Enhancement of phytochemical content and drying efficiency of onions (*Allium cepa* L.) through blanching

Running title: Blanching increases phytochemicals and drying efficiency of onions

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ABSTRACT

BACKGROUND: This study investigated the effect of blanching (60, 70 and 80 °C for 1, 3, 5 and 10 min) combined with oven drying at 60 °C on the phenolic compounds, antioxidant activity, colour and drying characteristics (drying time, drying rate constant, effective moisture diffusivity and activation energy) of onion slices.

RESULTS: Blanching of onion slices at 60 °C for 3 min and at 70 °C for 1 min prior to drying increased their bioactive compounds and antioxidant activity compared to the control samples and other treatments. Eighteen drying models were evaluated. The

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Modified Page and Two-term exponential models best represented the drying data. The effective diffusivity ranged from 3.32×10^{-11} m^2 s^{-1} (control) to 5.27×10^{-11} m^2 s^{-1}, 5.01×10^{-11} m^2 s^{-1}, and 4.74×10^{-11} m^2 s^{-1} for onions blanched at 60 °C, 70 °C and 80 °C , respectively. The higher activation energy was observed for the control (unblanched) sample and slightly lower values were found for 1 min and 3 min-blanched samples, confirming the higher drying efficiency as a result of the blanching pre-treatment.

CONCLUSION: The use of blanching as a pre-treatment before drying of onions resulted in enhanced phytochemical content and drying efficiency.

Keywords: antioxidant; blanching; colour; phenolic compounds; drying efficiency.

INTRODUCTION

Onion (*Allium cepa* L.), one of the most widely grown and consumed vegetables in the world, is known to contain high levels of bioactives with protective effects against different degenerative diseases.[1] Dried onions are used as a food ingredient in various food formulations including soups, sauces, salad dressings, sausage and other convenience foods.[2]

Hot water blanching is commonly used in the food processing industry as an essential thermal treatment carried out prior to many preservation processes such as drying, canning and freezing, and largely determines the product quality. The main objectives of blanching are: to inactivate enzymes to prevent possible deterioration reactions, reduce microbial load to prolong shelf-life, eliminate air in the intracellular space to increase the rate of heat and mass transfer, and prevent oxidation.[3, 4] The quality of blanched products depends significantly on the blanching time and temperature and also on the physical and chemical properties of the vegetable to be blanched. Industrial blanching processes involve treating fruits and vegetables with steam or hot water for 1 to 10 min at temperatures ranging from 70 to 95 °C.[5]

Drying of materials with high moisture content involves complex processes of simultaneous heat and mass transfer. A number of studies have been conducted on drying kinetics of various fruits and vegetables, so that preservation can be achieved by reducing the moisture content with minimal loss in nutrients. Several phenomena related to heat and mass transfer is involved in drying processes. The kinetics of mass

transfer (mainly water) during drying depends on temperature, relative humidity, air flow rate, product thickness, load density and product shape.[6] The predominant mechanism in food drying processes is the diffusion of water from as well as within the food to the surface in contact with the drying air. Modelling of the drying process is an efficient tool in the prevention of product deterioration, energy consumption, equipment stress and product yield.[6] A number of empirical equations has been proposed to describe drying processes, modelling kinetics and design of drying systems.[7] These equations derive a direct relationship between the change in moisture content and the drying time, and are strongly related to Fick's second law of diffusion.[8]

There is a dearth of literature on the effect of the combination between blanching temperature and blanching time on the phenolic compounds, antioxidant activity, colour and drying of onions. There are also few reports concerning the drying characteristics of onions pretreated by blanching. Therefore, the main objective of this study was to investigate the effect of blanching temperature-time combinations on the bioactive compounds and overall quality of onion slices.

In spite of onion's high phenolic content and antioxidant properties,[9] these properties have not been studied in fresh cut onion thin slices. As a survey of literature shows that the interest in the role of antioxidants in human health has been increasing, it is important to test appropriate processing such as blanching and drying to thin sliced onions. Onion slices are highly susceptible to oxidation, therefore a pretreatment before drying is necessary to reduce the changes in the phytochemicals to obtain a stable product.

The present study investigated the thin layer drying characteristics of onion slices in a tray dryer regarding the effect of blanching temperature and time. The best mathematical models to obtain the characteristic drying curves were selected. The effect of temperature and blanching time on the diffusion coefficient, activation energy, phenolic content, antioxidant activity and colour was also evaluated.

MATERIAL AND METHODS

Sample preparation and blanching

Organically grown onions (variety Red Baron) were obtained from the Horticulture Development Department in Teagasc, grown as part of the Kinsealy systems experiment, based in Kinsealy, North Dublin, Ireland. The onions were grown to organic standards, according to the methodology previously described in Ren *et al*[10]. Fresh onion slices (1×1 cm, total 2 kg) were prepared. A sample of 50 g was blanched in 100 mL of distilled water in a beaker using a temperature controlled water bath (DK-420 Glufex Medical and Scientific, England). The samples were blanched at 60, 70 and 80 ^{o}C for 1, 3, 5 and 10 min. After removed from the water bath, the samples had the excess water removed with tissue paper. Further 50 g of unblanched sliced onions were used as a control.

Control and blanched onion slices were dried in an oven at 0.3 m s^{-1} and 60 ^{o}C for 8 h. The slices were weighed at intervals of 1h during drying until the equilibrium moisture content was obtained (7.0±0.4%) for all samples. Therefore, the final dry

weight was the same for all samples (blanched and unblanched/control). The moisture content of both fresh and dried samples were determined according to AOAC (2005) (protocol number 930.15).[11]

Methods

Preparation of extracts from dried onions

The dried onions were blended by a kitchen blender. The samples (1 g) were mixed with 10 mL of methanol (80%) and homogenised at 24000 rpm using an Omni-prep multi-sample homogeniser (Omni International, USA). The homogenized sample suspension was shaken overnight with a V400 Multitude Vortexer (Alpha laboratories, North York, Canada) at 1500 rpm at room temperature. The sample suspension was then centrifuged (MSE Mistral 3000i, Sanyo Gallenkamp, Leicestershire, UK) at 3000 x g for 15 min and immediately filtered through 0.22 μm polytetrafluoethylene filters. The extracts were kept at -20 °C until further analysis.

Total phenolic (TPC), flavonoid (TFC) and anthocyanin (TAC) content

TPC was determined using the Folin-Ciocalteau method with slight modifications.[12] Briefly, 100 μL of the methanolic extract, 100 μL of MeOH, 100 μL Folin-Ciocalteau reagent (FC) and 700 μL of 20% Na_2CO_3 solution were added to a 1.5 mL micro-centrifuge tube. The tubes were vortexed and then left in the dark for 20 min at

room temperature. Thereafter, the samples were centrifuged (Eppendorf, Centrifuge 5417R, Germany) at 17000 g for 3 min. The absorbance of the samples was read at 735 nm in a spectrophotometer (Shimadzu UV-1700, Shimadzu Corporation, Kyoto, Japan) using aqueous gallic acid (10-400 mg L^{-1}) as a standard. The results were expressed as gallic acid equivalents per dry weight of sample (mg GAE g^{-1} DW). TFC was determined using the method described by Lin and Tang [13] Briefly, 100 µL of the methanolic extract was mixed with 300 µL of 95% ethanol, 40 µL of 10% aluminium chloride, 40 µL of 1.0 M potassium acetate and 520 µL of distilled water in eppendorf tubes. After incubation at room temperature for 40 min, the absorbance of the mixture was read against a blank at 415 nm in a spectrophotometer. TFC was expressed as mg quercetin g^{-1} DW.

TAC was determined by the pH differential method of Huang *et al.*[14] with some modifications. Briefly, 1 mL of onion extract samples were dissolved in a 0.2 mol L^{-1} potassium chloride buffer at pH 1.0, making up to 25 mL. Then, another 1 mL of anthocyanin extract was dissolved in a 0.2 mol L^{-1} sodium acetate buffer at pH 4.5, making up to 25 mL. Sample spectral absorbance measurements (OD) were read at 525 and 700 nm. The total anthocyanin content of the diluted samples was then calculated using Equation 1:

$$\text{TAC}\left(\frac{\text{mg}}{\text{L}}\right) = \left[(\text{OD}_{525} - \text{OD}_{700})_{\text{pH1.0}} - (\text{OD}_{525} - \text{OD}_{700})_{\text{pH4.5}}\right] \times 449.2 \times \frac{1000}{26900} \times \text{DF} \qquad (1)$$

where 449.2 is the relative molecular mass of cyanidin-3-glucoside, 26900 is the molar

absorptivity, OD is optical density and DF is the dilution factor.

FRAP and DPPH assays

The FRAP assay was carried out based on the method by Stratil *et al.*[15] with slight modifications. The sample extract (100 µL) or blank (100 µL methanol) and the Trolox standard dilutions (100 µL Trolox of appropriate concentration) were mixed with 900 µL of FRAP solution in a micro-centrifuge tube and the absorbance of the mixture was read at 593 nm using a spectrophotometer. The antioxidant activity was expressed as mg Trolox g^{-1} DW.

The DPPH (2, 2-diphenylpicrylhydrazyl) scavenging activity assay was performed following the method described by Goupy *et al.*[16] A sample extract (500 µL) was added to 500 µL of DPPH solution and the absorbance was measured at 515 nm in a spectrophotometer. The radical scavenging activity was expressed as mg Trolox g^{-1} DW.

Assessment of quercetin and its glycosides

Quercetin and its glycosides were determined using reversed phase high performance liquid chromatography (HPLC) according to the method of Tsao and Yang [17] Flavonols were separated on a ZORBAX SB-C18 column (4.6 mm x 150 mm, 5 µm particle size, Part no. 883975-902). A diode array detector system (SHIMADZU SPD-M10A) was used and the flavonols (target compounds) were detected at 360 nm.

The mobile phase consisted of HPLC grade water with 0.05% trifluoroacetic acids (TFA) (A) and acetonitrile with 0.05% TFA (B). The gradient involved a linear increase/decrease in the amount of solvent B in A (%B), which was set as follows: 0-15 min, 12-21%; 15-25 min, 21- 100%; 25-35 min, 100-12%. The flow rate was 1 mL min^{-1}. Samples (10 μL) were injected into the column and the separation took place at 30°C. The data was presented in the SHIMADZU EZ START Version 7.3 software and quercetin and quercetin glucoside concentrations were calculated against authentic calibration standards (quercetin 4' glucoside, quercetin 3,4' diglucoside, and quercetin). Quercetin and quercetin glucosides were quantified through comparison with the respective calibration curves.

Colour measurement

Colour (*L*, a* and b**) was determined using a colorimeter (Model: D25A DP-9000, Hunter Lab, Reston, VA, USA). The colour change, ΔE, was then calculated by Equation 2:

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

where L_0^*, a_0^*, and b_0^* are the values for fresh onion samples.

Drying characteristics

Eighteen commonly used empirical models were evaluated to describe the drying kinetics of onion slices. In these models, MR represents the dimensionless moisture ratio, which is defined as:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (3)$$

where M is the moisture content (kg kg^{-1} d.b.) of the product after time t (h), M_0 is the initial moisture content of the product (kg kg^{-1} d.b.) and Me is the equilibrium moisture content (0.08 kg kg^{-1} d.b).

The Fick's second law of diffusion was used to calculate the effective moisture diffusivity (Equation 4), where D_{eff} is the effective moisture diffusivity (m^2 s^{-1}) and L is half the thickness of the sample (m):

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (4)$$

The Arrhenius equation (Equation 5) was used to describe the temperature dependence of the effective diffusivity:

$$D_{eff=} \exp\left(-\frac{E_a}{RT}\right) \quad (5)$$

where D_0 is the pre-exponential factor of the Arrhenius equation (m^2 s^{-1}), is the activation energy (kJ mol^{-1}), R is the universal gas constant, 8.314 J mol^{-1} K, and T is the absolute temperature (K). The activation energy is determined from the slope of the Arrhenius plot, ln (D_{eff}) versus 1/T.

Statistics

All determinations were carried out in triplicate and the results were presented as means ± standard deviation. The data were analysed using the general linear models (GLM) procedure of SAS 9.1 (Cary, NC, USA). The Tukey-Kramer test was applied for multiple comparisons among means at a 95% significance level ($P<0.05$). The goodness of model fit was evaluated based on the root mean square error (RMSE), chi square (χ^2) and regression coefficient (R^2) using SPSS 20.0.

RESULTS AND DISCUSSION

Effect of blanching temperature and time on phenolics, flavonoids and anthocyanins

TPC in the onion slices was significantly affected ($P<0.05$) by both blanching temperature and time (Table 1). The blanching of onion slices for 3 min at 60 °C and for 1-3 min at 70 °C min significantly increased the TPC compared to the control sample. The TPC increase at the conditions mentioned might be attributed to the inactivation of

oxidative enzymes and the induced structural changes leading to improved release of extractable and non-extractable phenolic compounds.[18] Wolfe and Liu[19] reported similar findings for the short-time (10 s) blanching of apple peels with subsequent drying, which resulted in better retention of phenolic compounds.

However, a higher blanching temperature (80 ^{o}C) and longer blanching times (5-10 min) at any temperatures were detrimental to the TPC. Jaiswal *et al.*[20] reported similar conclusions about the effects of blanching time on the degradation of the total phenolic content of York cabbage. Amin [21] applied blanching methods for red, green, mustard, Chinese and Chinese white cabbage for 5, 10 and 15 min. A significant reduction in the total phenolic content was observed irrespective of cabbage type. Losses in polyphenol content are attributed to the disruption of the plant tissue due to the heating effect, leading into polyphenols leaching out into the blanching water environment.[22, 23] Furthermore, the reciprocal inter conversion of insoluble phenolics into more soluble forms can also occur, which may lead to additional losses in polyphenols. The phenolic content losses upon blanching could also be attributed to their respective solubility and stability, which are highly influenced by the type of blanching environment (hot water) and sample: blanching environment volume ratio. It is also worth noting that free polyphenols leach out faster in water as compared to bound polyphenols.[24]

In this work, the maximum loss of phenolics was observed at 80 °C for 10 min, with the TPC reduced by 34.23%. In fact, high temperatures and long blanching times can lead to loss of phenolic compounds due to thermal degradation, leaching or diffusion of components into water[22] and enzymatic oxidation. Enzymes such as phenylalanine

ammonia-lyase (PAL) and polyphenol oxidase (PPO) play an important role in the phenol synthesis in plants. PAL is the first key enzyme in the biosynthesis of phenolic components. The increased activity of PAL leads to an increase in the synthesis of phenolics.[25] As these enzymes get inactivated upon heating, there should be a consequent reduction in the phenolic components after heat treatments. However, there is a series of factors affecting the TPC of blanched samples, not only related to enzymatic activity. In our results, blanched onion slices in general showed lower TPC than control samples, except at 60°C for 3 min and at 70°C for 1-3 min. This result can be explained by several possibilities: the release of high amounts of antioxidant compounds (total phenolic content) due to thermal destruction of cellular and sub-cellular compartment walls, production of strong antioxidants and radical elimination by thermal chemical reaction, suppression of oxidation capacity of antioxidants due to thermal inactivation of oxidative enzymes and/or production of new non-nutrient antioxidants or formation of new compounds such as Maillard reaction products with antioxidant capacity. [26]

The total flavonoid content in the onion slices was also significantly affected ($P<0.05$) by the blanching time and temperature (Table 1). The TFC increased after 1-5 min of bleaching at 60 °C and 70 °C, which can be attributed either to the better extractability of flavonoids as a result of the cell disruption or to the reduced rate of polyphenol degradation. On the other hand, bleaching at 80 °C reduced the TFC, similarly to what occurred to the phenolic compounds.

The anthocyanin content significantly increased after bleaching at 60 °C for 3 min

and at 70 °C for 1 min. All the other conditions led to a TAC reduction. Although anthocyanins degrade with blanching at high temperatures, the drying air temperature of 60 °C was reported as the optimum for the retention of most phenolic compounds.[27,28] Mild heat treatments (at approximately 60 °C) can inactivate degradation enzymes such as polyphenol oxidase and glycosidase resulting in higher rates of polyphenols. Anthocyanins, phenolic compounds and flavonoids degrade enzymatically in the presence of, which catalyse the hydrolysis of anthocyanins to yield free sugars and aglycone.[29] However, bleaching may also cause excessive leaching of this pigment. In addition, heating can also encourage cellular fluids containing phytochemicals to diffuse from the plant cell to the water medium. Thus, the anthocyanin content after blanching is the net result of combined increased in extractability, degradation and leaching. Wahyuningsih [30], for instance, recorded a decreased in the anthocyanin content of red turi *(Sesbania grandiflora* L. (*Pers)* flower, which was ascribed to the leaching of anthocyanin in the blanching media. Khanal, Howard and Prior [31] found that the anthocyanin content was significantly degraded at high drying temperatures (higher than 60 °C) in grape and blueberry pomace. Generally, drying processes can induce undesirable effects on the profiles of plant phytochemicals. Therefore the importance of optimizing drying processes and pre-treatments of plant materials destined to the recovery of bioactive compounds.[32]

Effect of blanching temperature and time on individual phenolic compounds

The concentration of individual phenolic compounds significantly increased after blanching at 60 °C for 3 min and 70 °C for 1 min followed by drying when compared with unblanched samples. Dried blanched onion slices featured a significant increase in the concentration of individual phenolic compounds such as quercetin and its glucosides, since they are sub-groups of phenolic compounds, which was probably caused by the inactivation of degradation enzymes such as polyphenol oxidase and peroxidase.[33]

Figure 1S (supplementary) shows the chromatogram of the separation of the individual phenolic compounds in unblanched (control) and blanched dried onion slices. Blanching of dried onion slices at 60 °C for 3 min and 70 °C for 1 min caused a significant increase in most of the analysed quercetin compounds compared to the control (Table 2). Both blanching temperature and time influence the contents of Q, Q 4' G and Q 3,4' D. While blanching is detrimental to Q 3,4' D regardless of its conditions, blanching temperatures of up to 70 °C applied for 1-5 min increase the Q 4' G levels. The quercetin content, for its turn, is benefited from the application of blanching at any temperature and time duration, with optimum results at 70 °C for 1-3 min. There were no significant changes in the Q 3,4' D of onions during different blanching treatments followed by drying. After further heating, the values of Q 3,4' D decreased compared to the control samples. This phenomenon is ascribed to the leaching of Q 3,4' D in the water. Due to the enhanced water solubility, the additional hydroxyl group is assumed to support leaching of the former compound into the blanching water. Accordingly, the lesser gain of some phenolic compounds upon extended water-blanching compared to the control may be attributed to enhanced leaching of Q 3,4' D into the blanching water.

Therefore, the leaching effect of blanching is assumed to be more decisive than the degradation or release of the phenolic compounds. On the other hand, the increases observed in the Q 4' G and Q contents appeared to occur at the expense of Q 3,4' D, which is in agreement with the study by Price and Rhodes, [34] where decreases in Q 3,4' D were quantitatively explained by increases in the Q 4' G and quercetin contents. This was as result of the conversion of Q 3,4' D in Q 4' G and further breakdown of Q 4' G in quercetin aglycon by enzymatic hydrolysis of glucosides during blanching.[35]

Effect of blanching temperature and time on antioxidant activity

The antioxidant activity of fresh and blanched samples is presented in Table 1. The blanching pre-treatment in general lowered the antioxidant activity of the onion slices, especially as blanching temperature and time increased ($P<0.05$). However, onions blanched at 60 °C for 3 min and 70 °C for 1 min after drying resulted in a significant increase of the antioxidant activity in comparison with the control. Similar conclusions on drying and blanching of apple pomace were published by Heras-Ramírez *et al*.[36], who reported that blanched apple pomace showed higher antioxidant activity than the unblanched peels. The increase of total phenolic contents and antioxidant capacities during blanching may be mainly ascribed to the increase of the contents of individual phenolic compounds. Furthermore, synergistic and additive effects of phenolic compounds may enhance the antioxidant activity.[37] In fact, some studies have reported an increase of the antioxidant content derived from structural changes in tissues that

may release bound antioxidant polyphenols,[18] resulting in an increase of antioxidant activity despite the thermal treatments applied to the food materials.[38] On the other hand, thermal processes may also induce chemical changes of phenolics resulting in the formation of degradation products, which may retain or even feature a higher antioxidant activity.[39] Chantaro *et al.* [40], for instance, observed that the drying of carrot peels led to the reduction of antioxidant capacity with correlation to the loss of total polyphenols.

Colour analysis

The colour parameters of fresh and blanched onion slices are shown in Table 3. Blanching temperature and time had significant effect on the colour of the dehydrated onion slices ($P<0.05$). All the blanched-dried samples had a lower luminosity compared to the unblanched-dried samples (Table 3), which decreased further as blanching time and temperature time increased. The same trend was observed for the a* and b* coordinates, meaning that higher temperatures and blanching times result in slightly greener/yellower onion slices rather than redder/bluer. At 80 °C for 10 min, excessive loss in the natural pigments and decreased lightness were observed. This might be the result of the non-enzymatic browning and caramelization due to the high temperature, similarly to the results found in carrots by Gonçalves *et al.*[22]

Effect of blanching temperature and pre-treatment time on drying kinetics of

onion slices

The moisture ratio (MR) of the blanched and unblanched onion slices decreased continuously with drying time (Figures 1a-d). This continuous decrease in moisture ratio indicates a diffusion controlled internal mass transfer. This is in agreement with the observations of Kingsly *et al.*[41] regarding the drying properties of blanched onion, figs and peach. The blanching pre-treatment increased the drying rate of onion samples. The drying rates of unblanched and blanched onions were initially high as a result of the great initial amounts of free water, but decreased rapidly to almost the same rate in the course of drying.

At any blanching temperature (60, 70, 80 °C), the initial drying rate increased as the blanching time increased from 3 to 10 min. However, there was a progressive drop in the drying rate at a higher blanching time than at a lower blanching time, resulting in a longer drying time. This drop in the drying rate at a higher blanching time may be ascribed to the gelatinization of carbohydrates,[42] which increased as blanching time increased, thus leading to lower rates of moisture transport from inside the blanched onions to their surface during drying.

In addition, at all each blanching times (1, 3, 5 and 10 min), the initial drying rate increased as the blanching temperature increased from 60 to 80 °C (Figures 1a-d). However, there was a more gradual decrease in the drying rate for samples blanched at higher temperatures, probably due to the greater extent of the carbohydrate gelatinization, which seems to affect the mobility of water during drying and

accordingly reduces the water diffusivity of the onion slices.[42]

Evaluation of the models

The purpose of testing different models was to compare the drying efficiency between unblanched (control) and blanched samples.

The experimental moisture content obtained during the drying experiments was converted to moisture ratio (MR) and then fitted to the 18 different models (Table 4). Based on the statistical results of reduced chi-square (χ^2), root mean square (RMSE) and correlation coefficient (R_2), the Two-term model had the best performance for the unblanched samples (Table 5), while the Modified Page and the Two-term exponential model had the best fit for the blanched onions (Table 6). According to Table 6, the χ^2 and RMSE values were very low for all blanching conditions, with R^2 between 0.927 and 0.999, indicating an excellent fit. Table 7 shows the constants of the two models aforementioned.

Effective moisture diffusivity and activation energy

The effective moisture diffusivity (D_{eff}) during drying and the activation energy were determined by the Fick's diffusion model and the Arrhenius model, respectively, and the results are shown in Table 8. The effective diffusivity ranged between 3.32×10^{-11} m^2 s^{-1} to 5.27×10^{-11} m^2 s^{-1}, 5.01×10^{-11} m^2 s^{-1}, and 4.74×10^{-11} m^2 s^{-1} for the

samples blanched at 60 °C , 70 °C and 80 °C, respectively. The effective diffusivity was higher for longer blanching times. An increase in moisture diffusivity was observed for all blanched samples in comparison to the control (unblanched). Agarry *et al.*[43] reported that blanching prior to drying improves the effective moisture diffusivity as a result of the high draining of additional water absorbed during blanching. An Arrhenius-type equation was used to calculate the activation energy. The natural logarithm of D_{eff} as a function of the reciprocal of absolute temperature was plotted for the blanched samples (Figure 2). The activation energy ranged from 2.367 to 9.779 kJ mol^{-1}. Higher activation energies were observed for the control (unblanched) sample (9.779 kJ mol^{-1}). The slightly lower activation energy of pre-treated onions compared to untreated samples is an indication that less energy is used during drying of onions subjected to blanching. The fact that water travels faster in pre-treated samples indicates that blanching can be used as a pre-treatment to optimize the drying process of onion in terms of energy demand.[42] The cell wall rupture ascribed to blanching results in high internal mass transfer during drying and thus had higher moisture diffusivities. In fact, it has been reported that blanching generally increases water diffusion from within the product to its surface during drying of fruits.[41] Similar results of the influence of blanching pre-treatment on moisture diffusivity during air drying were reported in apricots.[44]

CONCLUSIONS

Hot water blanching is currently the most preferred pre-treatment to fruits and

vegetables due to the low capital costs and blanching uniformity. Short-time water-blanching was found to be a suitable initial step in the production of dried onion slices. Blanching affected the individual phenolic compounds, the total phenolic content and the antioxidant capacity, and proved to be a suitable method regarding the retention of polyphenols and antioxidant capacity at some operational conditions, since minor destruction of tissue may better protect secondary metabolites from degradation.

Pre-treatments such as blanching are effective in retarding the oxidation reactions by native enzymes present in onion slices. This method increases the phytochemical constituents of the onion slices responsible for its antioxidant activity and total phenolics. From the current study, it can be deduced that blanching at 70 ºC for 1 min and at 60 ºC for 3 min followed of drying are the optimum process conditions.

The combination of blanching and hot air oven drying treatments led to a higher recovery of phenolic compounds and enhanced the antioxidant capacity. For better recovery of bioactive phenolic compounds from onion slices, the combination of blanching with short time and hot air oven drying (60 ºC) as a pre-treatment may be favourable.

The use of blanching as a pre-treatment in the drying of onions is also recommended because it reduces the drying time. In addition, since the use of blanching as a pre-treatment optimizes the drying process of onions in terms of energy utilization, it is recommended for use by local processors in order to reduce the energy demand involved in onion drying. This will lower the production cost which will accordingly result in higher earnings by the processors.

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Table 1 – Phenolic content, flavonoid content, anthocyanin content and antioxidant activity of blanched and unblanched onion slices.

Blanching temperature (^{o}C)	Blanching time (min)	TPC	TFC	TAC	FRAP	DPPH
Control	0	7.59±0.37^{b}	2.26±0.04^{bcd}	1.15±0.20^{c}	12.40±0.12^{bc}	8.00±0.23^{b}
60	1	7.60±0.20^{b}	2.84±0.13^{ab}	0.87±0.19^{d}	12.43±0.12^{bc}	8.09±0.26^{b}
	3	9.31±0.19^{a}	3.01±0.49^{a}	1.55±0.14^{b}	13.69±0.11^{a}	8.76±0.07^{a}
	5	7.08±0.11^{bc}	2.76±0.33^{ab}	0.77±0.06^{d}	11.98±0.11^{cd}	7.36±0.14^{cd}
	10	5.79±0.30^{de}	1.84±0.06^{cde}	0.51±0.04^{de}	11.29±0.16^{def}	7.20±0.10^{d}
70	1	9.65±0.29^{a}	3.21±0.05^{a}	1.98±0.05^{a}	13.53±0.15^{a}	8.62±0.23^{a}
	3	8.91±0.21^{a}	2.86±0.17^{ab}	0.75±0.15^{d}	12.33±0.13^{bc}	7.92±0.15^{b}
	5	7.43±0.42^{b}	2.38±0.09^{bc}	0.58±0.08^{de}	11.82±0.11^{cde}	7.26±0.11^{d}
	10	5.91±0.20^{de}	1.67±0.15^{de}	0.47±0.05^{de}	11.19±0.13^{ef}	7.03±0.17^{d}
80	1	7.07±0.16^{bc}	2.28±0.22^{bcd}	1.08±0.17^{c}	12.03±0.23^{cd}	8.02±0.24^{b}
	3	6.46±0.29^{cd}	1.72±0.13^{de}	0.85±0.06^{d}	11.33±0.24^{def}	7.80±0.19^{bc}
	5	5.55±0.40^{ef}	1.79±0.11^{cde}	0.54±0.13^{de}	10.58±0.32^{g}	7.13±0.46^{d}
	10	5.11±0.19^{f}	1.51±0.17^{e}	0.53±0.15^{de}	10.57±0.34^{g}	6.50±0.37^{e}

The results are expressed in mean ± standard deviation for triplicates. Means in the same columns with different superscript letters are significantly different according to the Tukey's test ($P<0.05$).

TPC: Total phenolic content (mg GAE g $^{-1}$ DW); TFC; Total flavonoid content (mg quercetin g $^{-1}$ DW); TAC: Total anthocyanin content (mg cyanidin 3 glucoside^{-1} g DW); Antioxidant activity: FRAP (mg Trolox g^{-1} DW); Antioxidant activity: DPPH (mg Trolox g^{-1} DW).

Table 2 – Quercetin content of blanched and unblanched onion slices.

Blanching temperature (°C)	Blanching time (min)	Q 4' G	Q 3,4' D	Q
Control	0	812.08±97.80^{c}	1090.17±200.53^{a}	25.40±2.39^{f}
60	1	936.51±34.60^{b}	87.80±1.97^{b}	139.42±25.60^{c}
	3	1124.32±97.73^{a}	114.75±14.43^{b}	226.20±24.29^{b}
	5	961.53±29.97^{ab}	77.79±6.81^{b}	141.96±14.23^{c}
	10	310.49±17.18^{ef}	11.01±2.61^{b}	46.96±3.38^{ef}
70	1	981.50±16.91^{ab}	180.06±4.64^{b}	392.31±23.51^{a}
	3	940.73±44.16^{b}	175.75±14.72^{b}	362.03±24.85^{a}
	5	826.29±44.28^{bc}	145.83±30.87^{b}	228.79±34.38^{b}
	10	346.77±83.01^{e}	63.65±14.18^{b}	46.38±10.44^{ef}
80	1	740.90±123.48^{cd}	100.98±17.17^{b}	126.25±10.94^{cd}
	3	625.57±42.51^{d}	83.75±6.91^{b}	181.14±14.09^{bc}
	5	339.49±44.11^{e}	49.22±13.22^{b}	77.74±11.82^{de}
	10	294.87±42.38^{ef}	30.93±6.15^{b}	45.49±15.46^{ef}

The results are expressed in mean ± standard deviation for triplicates. The data is expressed as μg g^{-1} expressed on dry weight basis (DW). Q 4' G = Quercetin 4'glucoside; Q 3'4 D = Quercetin 3,4'diglucoside; Q = Quercetin. Means in the same columns with different superscript letters are significantly different according to the Tukey's test ($p<0.05$).

Table 3 – Effect of blanching temperature and time on luminosity (L*) and colour coordinates (a* and b*) of onion slices.

Blanching temperature (°C)	Blanching time (min)	L*	a*	b*
Control	0	46.70±3.45^{a}	7.34±1.33^{a}	-0.29±0.42^{g}
60	1	42.57±1.33^{b}	6.28±0.55^{b}	2.34±0.48^{f}
	3	40.99±1.12^{c}	5.69±0.12^{cd}	3.10±0.08^{e}
	5	40.90±1.82^{c}	5.40±0.99^{cd}	3.39±0.12^{de}
	10	39.57±1.11^{c}	4.62±0.32^{e}	3.53±0.72^{d}
70	1	40.27±1.32^{c}	5.82±0.04^{c}	6.27±1.77^{b}
	3	38.64±2.31^{d}	5.39±0.19^{cd}	6.62±0.50^{b}
	5	37.79±1.91^{d}	5.24±0.30^{cd}	8.17±0.03^{a}
	10	35.52±4.20^{e}	4.38±0.69^{ef}	8.37±0.43^{a}
80	1	38.88±1.33^{d}	5.80±0.99^{c}	4.55±0.35^{c}
	3	35.70±1.55^{e}	5.39±0.89^{de}	6.29±0.42^{b}
	5	34.27±1.26^{ef}	4.11±0.84^{f}	8.31±0.37^{a}
	10	32.83±1.97^{g}	4.08±1.49^{f}	8.42±0.22^{a}

L* ranges from 0 (black) to 100 (white), a, from -60 (green) to 60 (red), and b, from -60 (blue) to 60 (yellow). The results are expressed in mean ± standard deviation for triplicates. Means in the same columns with different superscript letters are significantly different according to the Tukey's test ($P<0.05$).

Table 4 – Drying models proposed by various authors and tested in this work.

Model	Expression	Reference
Newton	$MR=\exp(-kt)$	Wang et al. (2007)
Page	$MR=\exp(-kt^n)$	Akoy (2014)
Modified page	$MR=\exp(-(kt)^n)$	Vega et al.(2007)
Henderson and Pabis	$MR=a\exp(-kt)$	Hashim et al. (2014)
Logarithmic	$MR=a\exp(-kt)+c$	Kaur and Singh (2014)
Two-term	$MR=a\exp(-k_1t)+b\exp(-k_2t)$	Sacilik (2007)
Two-term exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Yaldiz O, Ertekin C (2001)
Midilli and others	$MR=a\exp(-kt)+bt$	Ayadi et al. (2014)
Parabolic	$MR=a+bt+ct^2$	Daghbandan et al. (2006)
Wang and Singh	$MR=1+at+bt^2$	Omolola et al. (2014)
Verma and others	$MR=a\exp(-kt)+(1-a)\exp(-gt)$	Akpinar (2006)
Modified Midilli and others	$MR=a\exp(-kt)+b$	Gan and Poh (2014)
Demir and others	$MR=a\exp(-kt)^n+b$	Demir et al. (2007)
Approximation of diffusion	$MR=a\exp(-kt)+(1-a)\exp(-kbt)$	Yaldyz and Ertekyn (2007)
Silva and others	$MR=\exp(-at-bt)$	Pereira et al. (2014)
Peleg	$MR=1-t/(a+bt)$	Da Silva et al. (2015)
Hii and others	$MR=a\exp(-k_1t^2)+b\exp(-k_2t^2)$	Kumar et al. (2012)
Aghbashlo and others	$MR=\exp(k_1t/1+k_2t)$	Aghbashlo et al. (2009)

Table 5 – Goodness of fit of different drying models applied to unblanched dried onion slices.

Model	χ^2	RMSE	R^2
Newton	1.20E-03	0.033	0.990
Page	5.30E-02	0.203	0.893
Modified Page	1.38E-04	0.010	0.999
Henderson and Pabis	1.26E-03	0.031	0.990
Logarithmic	9.61E-02	0.253	0.993
Two-term	2.90E-05	0.004	1.000
Two-term exponential	1.37E-03	0.033	0.990
Midilli and others	3.58E-03	0.049	0.993
Parabolic	9.19E-01	0.783	0.972
Wang and Singh	6.54E+01	7.134	0.990
Verma and others	1.57E-02	0.102	0.994
Modified Midilli and others	1.92E-03	0.036	0.993
Demir and others	6.62E-02	0.192	0.664
Approximation of diffusion	1.47E-03	0.038	0.950
Silva and others	6.00E+01	5.100	0.939
Peleg	5.74E+01	2.134	0.949
Hii and others	3.90E-05	0.054	0.980
Aghbashlo and others	7.98E-05	0.040	0.980

Reduced chi square (χ^2); Root mean square error (RMSE); Regression coefficient (R^2).

Table 6 – Goodness of fit of the best models evaluated in this work to describe the drying kinetics of blanched dried onion slices.

Model	Blanching time (min)	Blanching temperature (°C)	χ^2	RMSE	R^2
Modified Page $MR=\exp(-(kt)^n)$	1	60	1.29E-04	0.010	0.999
		70	1.35E-03	0.032	0.991
		80	3.90E-03	0.055	0.993
	3	60	8.61E-05	0.008	0.999
		70	3.70E-04	0.017	0.998
		80	5.04E-04	0.020	0.997
	5	60	8.28E-04	0.025	0.984
		70	4.16E-03	0.057	0.995
		80	1.12E-03	0.029	0.99
	10	60	1.63E-04	0.011	0.999
		70	4.73E-04	0.019	0.997
		80	4.36E-03	0.058	0.991
Two-term exponential $MR=a\exp(-kt)+(1-a)\exp(-kat)$	1	60	1.52E-04	0.011	0.999
		70	1.37E-03	0.033	0.990
		80	8.59E-03	0.082	0.927
	3	60	6.16E-05	0.007	1.000
		70	3.47E-04	0.016	0.997
		80	3.88E-04	0.017	0.998
	5	60	4.71E-04	0.019	0.997
		70	1.93E-03	0.039	0.988
		80	6.30E-03	0.070	0.948
	10	60	1.88E-04	0.012	0.999
		70	4.52E-04	0.019	0.997
		80	8.82E-04	0.026	0.992

Reduced chi square (χ^2); Root mean square error (RMSE); Regression coefficient (R^2).

Table 7 – Constants of the Modified Page model and the Two-term exponential model applied to blanched dried onion slices.

	Blanching temperature (°C)	Blanching time (min)	k	n
Modified Page	Control	0	0.562	1.267
	60	1	0.573	1.248
		3	0.643	1.230
		5	0.524	1.184
		10	0.638	1.196
	70	1	0.679	0.927
		3	0.611	1.106
		5	0.563	1.100
		10	0.549	1.095
	80	1	0.640	0.830
		3	0.643	0.837
		5	0.489	0.821
		10	0.467	0.800
	Blanching temperature (°C)	Blanching time (min)	k	a
Two-term Exponential	Control	0	0.608	1.058
	60	1	0.858	1.832
		3	0.969	1.848
		5	0.573	1.889
		10	0.895	1.736
	70	1	0.819	0.626
		3	0.799	1.609
		5	0.704	1.847
		10	0.687	1.555
	80	1	0.401	1.051
		3	2.450	0.208
		5	0.375	1.057
		10	0.778	0.519

k, n, a are empirical coefficients retrieved from drying experimental data.

Table 8 – Kinetic parameters of unblanched and blanched dried onion slices.

Blanching temperature (°C)	Blanching time (min)	D_{eff} (m^2 s^{-1})	Ea (KJ mol^{-1})
Control	0	3.32E-11	9.779
60		4.69E-11	
70	1	4.57E-11	2.367
80		4.47E-11	
60		4.97E-11	
70	3	4.78E-11	2.832
80		4.67E-11	
60		5.27E-11	
70	5	5.01E-11	5.194
80		4.74E-11	
60		5.03E-11	
70	10	4.81E-11	5.212
80		4.52E-11	

D_{eff}: Effective diffusivity; Ea: Activation energy.

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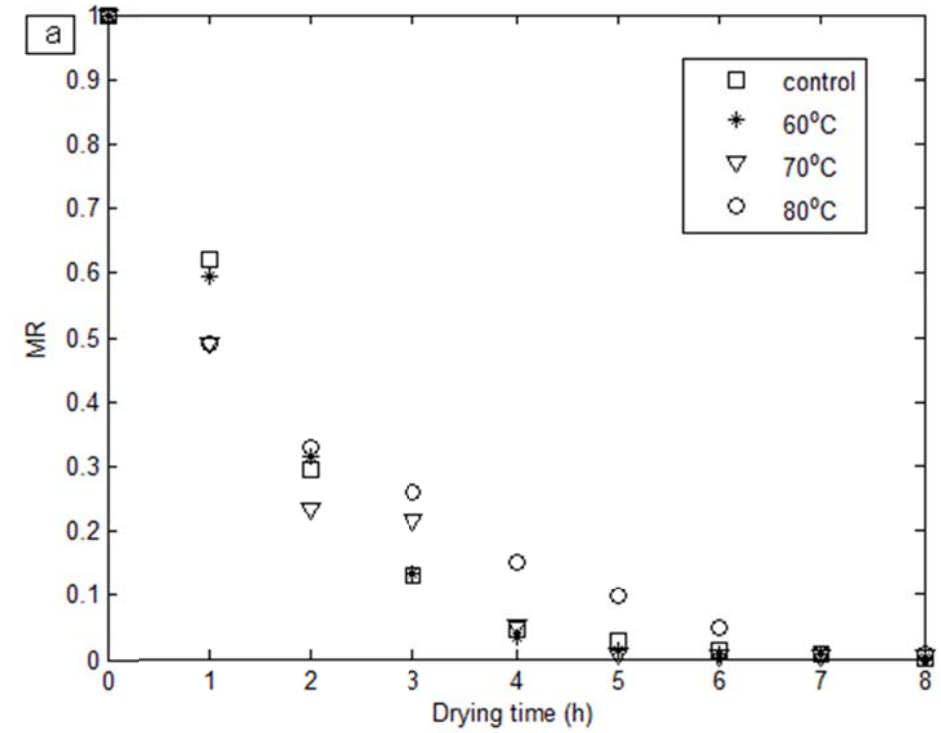

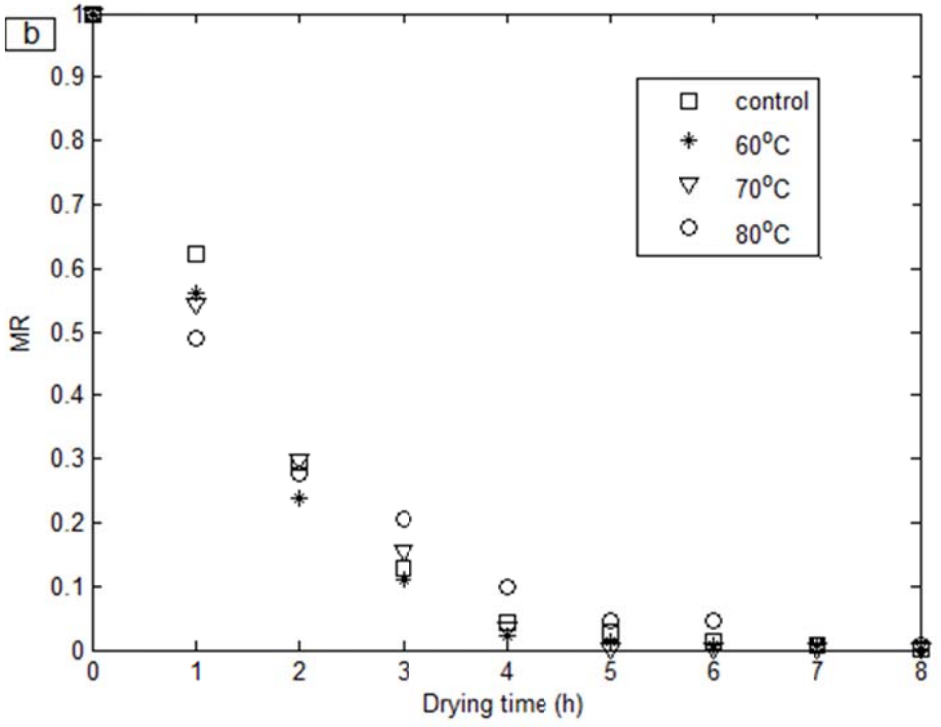

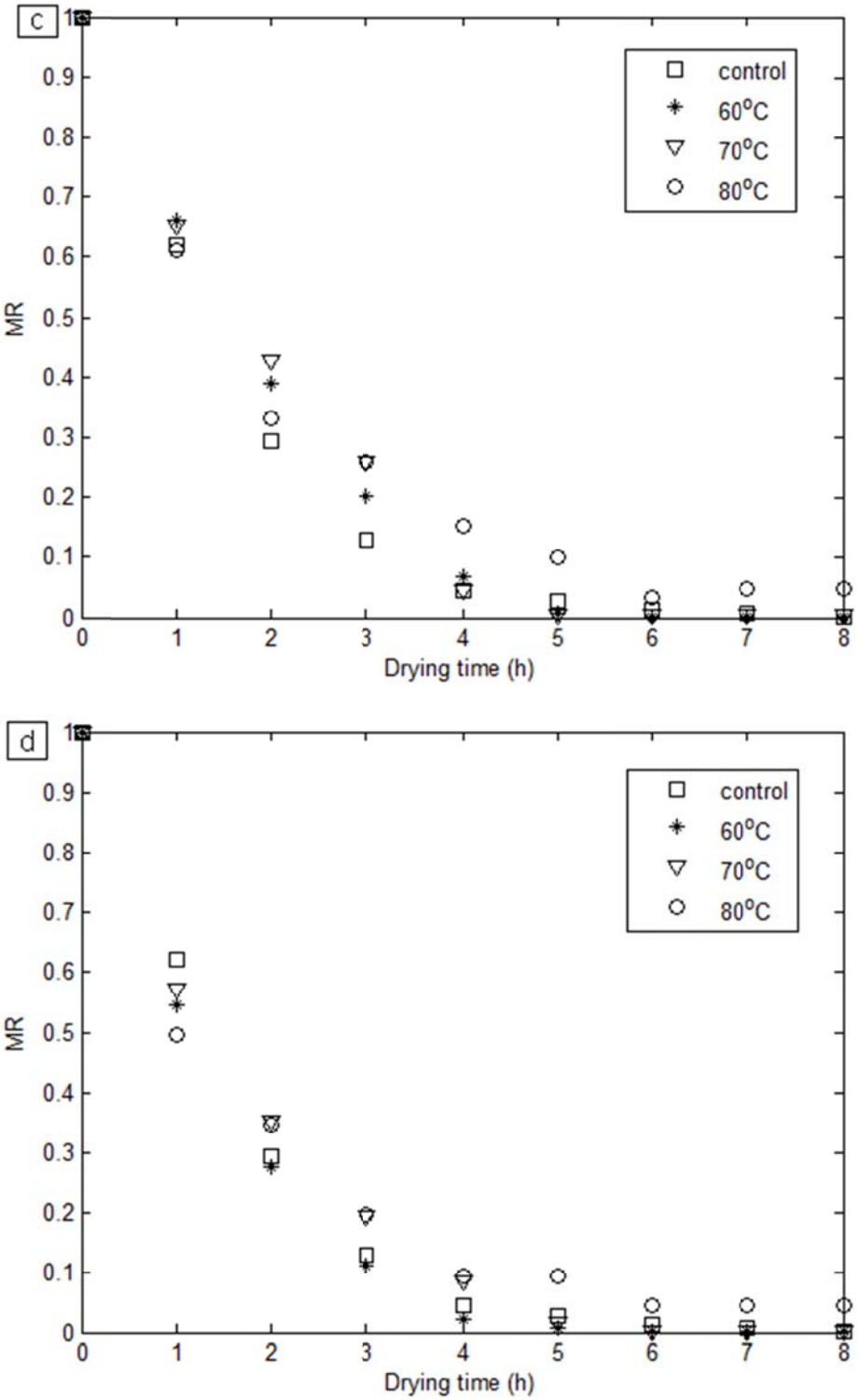

Figure 1 – Moisture content versus drying time of onion slices blanched for: (a) 1 min, (b) 3 min, (c) 5 min, and (d) 10 min.

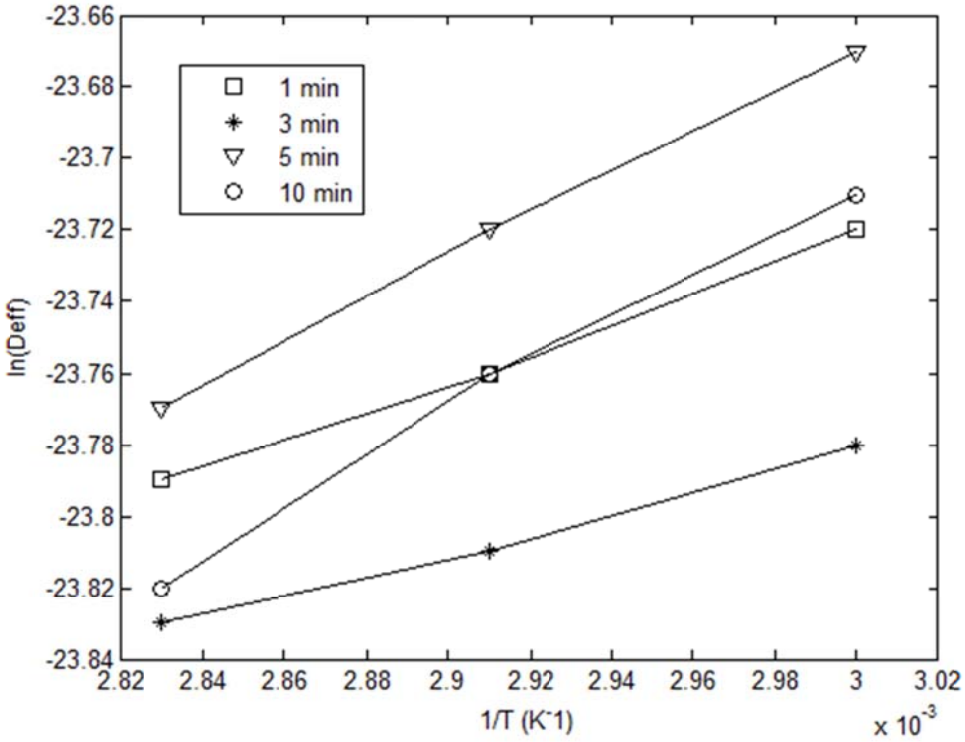

Figure 2 – Arrhenius plot of the activation energy.