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RESEARCH ARTICLE

Vitamin C (L-Ascorbic Acid) Degradation Kinetics during Simultaneous Infrared Dry-Blanching and Dehydration of Apple Slices with Intermittent Heating Method

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Abstract

Vitamin C (L-Ascorbic Acid) is the most important vitamin in nutritional terms. The polyphenols existing in apple exhibit the highest antioxidant rates hence the preservation of apples' nutritional quality during the heating process is of a great importance. Simultaneous infrared dry blanching and dehydration (SIRDBD) based on intermittent heating method is a novel process during which the temperature is kept constant. The present study investigated the effect of irradiation temperature and the product's thickness on polyphenol oxidase (the enzymatic browning agent) and Vitamin C degradation. For this purpose, apple slices, in different thicknesses, namely 5mm, 9mm and 13 mm, and diameter of 20 mm were prepared. Irradiation was carried out in three surface temperatures, i.e. 70, 75 and 80°C. The temperature of product center was recorded during processing. The enzymatic activity of polyphenol oxidase (PPO) and ascorbic acid content were assessed in various 2 min and 30 min intervals, respectively. Vitamin C degradation kinetics was studied. The results indicated that the enzyme degradation time was significantly lower in 80°C ($P<0.05$). At the time of blanching sufficiency, the center temperatures for apple slices with thicknesses of 5mm, 9mm and 13mm were 64.4, 61.7 and 60.8°C, respectively. The vitamin's degradation kinetic constant (k) was found significantly increased with the increase in temperature or thickness ($P<0.05$). With the increase in thickness, the vitamin degradation was more dependent on temperature elevation (higher activation energies or E_a). Vitamin C contents were very close at the beginning of the process in different temperatures. Therefore, the high-temperature short-time approach (HTST) can, meanwhile accelerating the enzymatic inactivation, preserve the nutritional quality of the products.

Keywords: *Vitamin C, Blanching, Infrared, Polyphenol oxidase.*

Introduction

Fruits, featuring a large diversity in terms of color, odor, flavor, as well as the vitamins play a significant role in human beings' dietary regimes [1]. Apple is realized as a widely consumed fruit in the dietary regimes. The polyphenols existent in apple, inter alia the other fruits and vegetables, display the highest antioxidant activities through controlling the free radicals and this works to decrease cancer risk.

Therefore, the preservation of nutritional characteristics of apple during thermal processing is of a great importance [2, 4]. Vitamin C, a phenolic compound, is the most important nutritional vitamin that cannot be synthesized in human body and L-ascorbic acid is the most substantial bioactive form of it [5]. This vitamin has been proved to have the highest antioxidant activity [6].

The recommended daily allowance (RDA) of Vitamin C consumption is about 60 mg/day for adults. One of the most important factors influencing the fruits quality alteration during heating and drying is the loss of their

water soluble vitamins (most importantly Vitamin C). It has been made clear that 10% to 50% of the ascorbic acid is wasted during drying processes [1]. Therefore, ascorbic acid is a thermo labile (heat-sensitive) compound that can be degenerated aerobically or an aerobically [7].

The degradation rates of ascorbic acid differ with the changes in environmental conditions such as temperature and water activity. It is ascertained that the other nutrients residing in a food can be preserved in case the Vitamin C content is preserved. Thus, the compound is considered as the nutritional quality index during the food processing [8]. A novel process in food industry is the simultaneous infrared dry blanching and dehydration operation (SIRDBD) exerted on fruits and vegetables that is known to enhance the quality of the final product [9]. One positive effect of blanching is its contribution to delaying the vitamin loss [10, 11].

The effect of Infrared heating on the ascorbic acid degradation has been less dealt with [12]. Simultaneous Infrared dry blanching and dehydration can be carried out both in a continuous as well as in an intermittent method. During continuous heating, the radiation intensity and in intermittent heating the surface temperature of the product is kept constant. The intermittent radiation possesses the advantage of energy storing and product quality improvement [13].

Over-blanching causes product quality decline and nutrients, especially vitamins, deterioration. Therefore, the precise process conditions (time and temperature) are specified with the objective of preventing over-processing. To do so, such factors as access to the specific center temperature, access to a certain level of enzymatic inactivation and preservation of a given ratio of Vitamin C should be taken into account.

This is subject to the biophysical properties of fruits and slices size and shape [10]. Timoumi et al [1] investigated the effect of Infrared drying temperature on Vitamin C degradation in apples. Their results indicated that the Vitamin C degradation rate coefficient was elevated with the increase in temperature within 40°C to 70°C range. They did not take the effect of thickness into consideration.

Vishwanathan et al [14] examined the Vitamin C retention in carrot slices during hybrid Infrared and hot air drying processes. The water-soluble Vitamin C retention of blanched carrots was found higher, 62%, in infrared radiation as compared to water vapor drying, 49%, and hot water drying, 43%. The study confirmed the potential of applying infrared dry blanching in improving the quality of food products and vegetables. Marfill et al [15] investigated the ascorbic acid degradation kinetics during drying tomatoes based on various studies.

They reported that temperature elevations increase the degradation rates. Erenturk et al studied the Vitamin C degradation during hot air drying of rosehips. The results indicated that the Vitamin C content during the drying process is subject to air temperature and the product's moisture content. Castro et al [16] examined the ascorbic acid degradation kinetics in ohmic heating of strawberries. Their results showed that vitamin degradation obeys the first order kinetic model for commonly and ohmic heating. Verbeyst et al [17] modeled Vitamin C degradation during thermal processing in a high-pressure treatment in Red Fruits. They applied Fractional Conversion Model to describe the vitamin degradation under aerobic conditions.

Their results indicated that reducing the oxygen concentration during the thermal processing can help preserving the vitamin. Also, it was made sure that the use of high pressure and temperature at the same time with the reduction in time can yield products with higher vitamin levels. In this study, the appropriate time and temperature of infrared dry blanching for polyphenol oxidase (PPO) degradation was determined in the first stage. Also, the temperature variations of the product center were recorded during processing and the temperature of product center was determined at the time of blanching adequacy.

In a second stage, the Vitamin C content variations was studied during radiation and the effect of slices' thickness and radiation temperature was surveyed on ascorbic acid degradation. There was found no research considering the various thicknesses of apple slices in studying the kinetics of Vitamin C degradation via infrared radiation featuring intermittent heating method (in constant

temperatures). This was carried out herein aiming at accelerating the enzyme degradation in fruit slices while preserving the product's nutritional value. In the current research paper, the blanching method was introduced as a fast and applied method in food industry.

Materials and Methods

Apple Slices Preparation

Apples (*Golden Delicious* variety) were purchased from a local market and kept, according to Acevedo et al [18], in 0°C±1°C and relative humidity ranging from 90% to 95%. Before every thermal processing, the apple specimens were picked up from the cold storage and then they were put into use after reaching the ambient temperature. The samples were skinned manually and then cut into slices with different thicknesses of 5mm, 9mm and 13mm, all 20mm in diameter. The sliced apples were immediately subjected to simultaneous blanching and infrared drying.

Infrared Drying System

Figure (1) illustrates the components of an automatic Infrared dryer used herein corresponding to the system proposed by Liu et al [19]. The dryer is consisted of a cuboid chamber and a ceramic IR radiation source with a power of 1000 watt accommodated inside the chamber. The surface temperature of the sample is continuously controlled inside the dryer chamber through taking advantage of a k-type thermocouple and programmable logic controller (PLC). The sample weight is also continuously controlled during the process by the use of a sensitive scale (ADAM, HCB 3001) with the precision of 0.1 g till the sample reaches a constant weight. The temperature of product center is also recorded by a K-type thermocouple.

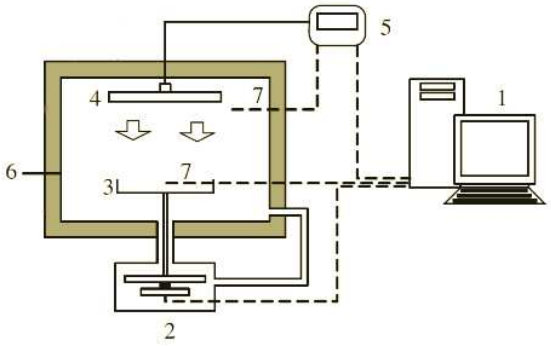


Figure 1: IR dryer system and its accessories, (1) computer; (2) scale; (3) sample tray; (4) ceramic IR radiator; (5) programmable logic controller (PLC); (6) dryer chamber; and, (7) K-type thermocouple

Intermittent Heating Operation

To run the intermittent heating operation, three constant surface temperatures, corresponding to what was conducted by Zhu et al[9], were selected, i.e. 70, 75 and 80°C. The maximum range of process times for various temperatures and thicknesses studied herein till reaching a predetermined weight have been given in Table (1).

Table 1: The approximate times for various treatments till reaching a constant weight

Thickness (mm)	Temperature (°C)	Time (min)
5	70	195
	75	165
	80	135
9	70	300
	75	240
	80	210
13	70	420
	75	300
	80	240

Chemical Solutions Preparation

Catechol Reagent: to prepare a 0.1 molar catechol solution, 1.1011 gram catechol powder was dissolved in 100 ml distilled water in an Erlenmeyer container to obtain the given concentration level.

Titrant 2, 6-Dichlorophenol-Indophenol (DCPIP)

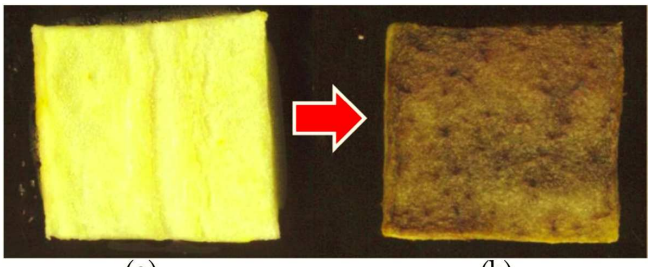
To prepare DCPIP with a concentration of 0.01 mol, 0.7252 gram 6,2--dichlorophenol-indophenol titrant and sodium monohydrate salt with a molecular weight of 290.08 g/mol was dissolved with 250 ml distilled water in a 250-liter Erlenmeyer so as to obtain the given concentration level. Titrant was prepared before use and kept in dark glass containers.

Standard Ascorbic Acid Solution

To prepare 5 millimoles of ascorbic acid with a molecular weight of 176.13 g/mol, 88.065 mg ascorbic acid was dissolved in 100 ml distilled water in an Erlenmeyer so as to obtain the predetermined concentration. The standard solution was kept in a dark container.

Enzymatic Activity Investigation

To evaluate the enzymatic activity of polyphenol oxidase (PPO) and its effect on the product color, apple slices were removed from the device in 2- minute intervals and the process was continued till the time no sign of color change stemming from catechol reagent addition was observable. Image acquisition of sample was performed. Then, according to the method proposed by Lee et al [20], 1 ml of catechol reagent was sprayed on the sample surface and the sample was immediately kept in 25°C (ambient temperature) for 15 minutes. As it can be seen in Figure (2), the enzymatic activity is intensified in the presence of catechol precursor and its effect is manifested in the form of browning. The sample's color transformation was also scanned.



(a) (b)

Figure 2: enzymatic activity investigation, (a) Apple slice (5 mm) heated using 70°C for 30 min. (b) intensification of enzymatic activity and sample's change of color as a result of catechol reagent spray and the sample's final color after 15 min in 25°C

Image Acquisition

There was made use of a flatbed scanner (HP Scanjet G2710), made in US, based on the method posited by Romani et al [21] in taking photos of the apple slices. The treated samples were placed on the scanner and then a black box was utilized so as to prevent the interferences of the peripheral lights and light reflections. The images featured a 300 dpi quality and were saved in TIFF-24 bit format.

Color Analysis

Color analysis of the obtained images was carried out in color spaces L*a*b* by the use of "color space convertor" pelagin in ImageJ software, version 1.6.0.

Browning Index

The browning index (BI) of the sample was calculated corresponding to the method proposed by Maskan [22] based on equation (1) before making use of catechol reagent (BI_0) and in the presence of catechol precursor (BI_c). The variable "x" given in the equation is calculated based on equation (2). The differential of the browning index ($\Delta BI = BI_c - BI_0$) was computed as the enzymatic activity residual. In the end, the time required for the enzyme degradation till attaining a zero residual between the browning index ($\Delta BI=0$) was taken into account.

$$BI = \frac{\left[100(x-0.31)\right]}{0.17} \quad (1)$$

$$x = \frac{(a+1.75L)}{(5.645L+a-3.012b)} \quad (2)$$

Sample Preparation for Vitamin C Assessments

To perform Vitamin C (analyte) assessments, as well, the experimental specimens were removed from the dryer in 30-minute intervals and the process continued till the achievement of a constant weight. The

processed sample was firstly grounded into finer particles in a porcelain mortar during which 10 ml distilled water was gradually added thereto. Each time, the obtained extract was transferred to a 100 ml Erlenmeyer. Finally, the grounded fruit pulps were pressed through cheesecloth and washed with 10 ml distilled water in the Erlenmeyer. In the end, the extracted liquid's volume in the Erlenmeyer was increased to 100 ml by the use of distilled water.

Dichlorophenol - Indophenol Standardization

To standardize the titrant, 5 ml standard ascorbic acid was poured into an Erlenmeyer and its PH was regulated to 3 by the use of Oxalic Acid, 2%. Knowing the ascorbic acid concentration (M_{vitc}) and its volume (V_{vitc}) and determining the volume of the used titrant (V_{DCPIP}), the actual concentration of titrant (M_{DCPIP}) was calculated based on equation (3) through performing titration:

$$M_{DCPIP} \times V_{DCPIP} = M_{VitC} \times V_{VitC} \quad (3)$$

Vitamin C Measurement

Vitamin C content measurement of the processed sample was carried out similar to the method put forth by Timoumi et al [1]. The task was carried out based on titration by the use of 2, 6-Dichlorophenol-Indophenol (DCPIP). According to Hossu and Maearu [23], the advantage of this method over the iodine solution-based titration is that there should be made use of starch reagent in the latter and this slows down the titrant's reaction with ascorbic acid as a result of which titration accuracy suffers.

Corresponding to Figure (3), displaying the titration method, the end point of the titration is when the pink color remains on solution for 15 continuous minutes (equation 4). Using equation (3), ascorbic acid concentration is calculated. Finally, the ascorbic acid content (C), in gram, is computed corresponding to equation (5). In this equation, n_{VitC} and MW_{VitC} denote molar number and molecular weight of the ascorbic acid, respectively.

$$DCPIP\ (blue) + H^{+} \rightarrow DCPIPH\ (pink) \quad (4)$$
$$DCPIPH\ (pink) + Vitamin\ C \rightarrow DCPIPH_2\ (colorless)$$

$$C = n_{VitC} \times MW_{VitC} = M_{VitC} \times V_{VitC} \times MW_{VitC} \quad (5)$$

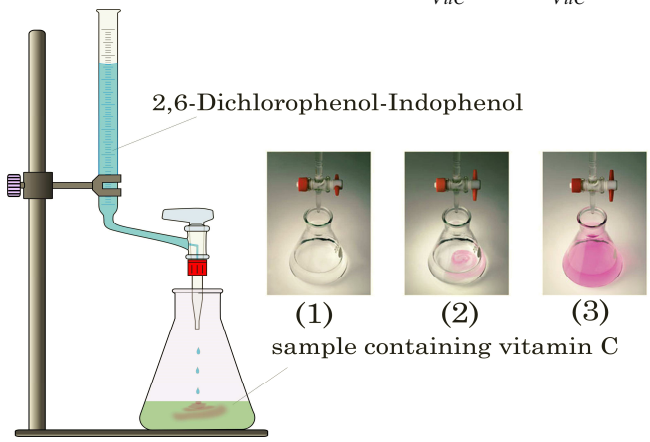


Figure 3: Titration stage by the use of 2, 6-Dichlorophenol-Indophenol (DCPIP) for measuring Vitamin C content. (1): titration initiation; (2): during titration; and, (3): titration end point

Vitamin C Degradation Kinetics Modeling

Vitamin C degradation kinetics modeling was done according to Timoumi et al [1]. The model can be defined as stated in equation (6). In this equation, C denotes Vitamin C content and k is the degradation kinetic constant (min^{-1}). The equation (7) is outputted from equation integration between zero time and any instant of the process.

$$Ln\ \frac{C}{C_0} = -kt \quad (6)$$

$$-\frac{dC}{dt} = kC^{n} \quad (7)$$

Arrhenius Model

The relationship between the Vitamin C degradation kinetic constant (k) with the various process temperatures and thicknesses was investigated based on the linear form of Arrhenius equation as

specified in equation (12) according to Jao et al. In the equation, k is the studied parameter, i.e. Vitamin C degradation kinetic constant, E_a is the activation energy in J.mol^{-1} and R is the universal gas constant equal to 8.309 J.mol^{-1}.k^{-1}. T is the absolute temperature in Kelvin.

$$Ln\ k = Ln\ \mathrm{k}_0 - \frac{E_a}{RT} \quad (8)$$

Goodness of Fit

The models' fit estimation was carried out by the use of curve fitting toolbox in MATLAB software, version 2009 in a 95% confidence level (P<0.05). To evaluate and compare the models, there was made use of adjusted R-squared (Adj.R^2) and the root mean square error (RMSE) according to Krokida et al [24] based on equations (9) and (10), respectively. In these equations, O and P are indicative of the observed and predicted values, respectively; and, n is the number of the observations and p is the number of the model parameters.

$$Adj.R^2 = R^2 - \frac{p-1}{n-p}\left(1-R^2\right) \quad (9)$$

$$RMSE = \sqrt{\frac{(o-P)^2}{n-p}} \quad (10)$$

Statistical Analysis

Statistical analyses were carried out in SPSS software, version 19. To do so and in order to assess the time required time for the blanching, there was made use of completely randomized design (CRD) in factorial format (3^2) considering two factors, namely thickness (in three levels) and temperature (in three levels). The statistical analyses of the vitamin degradation kinetic constant (k), as well, were conducted based on randomized complete block design (RCBD) in the course of which the temperature and thickness were considered as the block and the treatment, respectively. Mean comparisons were undertaken based on Duncan test in a 95% confidence level (P<0.05). All experiments were performed in three replications.

Results and Discussion

Temperature Variations during IR Radiation Heating

Figure (4) illustrates the temperature variations at the center of apple slices featuring various thicknesses during IR radiation drying process with intermittent heating. After the appropriate enzyme degradation time was specified, temperature diagrams can be applied to determine the enzyme inactivation adequacy. According to Figure (4a-b), the temperature curve was reflective of faster variations for a thickness value of 5mm as compared to thicknesses 9mm and 13mm. But, with the increase in the processing temperature to 80°C, the thickness was found having lesser effect as depicted in the temperature curve and a similar temperature profile was evidenced for the various thicknesses in that temperature (Figure 4c).

Tanaka et al [25] stated that after a short while since the initiation of the process, the temperature slightly increases in the product center and this can be due to the internal heat resistance of the product. Nowak and Lewicki [26] asserted that the apple slices' temperature highly depends on the amount of water existent in them. At the beginning of the IR drying process, the temperature increases rapidly and then it comes to a stop with the further passage of time. The temperature increase lasts about 10 min to 11 min during which time some 10% of the product moisture is lost in evaporation; moreover, the product's final temperature at the end of the process depends on the distance between the IR emitter and the product surface.

Meeso et al [27] introduced the direct IR energy infiltration into the interior parts of the product as the reason behind the rapid temperature elevation in the product substrates subject to IR radiation. As for the product thickness, Lin et al [28] stated that the thicker slices possess thicker conductive layers that can preserve the surface water for a longer period of time and, hence, the temperature variation is observed featuring milder slope at the onset. Ridah et al [29], as well, reported that drying is accomplished in a shorter time with the decrease in the product thickness and increase in the process temperature.

Ni and Detta [30] also introduced the presence of IR as the factor giving rise to higher surface temperature profiles and found the waves' penetration depth associated with the product temperature.

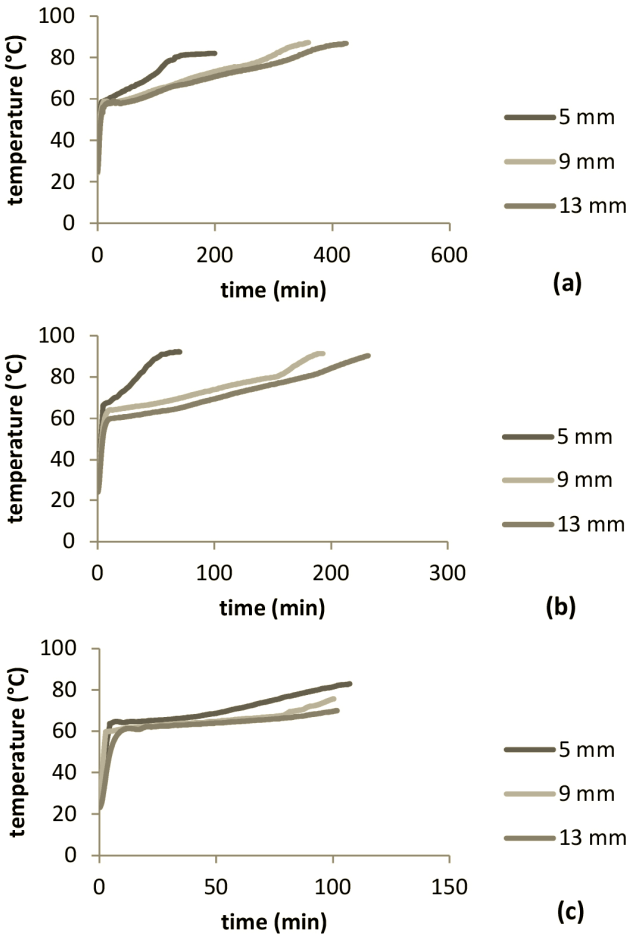


Figure 4: the temperature variations at the center of the apple slices in various temperatures during IR drying with intermittent heating in a constant surface temperature a) 70°C, b) 75°C and c) 80°C

Polyphenol Oxidase Inactivation

The enzyme inactivation variation trends in different surface temperatures during IR drying with intermittent heating has been exhibited in Figure (5) (thickness=5mm). The enzyme inactivation was found increased with the increase in heating time and the time required for blanching was decreased with the increase in temperature. This observation is consistent with the reports of the study by Bai et al [31]. The enzyme inactivation was found happening in an appropriate speed in 80°C. At the time blanching reaches adequacy point, the center temperatures for product thicknesses of 5mm, 9mm and 13mm were 64.4, 61.7 and 60.8°C, respectively.

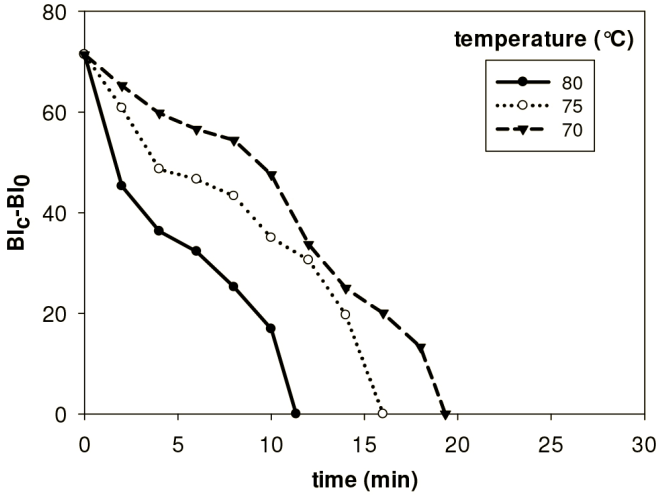


Figure 5: the enzyme inactivation variation trends in various surface temperatures till color fixation point of the apple slices by the use of catechol reagent (thickness=5mm)

Figure (6) demonstrates the mean comparisons of the time required for enzyme inactivation of apple slices in various thickness and various temperatures studied herein. Table (2) presents the results of variance analysis for the foresaid statistical analysis. As it can be seen, the time required for polyphenol oxidase is significantly lowered with the increase in temperature or reduction in thickness.

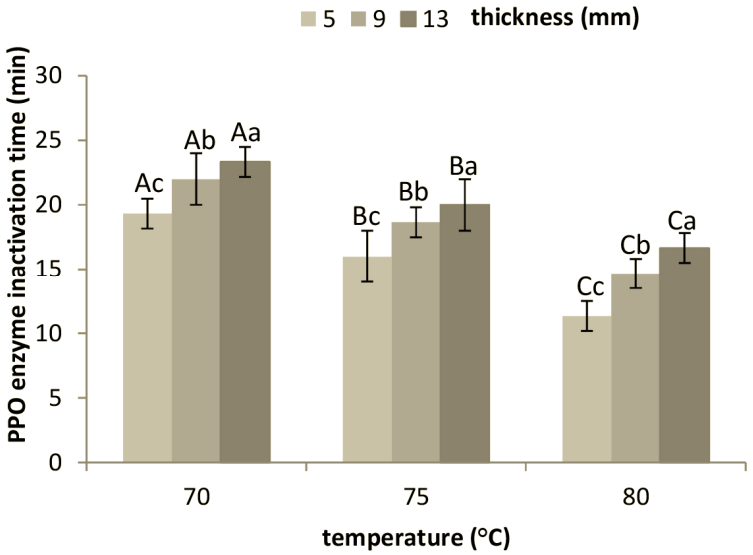


Figure 6: Statistical comparison of the time required for polyphenol oxidase inactivation in various treatments, the capital letters are comparisons between various temperatures and the small letters are comparisons between various thicknesses (P<0.05)

Table 2: ANOVA data obtained from the comparison of various treatments' effects on the time required for total inactivation of polyphenol oxidase in apple slices (P<0.05)

	Sum of squares (SS)	(df)	Mean squares (MS)	F	Significance level (sig.)
Model	9084.000	9	1009.333	454.200	0.0000
Temperature	242.667	2	121.333	54.600	0.0000
Thickness	91.556	2	45.778	20.600	0.0000
Temperature × thickness (interaction effect)	1.775	4	0.444	0.200	0.935
Error	40.000	15	2.222		
Total	9124.000	27			

In line with this, Zhu et al [9] expressed that enzyme inactivation takes place faster generally in IR radiation on thinner slices and/or in higher surface temperatures. As reported by Lin et al [28]. The increase in thickness causes reduction in the uniform distribution of temperature inside the product. Many of the researchers have reported rapid heating rates as well as temperature as factors influencing the enzyme inactivation [32, 36].

Caronni and Lavelli [37] reported that the expected water activity threshold according to color was equal to/over 0.32 for polyphenol oxidase activation in dehydrated apples. Oxygen presence can decrease the enzymatic inactivation rate during dry blanching. Quiles et al [38] stated that various apple varieties possess nearly similar enzymatic activity patterns and polyphenol oxidase activity is subjected to the microstructure changes of the apples' parenchymal texture.

In fact, the apple parenchymal tissue undergoes shrinkage during dehydration and this provides the enzyme with more access to the oxygen in the microstructures at its periphery which, per se, increases polyphenol oxidase activation in the absence of being floated in osmotic solution. Regarding the effect of enzymatic activity on Vitamin C content, Barret and Lloyd [39] stated that oxidative enzymes (polyphenol oxidase and peroxidase) might influence the ascorbic acid content, although this remains to be evaluated in further research. Oey et al [40] expressed that oxidation is the major factor leading to Vitamin C degradation during adiabatic heating.

Vitamin C Degradation Kinetics

Figure (7) shows the diagram of kinetic model fit estimations for ascorbic acid degradation in various temperatures (thickness=5mm). Table (3) summarizes the model's fit estimations on the empirical data in various treatments along with the statistical comparison of the degradation kinetic constants (k). Table (4) gives the results of statistical analyses in terms of the effect of treatments on vitamin degradation kinetic constant.

The difference between the studied temperatures has been found statistically significant in terms of the kinetic constant in all of the cases and the vitamin degradation constant was found elevated with the increase in temperature. In terms of thickness effect, as well, the vitamin degradation kinetic constant was found elevated in smaller thicknesses of the slices and there was found a significant difference between the 5-millimter thickness with the other two thickness values, to wit 9mm and 13mm. These results are in compliance with what was found by Uddin et al, 2001[41] Chua et al,[42] Timoumi et al, [1] Wu et al,[43] Kaya et al,[44] and, Mrad et al, [45].

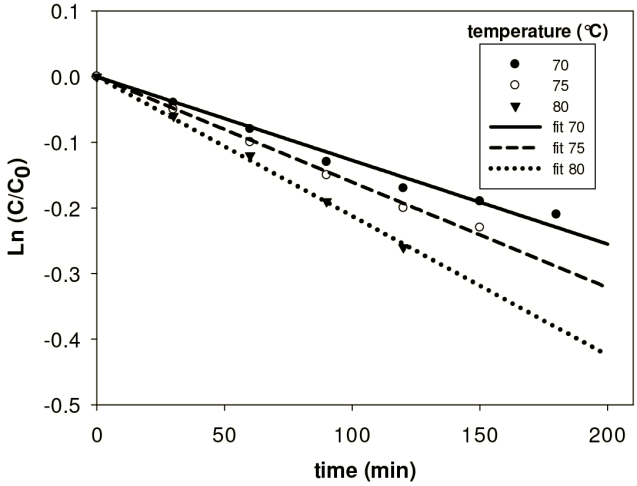


Figure 7: Ascorbic acid degradation kinetic model fit estimation in various radiation temperatures for a thickness of 5 mm

Table 3: Vitamin C degradation model fit estimations over the experimental data obtained from various treatments

Thickness	Temperature (°C)	k (min^{-1})	Adj.R^2	RMSE
5	70	-0.001275^{Ca}	0.9758	0.01237
	75	-0.001606^{Ba}	0.9944	0.006606
	80	-0.002122^{Aa}	0.9977	0.004916
9	70	-0.001152^{Cb}	0.9981	0.005043
	75	-0.001533^{Bb}	0.9953	0.008689
	80	-0.00196^{Ab}	0.9933	0.01191
13	70	-0.0011^{Cb}	0.9967	0.007898
	75	-0.00149^{Bb}	0.9953	0.0105
	80	-0.001900^{Ab}	0.989	0.01757

Capital letters denote the comparisons between the test temperatures and the small letters denote the comparisons between the slices' thicknesses; similar letters denote the absence of significant difference (P<0.05)

Table 4: ANOVA data for the comparison of the effect of treatments on Vitamin C degradation constant of the apple slices (P<0.05)

Treatment	Sum of squares (SS)	(df)	Mean squares (MS)	F	Significance level (sig.)
Model	2.326×10^{-5}	5	4.653×10^{-6}	5716.209	0.000
Thickness (treatment)	4.615×10^{-8}	2	2.308×10^{-8}	28.350	0.004
Temperature (block)	1.008×10^{-6}	2	5.040×10^{-7}	619.209	0.000
Error	3.256×10^{-9}	4	8.139×10^{-10}		
Total	2.327×10^{-5}	9			

Silva and Santos [12] stated that ascorbic acid degradation during dying processes depends on time, temperature and moisture. In fact, the effect of moisture content is more prevalent at the onset of the process and the effect of temperature becomes greater with

the pass of time since the process initiation. The increase in water amount (increase in thickness) causes the hydrous phase to be less viscous and this enhances the infiltration and dispersion phenomena in the product which will per se facilitate the oxidation reaction and ascorbic acid degradation, although in higher water activities, the water content might mitigate the degradation through diluting ascorbic acid.

Therefore, water content control for having control over ascorbic acid degradation is very complicated. This is whole Singh et al [46] reported that ascorbic acid degradation constant increases with either the increase in temperature or the increase in water activity or both. Mclaughlin and Magee [47], as well, found ascorbic acid more stable in lower temperatures and lower water activities. Sablani [48] stated that ascorbic acid can be easily degraded during drying in lower temperatures and that it is, unlike carotenoids, more sensitive to drying time than to the drying temperature (using high temperature in a short time).

Joshi et al [49] realized the use of Vitamin C, for its protection against polyphenols oxidation, as the major reason behind ascorbic acid oxidation under high temperature conditions hence reduction of its concentration. In the present study, as well, the sample's vitamin content was found almost similar in shorter times in various temperatures (Figure 7-in 30 minutes). Thus, the use of high temperature and short time (HTST), meanwhile accelerating the enzyme degradation and annihilation of oxidative enzymes, can be appropriate in preserving the product quality.

Arrhenius Model

Figure (8) demonstrates the Arrhenius liner model fit estimation over the natural logarithm of degradation kinetic constant (Ln k). The information pertaining to Arrhenius linear model fit estimation has been presented in Table (5). Vitamin degradation constant was increased with the elevation in activation energy/thickness. Marfil et al [15] stated that higher activation energy levels are suggestive of a greater association between the ascorbic acid degradation reaction rate and temperature. In other words, in higher thicknesses, ascorbic acid degradation becomes more dependent on temperature elevation.

The calculated activation energy in the present study was 50 KJ/mol which is higher than activation energy (about 15 KJ/mol) obtained by Timoumi et al [1]. Lima et al [50] realized the higher temperature dependencies as the reason behind such an issue. Although the vitamin's degradation kinetic constant is similar to what has been reported by Timoumi et al [1] ($0.8\text{-}1.4\times10^{-3}$ min^{-1}), there are researchers who have reported activation energy rates in a range from 36 KJ/mol to 71 KJ/mol for ascorbic acid degradation [41, 50].

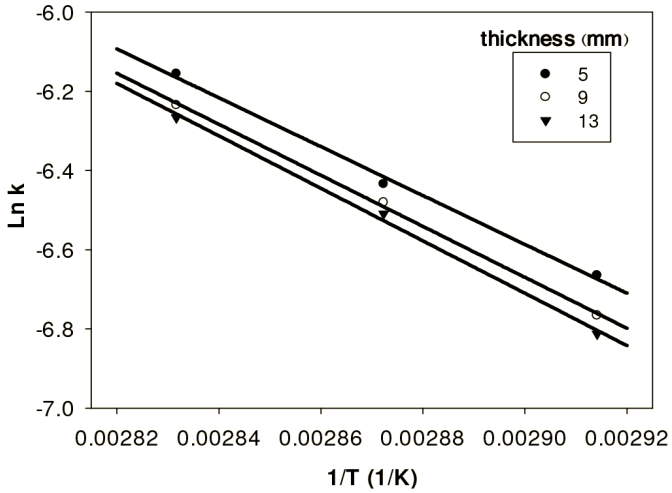


Figure 8: the natural logarithm of Vitamin C degradation constant against inverse of temperature in various thicknesses of apple slices

Table 5: the fit estimation data of Arrhenius equation for the Vitamin C degradation constant in various thicknesses

Thickness (mm)	Ln (k_0)	E_a (J.mol^{-1})	Adj.R^2	RMSE
5	11.31	51266.53	0.9922	0.0225
9	12.01	53526.58	0.9975	0.01322
13	12.51	55055.43	0.9939	0.02145

Conclusion

The present study aimed at speeding the blanching operation meanwhile preserving the nutritional quality of the fruit slices during radiation featuring constant temperatures. The study selected higher temperature ranges so as to conduct a rather fast enzyme deactivation. The results of the study indicated that the enzyme deactivation is significantly lower in 80°C as compared to the other temperatures examined herein and, on the other hand, Vitamin C content variations were almost similar during the early radiation process for various temperatures. Hence, the high temperature-short time (HTST) approach was envisaged more appropriate for accelerating IR blanching operation. After the exertion of the temperature and time conditions appropriate for the annihilation of polyphenol oxidase, dehydration process can be, if necessary, continued in lower temperatures so as to preserve the nutritional quality of the fruit slices in terms of their Vitamin C content.

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