegetables, use of RF heating for blanching has not yet been investigated. In this study, the objective was to investigate the effect of thickness on tomato slices under RF assisted blanching and further to determine the optimum RF blanching conditions with high product quality.

2. Material and Methods

2.1 Materials and preparation

Tomatoes (*Solanum lycopersicum*) were procured from the local market of Thanjavur, Tamil Nadu, India. Good quality fresh, firm and ripened tomatoes were selected. The tomatoes were washed and sliced into the thickness of 3, 6 and 10 mm using a vegetable slicer.

2.2 Radio frequency heating system

RF assisted blanching was performed by a pilot scale free running oscillator RF system (No: 12109, Lakshmi RF Sterilizer, Lakshmi Card Clothing Mfg. Co. Pvt. Ltd). The system includes a RF generator and RF applicators with two rectangular electrodes placed side by side. The samples to be treated are kept under these electrodes and the high voltage alternating electric field is applied. All the experiments are repeated thrice. In RF system the parameters are taken for consideration is electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85 ºC). The conveyor speed is maintained at 10m/h. After the treatment, the treated tomato slices are studied for its quality. The process characteristics such as moisture content reduction and polyphenol oxidase (PPO) activity were studied. The quality characteristics, texture, colour, lycopene content and total carotenoids were also determined.

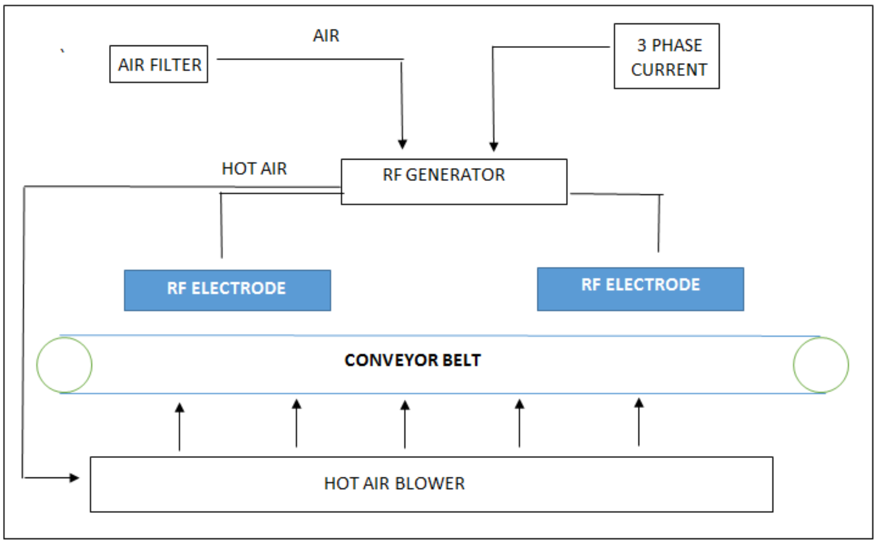

Fig 1: Schematic diagram of the radio frequency heating system

2.3 Moisture content

The moisture content of tomato slices was analysed to evaluate the loss of water excluded from the samples during RF heating pre-treatment. The tomato slices were weighed prior to RF pre-treatment. Immediately after RF blanching, the samples were taken out quickly and brought back to room temperature by keeping it in a desiccator. The weight of the treated tomato slices was weighed again. The results were presented as per Eq. (1):

$$\text{Moisture Content (\%)} = [(W0 - W1\,/W0) * 100] \text{ ---- (1)}$$

Where W_0 is initial weight of the samples untreated, W_1 is the weight of treated samples.

2.4 Texture measurement

The texture of the treated and non-treated tomato slice samples was determined at room temperature in texture profile analyser (TA HD Plus: Stable Microsystems) equipped with a 50 kg load cell. For puncture tests, the tomato slices were punctured on the stainless steel platform with a 2 mm diameter cylinder probe, at a rate of 2 mm/s. Each sample was punctured at three different positions and the mean value was measured.

2.5 Color measurement

The surface color of the non-treated and treated samples were measured using Hunter Colour Lab colorimeter (Model: Colour Quest XE, USA). Hunter L^*, a^*, b^* are color scales based on opponent colour theory. This theory assumes that the receptors in the human eye perceive color as the following pair of opposites. The L value for each scale indicates the level of light or dark, the a^* value redness or greenness, and the b^* value yellowness or blueness. All three values are required to completely describe an object color. The samples are placed over the eye of the CIELAB and the L^*, a^*, b^* values were measured for the samples. The colour difference is calculated using equation in terms of ΔE^*(Francis and Clydesdale., 1975).

$$\Delta E^* = [(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)]^{1/2} \text{-----------}(2)$$

Where L_0^*, a_0^*, b_0^* are the colour parameters of the untreated control sample.

2.6 PPO enzyme extraction and activity assay

Tomato PPO was extracted according to the methodology followed by Zhang *et al*., (2018) [28]. 40 ml cold phosphate buffer of 0.1M pH 6.5 is added to 20g mashed sample. The mixture was homogenized for 3 minutes by a digital high speed dispersing homogenizer. Subsequently the homogenized samples were centrifuged at 10,000 rpm, 4°C for 25 minutes. The supernatant is the crude enzyme extract used to determine the PPO activity. The crude extract is stored for 2 hours at 4°C prior to enzyme activity evaluation. The phosphate buffer of 0.1M, pH 5.5 and catechol of 0.2M were incubated at 25°C for 10 minutes prior to assay. The reaction mixture was composed of 1.5 mL phosphate buffer and 1 mL catechol. Then 0.5 mL crude PPO extract was added to the reaction mixture. Phosphate buffer was used as the blank to replace the enzyme extract. The PPO activity was assessed by spectrophotometer at 410nm. The absorbance was measured every 30 s for a total of 2 min. One unit of enzyme activity was defined as the amount of enzyme required to increase the absorbance by 0.001 per min under the assay conditions. The relative enzyme activity (REA) was calculated according to Eq. (3)

$$\text{REA (enzyme activity treated / enzyme activity native)} * 100 \text{-------} (3)$$

2.7 Lycopene estimation

Lycopene is a pigment responsible for the red color of tomato. Amount of lycopene present in the treated and non-treated samples are estimated (AOAC, 2000). 5-10g of mashed tomato pulp is taken and is extracted repeatedly with acetone until the residue is colourless. The acetone extract is transferred to the separating funnel containing 20ml petroleum ether and mixed gently. 20ml of 5% sodium sulphate solution is also added and separating funnel is continuously shaken gently. Most of the colour will be noticed in the upper petroleum ether layer. The two phases are separated and the lower aqueous phase is re-extracted with additional 20ml petroleum ether. The petroleum ether extracts are collected and washed with distilled water. Pour the liquids containing carotenoids into the bottle containing 10g anhydrous sodium sulphate. Keep it aside for 30 min. Decant the petroleum ether extract into 100ml volumetric flask through a funnel containing cotton wool. Measure the absorbance in a spectrophotometer at 503nm using petroleum ether as blank. The lycopene content in the sample can be calculated according to Eq. (4)

$$\text{Lycopene (mg)} = (31.206 * \text{Absorbance}) / \text{Weight of the Sample} \text{ -- } (4)$$

Where, Absorbance (1 unit) = 3.1206 µg lycopene/ml

2.8 Total carotenoids estimation

Amount of carotene present in the treated and non-treated samples are evaluated by method of Fish *et al*., (2012) [7]. 5-10g of mashed tomato pulp is taken. The sample is homogenized by homogenizer at low speed. Sample is taken in centrifuge tube and extracted with HPLC grade solvents of 10mL of hexane, 5 mL of ethanol, and 5 mL of acetone containing 0.05% butylated hydroxyl toluene. Samples were tightly sealed and placed on an orbital shaker for 15 min at 320 rpm, and then 3 mL of distilled water was added and samples were shaken again for 5-10 min. Afterwards, samples were put in a rack to allow solvent phase separation. Read the absorbance at 450nm.

$$\text{Total carotenoid} = (\text{absorbance @ 450nm} * V * 10000) / (\text{A\%1 1cm x amount of sample}) \text{ - (5)}$$

Where, V= 10 ml because of hexane layer is used,
A%1 1 cm=absorption coefficient = 2500 for total carotenoid.

2.9 Data analysis

All experiments were done in triplicates. The significant effects of the treatment were analysed by a one-way Analysis of Variance (ANOVA) using SPSS 20.0 (SPSS Inc., USA). This was followed by Tukey, multiple comparison test. The results are expressed at 95% significance level with P-values to identify the differences or similarities of different treatments.

3. Results and Discussion

The observations of the effect of thickness on tomato slices treated with radio frequency (RF) radiation are presented in Table 1. The process characteristics such as moisture content reduction and polyphenol oxidase (PPO) activity were studied. The quality characteristics, texture, colour, lycopene content and total carotenoids were also determined.

Table 1: Moisture content, firmness, colour, relatie enzyme activity of PPO, lycopene content and total carotenoid content values (mean ± SD) of RF pretreated (Blanched) tomato slices

Thickness	Electrode Height	Temperature	Moisture Content (%)	Firmness	Colour				Relative Enzyme Activity (%)	Lycopene Content (mg)	Total Carotenoids Content (mg)
					L*	a*	b*	ΔE			
Control			96.69±0.573^{m}	0.2647±0.003^{q}	43.57± 0.74^{l}	30.42±0.68^{b}	29.88±0.85^{l}	-	43.57±0.80^{mt}	3.472±0.59^{a}	5.344±0.47^{a}
3mm	180mm	65°C	88.723±0.218^{fg}	0.2555± 0.003^{no}	35.07±1.2^{bcd}	28.23±0.58^{b}	28.23±0.58^{b}	18.67±0.47^{bcd}	28.34±0.93^{k}	5.8±0.38^{c}	7.412±0.53^{f}
		75°C	87.697±0.239^{efg}	0.2512±0.003^{bcdefg}	34.27±0.90^{ab}	27.35±0.83^{ab}	27.35±0.83^{ab}	29.35±0.53^{ab}	14.26±0.89^{f}	9.711±0.65^{k}	11.556±0.76^{j}
		85°C	84.331±0.164^{abc}	0.2424±0.003^{a}	33.01±0.56^{a}	27.03±0.48^{a}	27.03±0.48^{a}	52.12±0.72^{a}	3.17±0.87^{a}	11.37±0.76^{m}	16±0.82^{p}
	190mm	65°C	89.576±0.122^{def}	0.2522±0.002^{efghijk}	38.36±0.74^{fgh}	29.4±0.65^{b}	29.4±0.65^{b}	15.92±0.48^{fgh}	31±0.91^{o}	4.522±0.42^{b}	7.092±0.69^{ef}
		75°C	87.658±0.233^{bc}	0.2521±0.005^{defghij}	36.39± 0.49^{cde}	29.35±0.73^{b}	29.35±0.73^{b}	23.613±0.84^{cde}	17.45±0.75^{g}	8.781±0.36^{ij}	11.144±0.74^{j}
		85°C	86.46±0.269^{eijk}	0.2504±0.006^{bc}	39.46±0.98^{hij}	28.01±0.59^{b}	28.01±0.59^{b}	39.51±0.83^{hij}	4.50±0.76^{a}	9.158±0.59^{k}	14.964±0.28^{n}
	200mm	65°C	89.64±0.241^{abf}	0.2479±0.002^{a}	41.44±0.63^{kl}	29.64±0.23^{b}	29.64±0.23^{b}	4.988±0.56^{kl}	34±0.59^{p}	3.881±0.24^{a}	6.848±0.58^{de}

		75°C	88.433±0.265^{afg}	0.2548±0.002^{mn}	37.7±1.12^{defg}	29.7±0.89^{b}	29.7±0.89^{b}	11.18±0.85^{defg}	19.6±0.86^{h}	6.591±0.76^{def}	10.664±0.65^{i}
		85°C	87.000±0.081^{befg}	0.2576±0.001^{op}	39.68±0.95^{hij}	27.73±0.58^{ab}	27.73±0.58^{ab}	19.49±0.76^{hij}	6.35±0.88^{c}	7.228±0.52^{fg}	14.084±0.80^{lm}
6mm	180mm	65°C	90.01±0.538^{afg}	0.2538±0.003^{jklm}	41.4±0.88^{jk}	28.79±0.86^{b}	28.79±0.86^{b}	11.28±0.49^{jk}	29±0.69^{n}	5.186±0.65^{c}	7.088±0.59^{ef}
		75°C	88.246±0.153^{bfg}	0.2533±0.006^{ijklm}	40.32±0.76^{hijk}	28.71±0.65^{b}	28.71±0.65^{b}	12.62±0.74^{hijk}	15.8±0.93^{f}	9.393±0.54^{jk}	10.572±0.65^{hi}
		85°C	86.293±0.205^{bc}	0.2497±0.007^{b}	34.96±0.56^{bc}	27.72±0.73^{ab}	27.72±0.73^{ab}	38.82±0.73^{bc}	3.9±0.87^{a}	10.154±0.86^{l}	15.436±0.71^{o}
	190mm	65°C	90.794±0.507^{jk}	0.2525±0.003^{fghijkl}	41.8±0.98^{kl}	29.24±0.34^{b}	29.24±0.34^{b}	4.53±0.55^{kl}	33.82±0.92^{p}	3.857±0.39^{a}	6.448±0.49^{c}
		75°C	87.363±0.385^{efg}	0.2515±0.002^{cdef}	40.09±0.87^{hijk}	28.2±0.47b	28.2±0.47^{b}	19.43±0.66^{hijk}	20.78±0.84^{i}	7.236±0.67^{gh}	10.892±0.74^{i}
		85°C	86.336±0.37^{bcd}	0.2539±0.005^{klmn}	35.03±1.09^{bcd}	28.13±0.94b	28.13±0.94^{b}	42.29±0.59^{bcd}	5.67±0.43^{bc}	8.16±0.74^{hi}	14.744±0.54^{mn}
	200mm	65°C	89.667±0.372^{e}	0.2528±0.003^{ghijkl}	41.25±0.77^{jk}	30.23±0.85^{b}	30.23±0.85^{b}	8.07±0.86^{jk}	39±0.65^{r}	3.794±0.48^{b}	6.304±0.85^{cd}
		75°C	86.113±0.356^{cfg}	0.2545±0.005^{mn}	39.06±0.89^{ghi}	29.13±0.39^{b}	29.13±0.39^{b}	14.18±0.72^{ghi}	22.41±0.76^{j}	6.625±0.73^{de}	10.004±0.66^{h}
		85°C	85.783±0.167^{efg}	0.2573±0.002^{p}	37.14±0.69^{cdef}	28.49±0.58^{b}	28.49±0.58^{b}	24.14±0.63^{cdef}	7.72±0.64^{d}	7.134±0.67^{fg}	13.912±0.73^{l}
10mm	180mm	65°C	90.367±0.309^{eg}	0.2512±0.004^{bcdefg}	40.16±0.78^{jk}	29.7±0.59^{b}	29.7±0.59^{b}	15.15±0.74^{jk}	32±0.56^{o}	4.499±0.69^{bc}	6.164±0.45^{c}
		75°C	89.865±0.436^{g}	0.2505±0.002^{bcde}	39.63±0.86^{hij}	28.14±0.75^{b}	28.14±0.75^{b}	13.59±0.83^{hij}	22.54±0.81^{j}	9.106±0.53^{jk}	9.124±0.87^{g}
		85°C	88.609±0.291^{efg}	0.2503±0.002^{bcd}	35.94±0.91^{bcde}	27.66±0.69^{ab}	27.66±0.69^{ab}	24.24±0.65^{bcde}	4.21±0.68^{ab}	9.945±0.76^{kl}	14.484±0.56^{mn}
	190mm	65°C	91.253±0.548^{jk}	0.2541±0.003^{lmn}	41.71±1.02^{jk}	29.01±1.0^{b}	29.01±1.0^{b}	6.31±0.78^{jk}	36±0.85^{q}	3.564±0.85^{a}	6.012±0.65^{bc}
		75°C	90.517±0.364^{fg}	0.2518±0.001^{cdefgh}	39.28±0.80^{hij}	28.43±0.98^{b}	28.43±0.98^{b}	18.94±0.58^{hij}	25.67±0.87^{k}	6.603±0.48^{def}	10.568±0.48^{i}
		85°C	89.286±0.358^{de}	0.2503±0.001^{bcd}	37.53±0.78^{efg}	28.25±0.73^{b}	28.25±0.73^{b}	26.67±0.75^{efg}	7.5±0.49^{d}	7.214±0.72^{efg}	14.276±0.73^{lm}
	200mm	65°C	92.616±0.145^{kl}	0.2600±0.001^{q}	41.88±0.58^{kl}	29.74±0.80^{b}	29.74±0.80^{b}	6.69±0.67^{kl}	40.12±0.62^{s}	3.785±0.82^{a}	5.648±0.81^{ab}
		75°C	91.869±0.145^{hijk}	0.2528±0.002^{hijklm}	40.55±0.87^{ijk}	29.45±0.92^{b}	29.45±0.92^{b}	9.72±0.93^{ijk}	27±0.52^{l}	6.244±0.43^{d}	9.112±0.48g
		85°C	90.891±0.301^{bcd}	0.2509±0.003^{bcdef}	38.47±0.91^{gh}	28.54±0.88^{b}	28.54±0.88^{b}	26.13±0.63^{gh}	9.2±0.78^{e}	6.603±0.79^{defg}	13.068±0.63^{k}

(Different letters in the same column indicate a significant differences (P < .05) among control and blanched samples using RF heating.)

3.1 Effect of RF heating on moisture content

The change in moisture content of tomato slices with different thicknesses are presented in figure 2. From the graph it was clear that the treated samples of all thickness had different level of weight loss. There were significant differences on weight loss of the sample at different electrode gaps and temperatures ($P<0.05$). The weight loss increased with increasing temperature. Thickness also had a significant effect on the moisture loss of tomatoes. The moisture loss was higher in the 3mm thickness at all electrode heights and temperatures. Maximum weight loss was observed in 3mm thickness of tomato slice at 180mm electrode height and 85 °C combination. Hence this shows lower the thickness so higher the moisture loss. This result was attributed to cellular damage causing water evaporation and nutrient outflow that increases with increase in blanching temperatures during the process. This result was in trend with a study that showed that the potatoes of lower thickness had higher moisture loss compared with higher thickness during IR- blanching of potato slices (Wu *et al.*, 2018) [27]. Also RF heating may have effect on the microstructure of the tomato. Zhang *et al.*, (2018) [28] observed destruction of microstructure of potato with increase in temperature and thereby releasing more moisture. Similar observation of higher moisture loss in carrot with RF treatment was reported by Gong *et al.*, (2019) [9]. On comparison with other blanching methods like steam blanching and PEF treatments, RF heating showed a considerable higher values of weight loss (Mukherjee *et al.*, 2007; Ignat *et al.*, 2015) [15, 11].

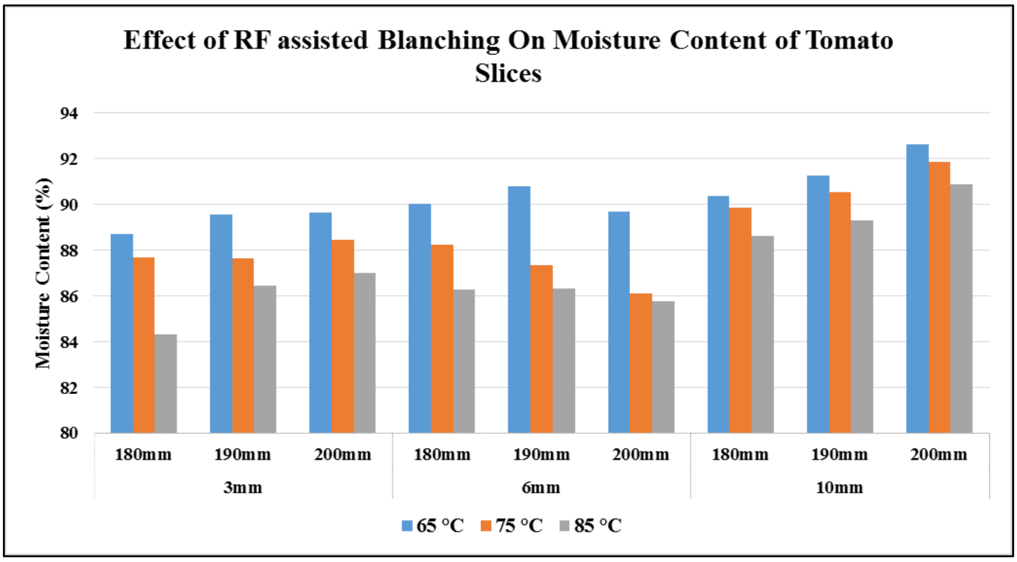

Fig 2: Effect of RF Blanching on moisture content of tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

3.2 Effect of RF pre-treatment (blanching) on texture

Temperature had significant effects (P < .05) on firmness. The statistical analysis shows that the thickness of samples and electrode height had no significant effect on the firmness of the treated samples. Under the same thickness and electrode gap, firmness of RF treated samples decreased with increasing temperature (Fig 3). This phenomenon was resulted from water loss which directly reduced turgor pressure (Rocculi *et al.*, 2009) [19]. Under all thickness and electrode gaps, the change of firmness was comparatively higher at 85°C than of 65°C and 75 °C irrespective of thickness. Overall change in firmness was less than 20% due to which the texture of the tomato slices was maintained to a major extent (Zhang *et al.*, 2018) [28]. This trend is consistent with that obtained by Abu-Ghannam and Crowley. (2006) [1]. However, the texture degraded rapidly when temperature was above 95°C. The results showed that RF heating had significant effect on the texture of tomato slices.

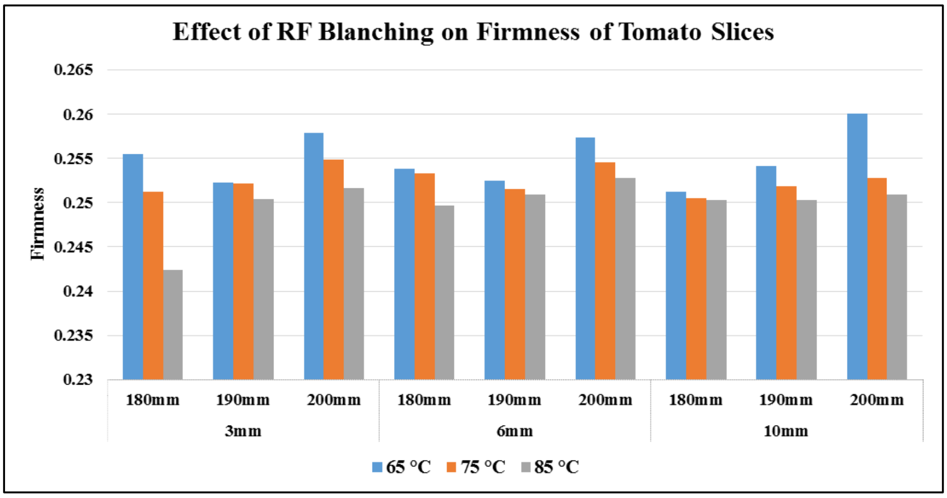

Fig 3: Effect of RF blanching on firmness of tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

3.3 Effect of RF pre-treatment (blanching) on colour

The parameters electrode gap and temperature had a significant effect (P < .05) on the value of *L**, *a**, *b**. In terms of thickness there was no significant effect. The increase in thickness had negligible effect on the colour of the treated samples (Fig 4). The value of *L** and *a** decreased with increasing temperature for all thickness. This phenomenon was probably due to cell collapse and liquid release leading to a lower reflectance. The decrease in *a** value is not more than 12% after the treatment which shows that the radiofrequency pre-treatment does not affect the colour of the tomato slices to the major extent. Zhang *et al*., (2018) [28] conducted similar type of study where potato cuboids were subjected to radio frequency heating, the value of *L** and *b** decreased with increasing temperature. Similar studies were reported in Peruvian carrot and cocoyam, showing that high pressure processing induced a decrease in both L∗ and b∗ values (Tribst *et al*., 2016) [24]. Hence this RF Heating can be used as pre-treatment for blanching of tomato slices.

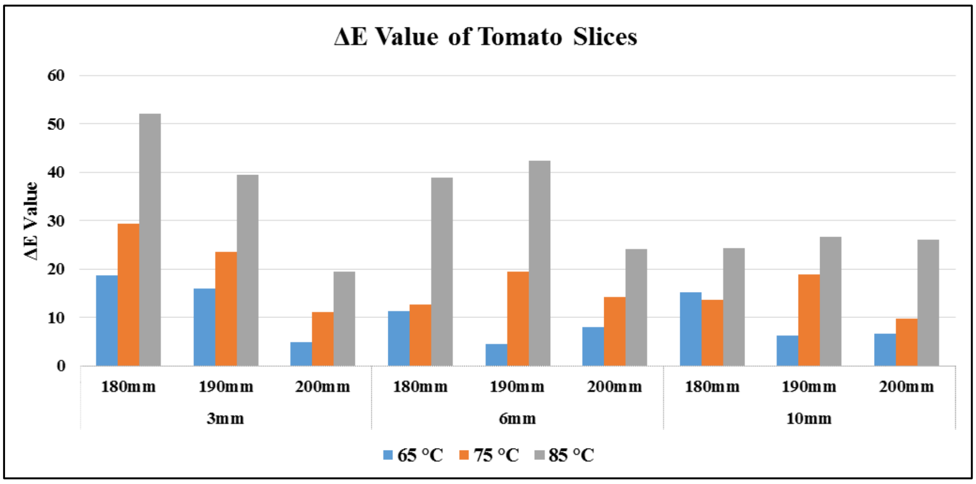

Fig 4: ΔE Value of the Tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

3.4 Effect of RF pre-treatment (blanching) on PPO Enzyme Activity

The thickness, electrode gap and the temperatures had significant effect (*P*<0.5) on the PPO activity as shown in figure 5. The tomato slices showed lowest relative activity of PPO at thickness of 3 mm, electrode gap of 180 mm when compared with 190 mm and 200 mm at the same final temperatures. The relative activity of PPO decreased with increase in the temperature. The PPO relative activity was only 3.17 % after the treatment for 3 mm thickness of tomato slice at 180mm electrode height and 85°C blanching temperature. This result was in agreement with the previous study which shows PPO relative activity of mushroom decreased with increase in temperature from 50 to 70°C at all electrode gaps (Zhang *et al*., 2018) [28]. The result can be attributed to the minimum thickness of the tomato slice at which the relative enzyme activity is low. However, there was significant variations between different blanching methods for inactivation of PPO. Terfe *et al*., (2010) reported that only 28% inactivation of strawberry PPO after 30 min treatment at 100 °C. Castro *et al*., (2008) [4] and Queiroz *et al*., (2008) [17] found that both green pepper and red pepper PPO had more than 50% activity subjected to thermal treatment at 80 °C with 2 min. Wang *et al*., (2017) [26] explored that the residual activity of red bell pepper PPO was 9.80% blanched at high microwave power (900 W) for 100 s. These studies indicated that the stability of PPO depended on source, variety, physicochemical components and also explained that RF heating had a great potential on inactivating PPO for blanching of vegetables and fruits.

Thickness of the tomato slices had an impact on the reduction of the PPO content during the treatment. The tomato slice of

3mm thickness had comparatively higher PPO inactivation. The slice of lower thickness have higher surface area so higher the effect of treatment. A study also revealed that the thin slices of potato samples had higher inactivation of PPO (Wu *et al*., 2018) [27]. From all these studies it was found that the PPO stability depends upon the variety, source and physicochemical component. It is also inferred that RF heating can be used as blanching treatment due to its great potential for inactivating PPO of fruits and vegetables. The vegetables of minimum thinness can be taken for treating in RF blanching to get the higher PPO inactivation.

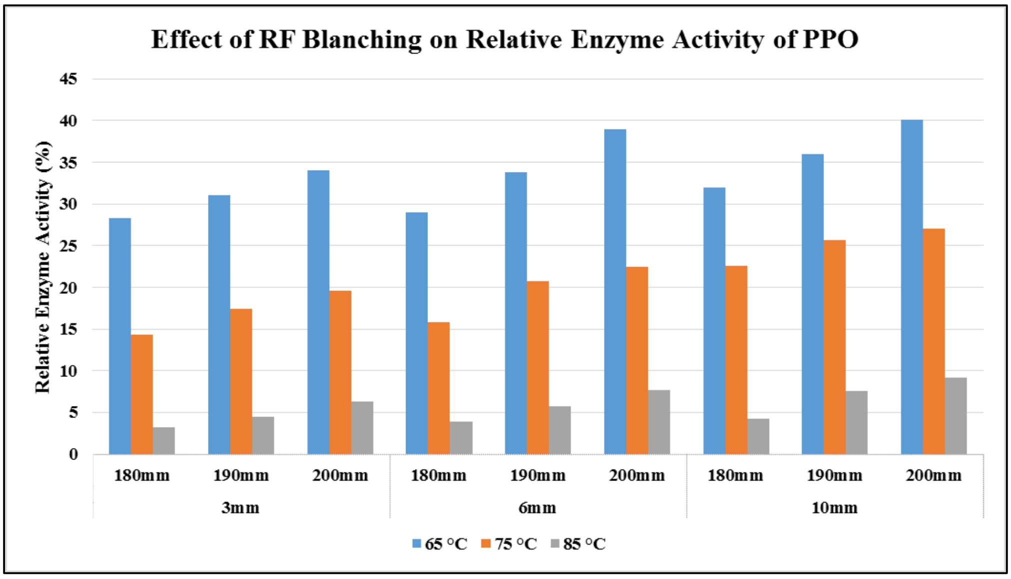

Fig 5: Effect of RF Blanching on relative enzyme activity of PPO of tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

3.5 Effect of RF pre-treatment (blanching) on lycopene content

The amount of lycopene in control and treated samples of tomato slices are presented in the fig.6. It is found that the thickness, electrode height and temperature had significant effect ($P<0.05$) on the samples. The thickness of the sample plays a significant role during the treatment. The tomato slices of minimum (3 mm) thickness has more surface area thus more lycopene enrichment. The 3mm tomato slice at 180mm electrode height and 85°C temperature showed higher lycopene content after the RF treatment. Data from the present study shows that the lycopene content of the blanched slices were found to be higher than the non-blanched tomato slices. The study shows that the 3 mm thickness samples treated with 180 mm electrode height and 85°C temperature showed highest amount of lycopene which is nearly 2 times that of non-treated sample. The increase in lycopene content is mainly attributed to the blanching process, thus at this blanching temperatures the lycopene content of the samples is enriched. Similar study by Urbonaviciene *et al*., (2012) [25] showed that the blanched tomato peels had twice the amount of lycopene content when compared with non-blanched tomato peels. Among the carotenoids the lycopene exhibits the highest antioxidant activity, so this RF pre-treatment method can be used as blanching process to enrich the naturally occurring lycopene content of the tomato slices. The tomato slices of minimum thinness can be taken for treating in RF to get the higher lycopene enrichment.

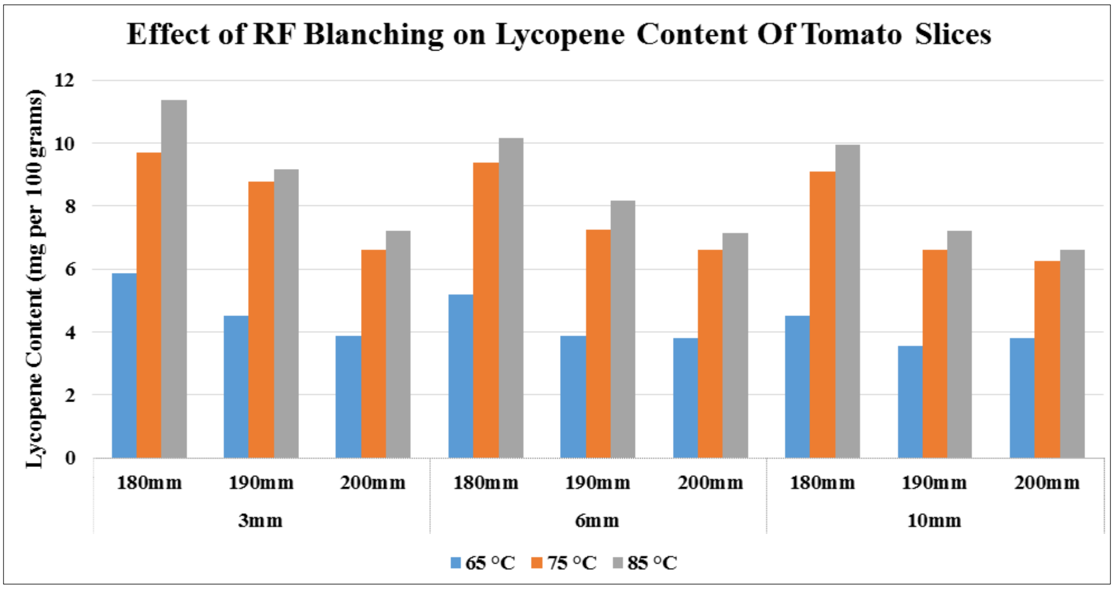

Fig 6: Effect of RF Blanching on lycopene content of tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

3.6 Effect of RF pre-treatment (blanching) on total carotenoid content

The treatment parameters, thickness of tomato, electrode height and temperature had significant effect ($P < 0.05$) on the samples total carotenoid content. From the fig.7 it can be inferred that the slices with minimum thickness (3 mm), lowest electrode height (180mm) and highest temperature (85°C) had high amount of total carotenoid than all other treatment combinations and control. The reason for increase in total carotenoid content is attributed to the blanching process at the treated temperature (85°C) and minimum electrode height (180mm). At all thickness and electrode height, the slices treated at 85°C comparatively had higher total carotenoid content than other blanched temperatures. The surface area also plays a role in increase in total carotenoid content. The minimum thickness of tomato slices contributed more surface area for the treatment, hence more the total carotenoids enrichment. The data shows that the 3mm thickness of tomato slices at 180mm electrode height and 85°C had higher total carotenoids enrichment. This shows that lower the thickness higher the total carotenoid enrichment. The amount of total carotenoid in RF blanched sample was found to be 2 times that of the non-blanched control sample. The RF blanched sample shows good effect on the total carotenoid content of tomato slices. Similar study by Urbonaviciene *et al.*, (2012) [25] showed that the blanched tomato peels had 2 times more of total carotenoid content than the non-blanched tomato peels where blanching process helps to enhance the total carotenoid content of tomato slices. Hence radio frequency heating at 85°C with minimum thickness and electrode height can be used as pre-treatment process for blanching of tomatoes.

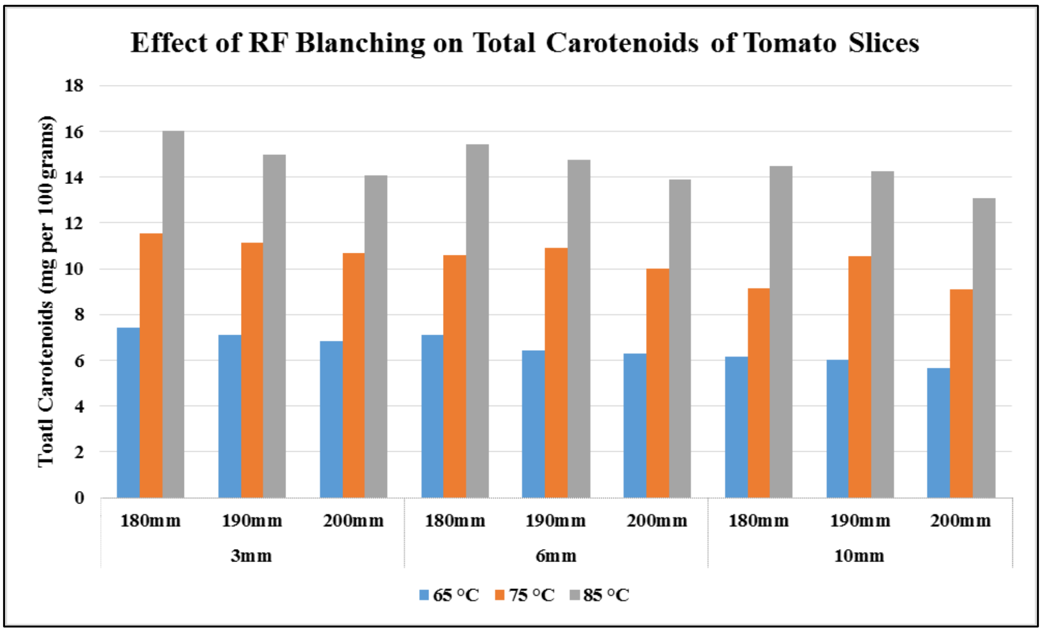

Fig 7: Effect of RF Blanching on total carotenoid content of tomato slices of different thickness (3, 6 and 10 mm), electrode height (180, 190 and 200 mm) and temperature (65, 75 and 85°C)

4. Conclusion

The thickness of tomato plays a significant role during RF pre-treatment as blanching process. The results show that the RF heating as a pre-treatment (blanching) can effectively inactivate the tomato PPO up to less than 10%. Among other heating methods the RF pre-treatment induced highest weight loss in tomato slices. The changes in colour and texture of the samples was comparatively less in RF pre-treatment (blanching) method. Hence their physical characteristics were retained to the possible extent. On the other hand the analysis on lycopene and total carotenoid content of the RF pre-treated (blanched) samples showed 2 times the increase of their content than the non-blanched sample. The increase in their content is attributed to the blanching process at the minimum thickness of tomato slices of 3mm, minimum electrode height of 180mm and the temperature of 85°C. From this study it can be inferred that the Radio Frequency pre-treatment can be used as effective blanching process for tomato.

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