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Full Length Research Paper

Modeling pre-treatments effect on drying kinetics of garlic (*Allium sativum L.*) slices in a convective hot air dryer

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The study investigated the effect of different pretreatments such as citric-acid (CA), potassium-metabisulphite (KMS), and ethylenediamine-tetraacetic acid (EDTA) on the drying kinetics, allicin and colour of garlic slices in a convective hot-air dryer at temperatures of 45, 50 and 55°C. The allicin content of the fresh garlic slices compared with the dried slices increased non-linearly with increase in temperature from 8.6 to 23.5, 13.3 to 22.4, 11.9 to 23.4 and 12.3 to 24.1 µg/ml for the control, CA, KMS, and EDTA samples, respectively. The drying characteristics were evaluated against Page et al. (1949) mathematical models on the basis of the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). The drying characteristics of garlic slices of the control were best described by the Midilli et al. (2002) model whilst the CA, KMS, and EDTA pretreated samples were best described by the Henderson and Pabis (2006) model within the confines of the experiments. The colour of the fresh and dried garlic slices were measured in Hunter parameters. The KMS pretreated samples showed greatest brightness (85.95) and least redness (1.36) in colour at 50°C and 45, respectively compared with the fresh, whereas the EDTA pretreated samples were yellower (17.43) at 45°C.

Key words: Garlic slices, drying models, pre-treatments, allicin content, colour.

INTRODUCTION

Garlic (*Allium sativum L.*) has been a subject of considerable interest as a medicine world-wide since ancient times (Arzanlou and Bohlooli, 2010). It is a nutritional herbaceous plant known for its medicinal as well culinary benefits, which originated from the mountains of Central Asian regions. Globally, China is by far the largest producer of garlic, producing over 75% of world tonnage followed by India, Korea, and the USA (FAOSTAT, 2005). By the action of the enzyme alliinase, allyl-S-cysteine sulfoxide (alliin) is converted to diallyl thiosulphate (allicin) and finally disproportionate to disulfides and thiosulphates (Krest et al., 2000). Many studies have provided strong evidence that most of these biological functions of garlic are attributed to allicin (Li and Xu, 2007; Krest et al., 2000; Mousa, 2001). These biological effects of thiosulphates can be related to their strong sulfhydryl-modifying and antioxidant properties (Rabinkov et al., 1998; Prasad et al., 1996). Li and Xu (2007) reported that no compound outside the thiosulphate, of which allicin is about 60 to 80% has been

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found that accounts for a significant portion of the pharmaceutical activities of crushed garlic at levels representing normal human consumption (2 to 5 g/d). In *in-vitro* studies, garlic is demonstrated to possess antimicrobial (Ankri and Mirelman, 1999), antithrombotic, anticancer, anti-platelet aggregation and antioxidant (Corzo-Martinez et al., 2007) activities. Additionally, *in-vivo* studies in animal and human clinical trials demonstrated enormous benefits of garlic in a number of pathological conditions, including hyperlipidemia (Jabbari et al., 2005), cardiovascular disorders, and arteriosclerosis (Rahman and Lowe, 2006). Besides, epidemiological studies have revealed that people with high intake of garlic have lower risk of stomach cancer (Galeone et al., 2006). The relatively high moisture content of fresh garlic (about 70% w.b) shows that it is unfit for long time storage. Consequently, majority of the garlic supplements sold today is dried garlic powder tablets that are standardized on allicin (Sovova, 2000; Lawson et al., 2001).

Pretreatment is an essential step in the processing of food materials (Senadeera et al., 2000). Various methods of pretreatment, which reduce drying time includes chemical pretreatment, blanching, and osmotic dehydration (Ade-Omowaye et al., 2003; Piga et al., 2004; Tharrington et al., 2005, Xiao et al., 2009, Tunde-Akintunde, 2010). Many workers reported that pretreatment can speed up drying rate, improve the quality of dried product, prevent browning, and help retain volatile compounds (Jayaraman and Gupta, 2006; Singh et al., 2008). Studies done by Xiao et al. (2009), Davoodi et al. (2007), Gazanfer and Sefa (2006) and Doymaz (2004) showed that chemical pretreatment could significantly accelerate the drying process and remarkably improve the quality of dried products such as sweet potatoes, mushrooms, red pepper, and plums.

Garlic has to be dried in slices to ensure uniformity of dried products for the pharmaceutical and food industry. The demand for high-quality dried products is increasing all over the world (Doymaz, 2010). Drying is an energy-intensive operation and a complex thermal process in which unsteady heat and moisture transfer occur simultaneously (Sahin and Dincer, 2005). Mathematical modeling of the drying process is very important because of the simultaneous heat and mass transfer mechanisms (Erbay and Icier, 2008). From an engineering point of view, modeling is necessary for predicting the drying time, product moisture content, developing new products, designing the appropriate equipments, and control parameters for optimization of the drying process. Many food materials such as onions, carrot, tomatoes, due to their nature are often sliced into thin thickness and frequently dried as one layer of sample particles called thin-layer drying. Several mathematical models have been proposed to describe the drying process, among which, thin-layer drying models have been used extensively. Thin layer drying models describing the drying phenomenon of agricultural materials have been categorized into theoretical, semi-theoretical, and empirical (Özilgen and Özdemir, 2001; McMinn, 2006).

The determination of the best model describing the drying bahaviour of garlic leaves could give benefit to obtain design parameters for industries in the drying of garlic. Although thin-layer drying models of onions, red/chilli pepper, olive leaves, mistletoe, nestle leaves, rehmannia, barberries, tea leaves, thyme, and spinach leaves have been developed for various drying conditions and techniques (Mota et al., 2010; Tunde-Akintunde, 2010; Erbay and Icier, 2008; Kose and Erenturk, 2010; Alibas, 2008; Rhim et al., 2007; Aghbashlo et al., 2009; Ghodake et al., 2006; Doymaz, 2009/2010), few research results are available on modeling pre-treatments effect on the drying kinetics of garlic slices in a convective hot air dryer in open literature to the best of authors knowledge.

Therefore, the objective of the study was to model the effect of pre-treatments such as ethylenediamine tetraacetic acid (EDTA), potassium metabisulphite (KMS), and citric acid (CA) on the drying kinetics of garlic slices in a convective hot air dryer against the Page (1949), Henderson and Pabis (2006) and Midilli et al. (2002) widely used drying models available in scientific literature. The most important quality attribute of dried garlic such as allicin content and colour were also investigated.

MATERIALS AND METHODS

Fresh garlic of good quality was procured from Qin Hua Garlic Company in Xu Zhou, China. The garlic was stored in a refrigerator at a temperature 5°C in order to slow down the respiration, physiological and chemical changes (Maskan, 2001; Karaaslan and Tuncer, 2008). Prior to drying, the white thin papery coverings were removed from the whole bulb and the cloves. The individual cloves were cut into slices of thickness 3 mm using a cutting machine. Three pretreatments of 0.5% citric acid (CA), 0.5% potassium metabisulphite (KMS), and 0.75% ethylene diamine tetraacetic acid (EDTA) were used. A soaking time of 10 min each was used for the various pretreatments. One sample was used as the control (CONT) (treated with distilled water).

Drying equipment and drying method

The adjustable cabinet oven dryer used in the study (Shanghai Experimental Apparatus Company Limited, 101C-3B) has the technical features of 230/380 V, 50 Hz and 59 kW, with a maximum temperature of 300°C. The velocity of the drying air was kept constant at 1.2 m/s throughout the whole experiment. 50 g of the pretreated garlic slices, each replicated three times were dried in the oven dryer at drying air temperatures of 45, 50 and 55°C. The mass of the drying samples was monitored every 2 h until constant mass was observed. The electronic balance used to monitor the mass of drying samples was of 0.01 g precision (Sartorius BS2202S, Germany). The moisture contents of the samples during drying were calculated using the mass balance approach. The

Table 1. Mathematical models applied to the drying curves.

Model number and name	Model expression	References
Page	$MR = \exp(-kt^n)$	Page (1949)
Midilli et al.	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002)
Henderson and Pabis	$MR = a\exp(-Kt)$	Ghodake et al. (2006).

garlic slices were put in a thin layer on a round stainless steel meshed bowl and dried to a final moisture content of about 4.94 to 9.53% (w.b). The initial moisture content of the fresh garlic was determined using the oven dry method at 105°C for 24 h. The average moisture content was used to plot the drying characteristics curves for the various pretreated garlic slices with dimensionless moisture ratio against drying time.

Drying kinetics expressed in terms of empirical models

The drying kinetics of garlic slices was expressed in terms of empirical models, where the experimental data obtained for the three different temperatures (45, 50 and 55°C) was plotted in the form of dimensionless moisture ratio (MR) (Equation 1) against drying time (expressed in hours).

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

where, MR is the moisture ratio, M is the moisture content at any time, t, M_e is the equilibrium moisture content, and M_0 is the initial moisture content.

The experimental set of (MR, t) were fitted to three different empirical drying models widely used in scientific literature shown in Table 1 to describe the drying kinetics of garlic slices. Three primary criteria were used to determine the goodness of fit to the models; the correlation coefficient (R^2), the root mean square error (RMSE) and the reduced chi-square (χ^2). The highest R^2, lowest χ^2 and RMSE were used to determine the goodness of fit. Several authors have used these criteria to select the best models for drying mistletoe (Köse and Erentürk, 2010), onion slices (Mota et al., 2010), aromatic plants (Akpinar, 2006), olive leaves (Erbay and Icier, 2008), okra (Doymaz, 2005), thyme (Doymaz, 2010), and aloe vera (Vega-Galvez et al., 2007).

Determination of allicin content

The allicin content of the garlic slices was determined using the modified Lawson's method (Lawson et al., 1995). Many authors have used similar method to quantify the allicin content in fresh garlic, garlic powder and microencapsulated garlic powder (Miron et al., 1998; Li and Xu, 2007). One gram of fresh garlic cloves was homogenized in 5 ml of Hepes (50 mM, pH 7.5). The homogenate was allowed to stand for 5 to 10 min to ensure complete enzymatic conversion to thiosulphates, and the garlic juice was obtained by centrifuging at 3000 rpm for 5 min. A solution of L-cysteine was freshly prepared in 50 mM Hepes buffer (pH 7.5). The concentration of cysteine was determined by measuring the amount of 2-nitro-5-thiobenzoate (NTB) formed after the reaction with 5,5,-dithio-bis (2-nitrobenzoic acid) (DTNB). All the reactions were carried out at a temperature of 26°C. Five millilitres of L-cysteine solution was added to 1 mL distilled water. One millilitre of the reacted mixture was taken to 100 ml flask and diluted to the mark. Four and a half of the diluted solution was added to 0.5 ml of 50 mM Hepes buffer (pH 7.5) containing 1.5 mM DTNB. The mixture was incubated in a water bath at 26°C for 15 min. The absorbance at 412 nm was measured using UNICO 7200 spectrophotometer after the incubation and denoted as A_o. Five millilitre of L-cysteine was added to 1 ml of garlic juice and the mixture was incubated for 15 min. Reaction mixture of 1 ml was diluted to 100 ml. Four and a half of the diluted solution was added to 0.5 ml of DTNB and incubated in a water bath at 26°C for 15 min. The absorbance at 412 nm was measured after 15 min and denoted as A. The allicin content was determined using the Equation (2)

$$c = \frac{\beta(A_0 - A) \times 0.7 \times 162}{28300} \tag{2}$$

where, c is the concentration of allicin (mg/ml), β is the diluted multiple, 0.7 is the percentage of total thiosulfinate, 162 is the molecular weight of thiosulphate (g/mol).

Garlic extract was prepared by homogenizing 1 g of garlic powder in 5 ml of distilled water. The supernatant obtained by centrifugation at 3000 rpm for 5 min was used to determine the allicin content as indicated previously.

Colour measurements

The colour of the fresh and dried tomato slices was measured in Hunter parameters with an automatic colour difference meter (DC-P3, Beijing, China). The calibration is standardized by placing the tip of the measuring heat flat against the surface of the white and black calibration plates. After standardization, three random readings was recorded; the colour brightness coordinates L measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinates a, measures the red when positive and green when negative, and the chromaticity coordinate b measures yellow when positive and blue when negative. Also, the chroma C (Equation 3) and hue angle (Equation 4) were calculated from the values of L, a, and b, and used to describe the changes in colour after drying. The chroma indicates colour saturation and is proportional to its intensity. The hue angle is another parameter used to characterize colour of food products. An angle of 0^0 or 360^0 represents red hue, while angles of 90°, 180°, and 270° represent yellow, green, and blue hues respectively (Karaaslan and Tuncer, 2008)

$$C = \sqrt{a^2 + b^2} \tag{3}$$

$$\alpha = \tan^{-1}\left(\frac{b}{a}\right) \tag{4}$$

Table 2. Pre-treatments effect on Allicin contents (µg/ml) of fresh and dried garlic slices.

Treatment	Fresh	Dried at 45°C	Dried at 50°C	Dried at 55°C
CA	13.3[a]	20.9[c]	20.8[b]	22.4[d]
KMS	11.9[a]	24.6[d]	20.4[b]	23.4[c]
EDTA	12.3[a]	22.6[c]	19.6[b]	24.1[d]
CONT	8.6[a]	25.0[d]	20.8[b]	23.5[c]

Means bearing the same letters are not significantly different at p = 0.05.

Statistical analysis

Analysis of variance (ANOVA) was carried out on the effect of various pre-treatments on the parameters measured with statistical package program SPSS 16.0 (SPSS, 2007). The Fishers least significance difference (LSD) was used to compare the means of allicin content and colour. Where significant differences were observed, the Duncan multiple range test was employed to separate the means. To evaluate the extent to which the model equations found to describe the variation of moisture ratio against drying time was accurate, non-linear regression analysis was performed. The different statistical test used to describe the goodness of fit of the dried garlic slices are as follows:
Correlation coefficient:

$$R^2 = \frac{N\sum_{i=1}^{N} MR_{\text{pred},i} MR_{\text{expt},i} - \sum_{i=1}^{N} MR_{\text{pred},i} \sum_{i=1}^{N} MR_{\text{expt x},i}}{\sqrt{\left(N\sum_{i=1}^{N} MR_{\text{pred},i}^2 - \left(\sum_{i=1}^{N} MR_{\text{pred},i}\right)^2\right)\left(N\sum_{i=1}^{N} MR_{\text{expt},i}^2 - \left(\sum_{i=1}^{N} MR_{\text{expt},i}\right)^2\right)}} \quad (5)$$

Root mean square error:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{\text{expt},i} - MR_{pred,i}\right)^2} \quad (6)$$

Reduced chi-square: $$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\text{expt},i} - MR_{pred,i}\right)^2}{N - z} \quad (7)$$

where $MR_{\text{expt},i}$ and $MR_{\text{pred},i}$ are the experimental and predicted dimensionless *MR* respectively, N is the number of observations, and z is the number of constants.

RESULTS AND DISCUSSION

Effect of pretreatments and drying temperature on the allicin content

Table 2 displays the allicin content of garlic, fresh and dried under different pretreatments and different temperatures (45, 50, and 55°C). Figure 1 shows the variation of allicin content against drying time for the different pre-treatments at 55°C hot air temperature. From the results obtained, it is possible to see that allicin are influenced by the pretreatments and temperatures used. The diallyl thiosulfinate (allicin) of the garlic generally increased non-linearly with increasing temperature for all the pretreatments used. The allicin content of the EDTA pretreated samples increased significantly from 22.6 to 24.2 µg/ml as drying air temperature increased from 45 to 55°C. At drying temperatures of 45 and 55°C, the control and KMS pretreated samples were significantly higher in allicin content than the CA and EDTA pretreated samples. However, at 50°C, no significant difference (p = 0.05) was found for the control and dried garlic pretreated with CA, EDTA, and KMS. The allicin content of the EDTA pretreated samples increase significantly from 22.6 to 24.2 µg/ml as drying air temperature increases from 45 to 55°C. The general nonlinear increasing trend for the allicin content might be attributed to the decomposition and rearrangement of allyl-S-cysteine sulfoxide to a rather large number of dially thiosulfinate as the temperature increased from 45 to 55°C. The unstable sulfenic acid in onion is reported to behave in a similar manner where it rearranges and decomposes to a rather large number of mercaptans, disulfides, trisulfides, and thiophenes (Lindsay, 1996). The values obtained are relatively higher than what Miron et al. (1998) reported for fungi-resistant garlic (8.85±1.9 µg/ml), fungi prone garlic (3.83±0.6 µg/ml), and commercial garlic (14.20±6.8 µg/ml). Arzanlou and Bohlooli (2010) reported higher values of 0.48, 0.44, and 0.26 mg/ml allicin content for green garlic leaf, garlic

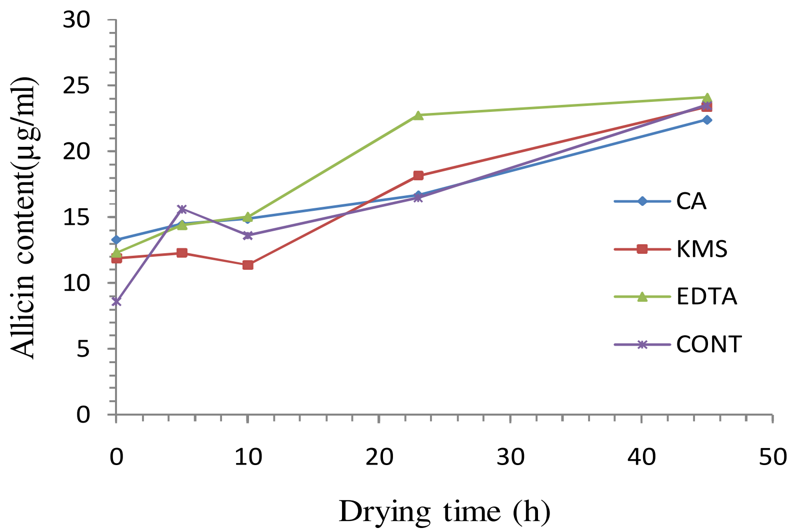

Figure 1. Variation of allicin content against drying time for the different pre-treatments at 55°C hot air temperature.

shoot extract, and garlic leaf extract, respectively. Li and Xu (2007) however, reported 90.2% retention of thiosulphates with microvave-vacuum and freeze drying.

Effect of pre-treatments and temperature on drying curves

The variations of dimensionless moisture ratio with drying time for different pretreatments for the garlic slices dried at various drying temperatures are shown in Figures 2a to c. Table 3 displays the pre-treatment effect on the final moisture content of the fresh and dried garlic slices. The moisture content of the fresh garlic (both the control and treated samples) was found in range of 71.86 and 72.15% (w.b), which reduced to 4.94 to 9.53% after hot air drying at various temperatures of 45, 50, and 55°C. It is clear how the moisture loss followed an exponential decay and how the increase in temperature accelerated the drying process. It took nearly 70 h of drying to reduce moisture content from 71.95 to 5.76 for the control at 45°C hot air temperature. As temperature increased from 50 to 55°C, it took about 40 and 38 h respectively to accomplish the same purpose. Therefore, it can be observed from the drying characteristics curves that temperature of drying air has significant effect on the drying time. As the drying air temperature increased from 45 to 50°C, there was approximately 43% savings in time. These results agree with those reported by Mota et al. (2010) Kose and Erenturk (2010) and Allibas (2008) for convective drying of onion, mistletoe, and nettle leaves.

A similar trend was observed for CA, KMS, and EDTA treated samples. There was significant effect of pretreatment on the drying rate of garlic slices at 45°C drying temperature. EDTA and KMS treated samples increased the drying rates than the Control but were not significant at the 0.05 probability level. As temperature increased to 55°C, the CA and KMS, and the EDTA were significantly different from the control samples. This shows that in terms of the final moisture content of the dried garlic, the pretreatments used did not significantly improved the rate of moisture removal at certain temperatures. For all the pretreatments used, there were gentle moisture removal rates from the garlic. Singh et al. (2008) reported a similar trend when they investigated the effect of pretreatment on the drying characteristics of button mushroom in the temperature range of 40 to 55°C. However, in their investigation, most of the moisture was removed in the early hours of drying. This difference probably might be due to the different cell arrangements and water activity in different food materials.

Fitting of the pretreated drying curves

The dimensionless moisture ratio of the various pre-treatments against drying time for all the experimental data of the 45°C drying air temperature was fitted to the Page (1949), Henderson and Pabis (2006) Midilli et al. (2002) empirical thin-layer drying models available in literature. Figures 3 to 5 display the fitting of the experimental and simulated points to the Page (1949), Midilli et al. (2002) and Henderson and Pabis (2006) models, respectively. The results of such fitting, obtained with SPSS 16.0 software are shown in Tables 4 to 6, which show the values of the estimated constants with the corresponding statistical R^2, χ^2, and RMSE values characterizing each fitting. From the results obtained, it is

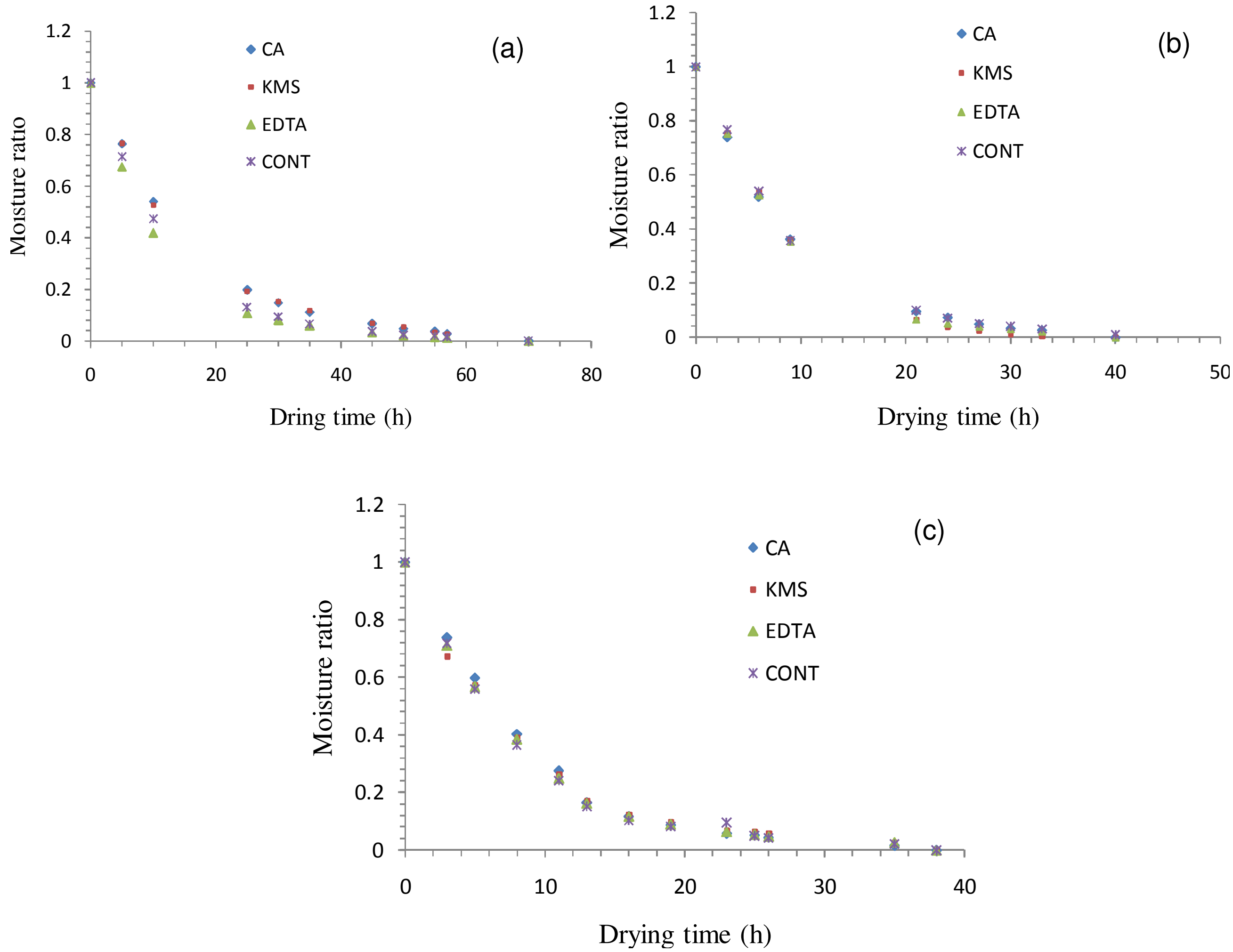

Figure 2. Variation in moisture ratio with drying time for different pretreatments on the drying characteristics curves of garlic slices (a) dried at 45°C hot air temperature, (b) dried at 50°C hot air temperature and (c) dried at 55°C hot air temperature.

Table 3. Pre-treatments effect on moisture contents (%, w.b) of fresh and dried garlic slices.

Treatment	Fresh	Dried at 45°C	Dried at 50°C	Dried at 55°C
CA	72.15	9.53^{c}	4.63^{a}	7.05^{b}
KMS	71.86	2.61^{a}	7.72^{b}	6.58^{b}
EDTA	71.75	4.95^{a}	6.40^{a}	7.01^{b}
CONT	71.95	5.76^{a}	4.94^{a}	4.83^{a}

Means bearing the same letters in rows are not significantly different at p = 0.05

possible to verify that the experimental data fitted to the models used in this study. The correlation coefficients obtained were in the range of 1.0000-0.99823. This means that the three models could satisfactorily describe the convective hot air drying of all the pretreated garlic slices. The relatively high values of correlation coefficients, low reduced chi-square, and low root mean square errors indicate a good predicting capacity for the temperature tested over the entire duration of the drying process. Among the three thin-layer drying models tested, Midilli et al. (2002) drying model obtained the highest R^2 values and the lowest χ^2, and RMSE values for the control whereas the Henderson and Pabis (2006) model obtained highest R^2 values and the lowest χ^2, and RMSE values as well as lowest SEE for the CA, KMS, and EDTA pretreated samples in the temperatures studied. These relatively high R^2 and low RMSE and χ^2 values indicate the suitability of the Midilli et al. (2002)

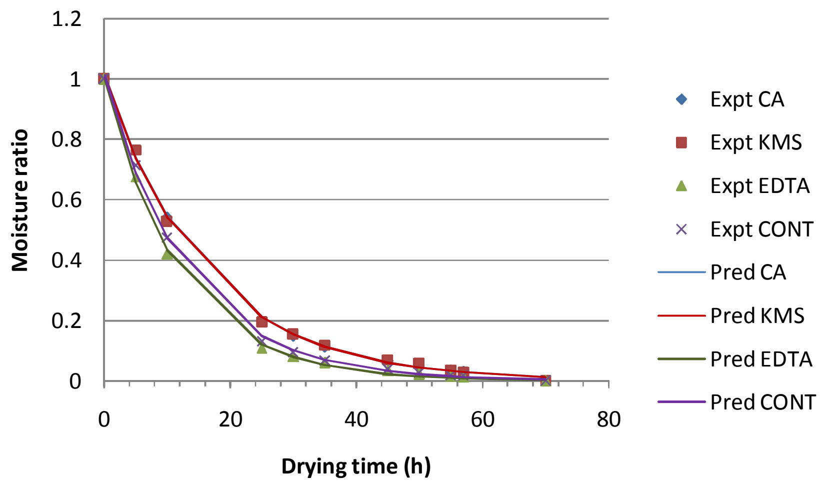

Figure 3. Fitting of the Page (1949) model to the 45°C hot air experimental data.

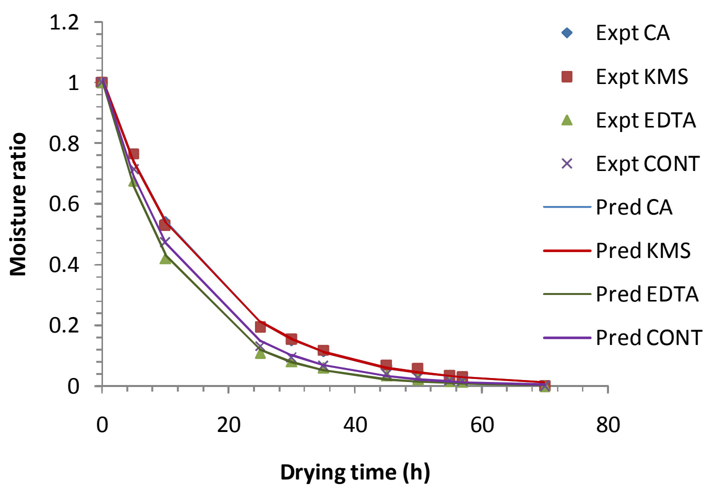

Figure 4. Fitting of the Midilli et al. (2002) model to the 45°C hot air experimental data.

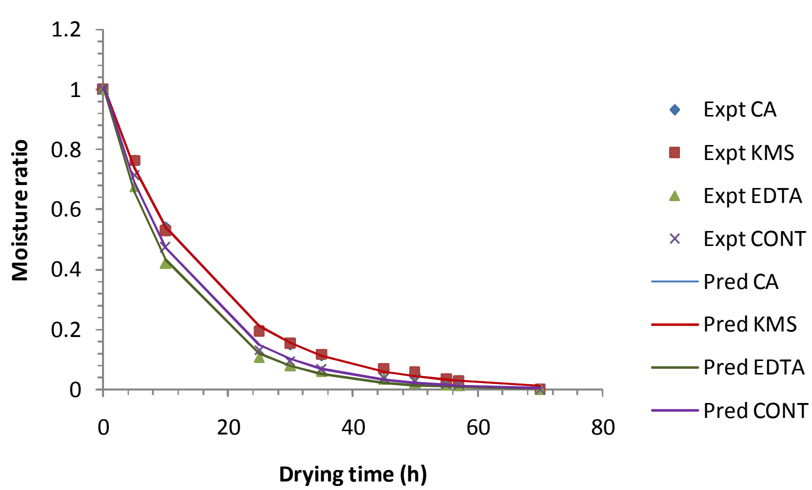

Figure 5. Fitting of the Henderson and Pabis (2006) Model to the 45°C hot air experimental data.

Table 4. Results of the fitting to the Page (1949) model.

Treatment	Model constant (±SEE)	R^2	χ^2	RMSE
CA	k:0.054 (±0.003), n:1.047 (±0.021)	0.99915	1.11×10^{-4}	0.00953
KMS	k:0.057 (±0.005), n:1.026 (±0.028)	0.99827	2.22×10^{-4}	0.01348
EDTA	k:0.081 (±0.005), n:1.015 (±0.024)	0.99911	1.11×10^{-4}	0.00953
CONT	k:0.064 (±0.003), n:1.061 (±0.019)	0.99914	1.11×10^{-4}	0.0095

SEE: Standard error of estimates.

Table 5. Results of the fitting to the Henderson and Pabis (2006) model.

Treatment	Model constant (±SEE)	R^2	χ^2	RMSE
CA	k:0.063 (±0.001), a:1.013(±0.010)	0.99915	1.11×10^{-4}	0.00953
KMS	k:0.063 (±0.001), n:1.010(±0.012)	0.99827	2.22×10^{-4}	0.01348
EDTA	k:0.085 (±0.002), n:1.005(±0.009)	0.99911	1.11×10^{-4}	0.00953
CONT	k:0.076 (±0.002), n:1.012(±0.010)	0.99914	1.11×10^{-4}	0.00953

SEE: Standard error of estimates.

Table 6. Results of the fitting to the Midilli et al. (2002) model.

Treatment	Model constant (±SEE)	R^2	χ^2	RMSE
CA	k:0.053 (±0.005), a:1.004(±0.011) n:1.055 (±0.032), b: 8.79×10^{-5}(±0.000)	0.99915	1.11×10^{-4}	0.011952
KMS	k:0.057 (±0.008), a:1.006 (±0.015) n:1.031 (±0.045), b: 8.40×10^{-5} (±0.000)	0.99823	2.22×10^{-4}	0.016903
EDTA	k:0.078 (±0.006), n:1.003 (±0.010) n:1.037(±0.031), b: -3.93×10^{-5}(±0.000)	0.99911	1.11×10^{-4}	0.011952
CONT	k:0.062 (±0.004), n:1.002 (±0.007) n:1.080 (±0.023), b: -3.86×10^{-5} (±0.000)	1.00000	0.000000	0.000000

SEE: Standard error of estimates.

and Henderson and Pabis (2006) models to describe the profile of the moisture ratio of control garlic slices and the pretreated samples respectively to the temperatures studied. On the contrary, Sharma and Prasad (2004) found that the parabolic model best describes the drying kinetics of garlic cloves.

Colour parameters

The results of colour parameters obtained from the hot air drying processes of various pretreatments at different temperatures are displayed in Table 7 for L (brightness), a (redness), and b (yellowness) values, respectively. It is evident from the table that there was an increase in the brightness of all the garlic samples from 61.86 in the fresh garlic to 85.95 after drying. Compared with the fresh ones, the dried garlic slices showed significant ($p = 0.05$) increase in brightness. At a drying air temperature of 45°C, no significant increase in colour occurred between the CA, CONT and KMS pretreatments. However, there was significant increase in colour, which resulted in samples pretreated with EDTA compared with the others. The greatest increment occurred in KMS treated samples whereas the least occurred in the EDTA pretreated ones. A similar trend occurred as the drying air temperatures increased to 50°C for KMS treated samples. However, CA and EDTA treated samples were significantly brighter than the control. On the contrary, compared with the other samples, the control performed better in terms of the brightness when the temperature increased to 55°C. The results are consistent and higher in brightness than the 73.74 and 72.24 reported by Li and Xu (2007) for combined microwave-vacuum at microwave powers of

Table 7. Comparison between pretreatments for colour parameters during garlic drying (L: brightness, a: redness, b: yellowness, C: chroma, α°: hue angle, SEE: standard error of estimate).

Treatment		*L*	*a*	*b*	*C*	*α°*
Fresh	CA	61.86 (±0.033*)a	0.92 (±0.000)a	22.27 (± 0.033)d	22.28 (± 0.033)d	87.63 (± 0.003)d
	CONT	61.86 (±0.033)a	0.92 (±0.000)a	22.27 (± 0.033)d	22.28 (± 0.033)d	87.63 (± 0.003)d
	EDTA	61.86 (±0.033)a	0.92 (±0.000)a	22.27 (± 0.033)d	22.28 (± 0.033)d	87.63 (± 0.003)d
	KMS	61.86 (±0.033)a	0.92 (±0.000)a	22.27 (± 0.033)d	22.28 (± 0.033)d	87.63 (± 0.003)d
Dried at 45°C	CA	83.95 (±0.026)c	1.90 (±0.009)d	16.49 (±0.022)c	16.59 (± 0.022)c	83.44 (± 0.023)c
	CONT	83.91 (±0.023)c	1.73 (±0.007)b	16.92 (±0.023)c	17.0 (±0.024)c	84.17 (± 0.015)c
	EDTA	83.89 (±0.014)b	1.75 (±0.007)b	17.43 (±0.020)b	17.51 (±0.019)b	84.28 (± 0.028)c
	KMS	84.83 (±0.23)c	1.36 (±0.006)b	16.48 (±0.014)a	16.53 (±0.014)a	85.28 (± 0.024)c
Dried at 50°C	CA	84.30 (±0.006)d	1.70 (±0.003)b	14.17 (±0.011)a	14.27 (± 0.012)a	83.14 (± 0.009)b
	CONT	83.11 (±0.37)b	1.92 (±0.025)c	15.09 (±0.020)b	15.21 (±0.020)b	82.75 (± 0.094)b
	EDTA	84.71 (±0.021)d	1.98 (±0.020)c	17.28 (±0.009)b	17.39 (±0.007)b	84.46 (± 0.068)b
	KMS	85.95 (±0.011)b	1.59 (±0.003)c	16.81 (±0.017)b	16.88 (±0.016)b	84.58 (± 0.015)b
Dried at 55°C	CA	83.78 (±0.007)b	1.80 (±0.015)c	14.47 (±0.033)b	14.58 (± 0.031)b	82.91 (± 0.075)a
	CONT	84.67 (±0.003)d	2.53 (±0.012)a	13.41 (±0.011)a	13.65 (±0.011)a	79.33 (± 0.052)a
	EDTA	84.15 (±0.018)c	2.12 (±0.030)d	14.66 (±0.103)a	14.81 (±0.097)a	81.77 (± 0.174)a
	KMS	83.80 (±0.007)b	1.97 (±0.035)d	16.88 (±0.027)b	17.0 (±0.023)c	83.34 (± 0.126)a

Columns with the same letters are not significantly different at the 0.05 level. *Values are means ± SEE

282, 188 and 94 W, and freeze drying for 48 h of garlic slices, respectively. Sharma and Prasad (2001) studied colour change of fresh garlic cloves in a hot air dryer at 70°C and microwave hot air drying and reported brightness value of 79.32 for both methods. The relatively low temperatures used in this study might have accounted for higher values for brightness. Colour is one of the most important criteria of food and brightness is an important indicator for many powders. In the pharmaceutical industry, brightness of powder may be an indicator of its freshness or purity. At the temperatures studied, the control samples were significantly brighter. This indicates that in terms of the brightness of the dried garlic slices, the pretreatments used did not significantly improved the brightness better than the control at the 5% probability level.

The redness of dried garlic slices compared with the fresh one increased significantly. This shows that all pretreated dried samples were significantly redder than the fresh ones. At hot air drying temperatures of 45 and 50°C, the control, EDTA, and KMS showed no significant difference in redness. In addition, at 55°C hot air temperature, the control/EDTA and CA/KMS were also not significantly different. The increase in redness may be attributed to the occurrence of reaction between the amino acids and reducing sugars in the garlic during drying. The yellowness generally decreased significantly ($p = 0.05$) as drying proceeded. EDTA treated samples were more yellow than others at lower temperatures whereas KMS treated samples became yellower at higher temperatures. Therefore, in terms colour degradation, preservation of the dried garlic in the temperature range of 45 to 55°C was good. The higher L values and a/b values are desirable in dried products (Arslan and Ozcan, 2008).

Conclusion

Hot air drying experiment was carried out for garlic slices pretreated with three different treatments of citric acid, KMS, and EDTA, and control (treated with distilled water) under three drying air temperatures of 45, 50 and 55°C. The results obtained showed that drying characteristics of garlic slices were significantly affected by hot air temperature. The increase in hot air temperature significantly reduced the drying time of garlic slices. The Page (1949), Henderson and Pabis (2006) and Midilli et al. (2002) widely used thin-layer models were fitted to experimental data with the Midilli et al. (2002) model showing the best fit curves for the control garlic slices whereas the Henderson and Pabis (2006) best described the CA, KMS, and EDTA treated samples, even though the three models could satisfactorily describe the drying process of garlic slices. KMS and EDTA treated samples did not show any significant improvement at $p = 0.05$ in the drying rates of the garlic slices at the temperature range used. However, there were significant differences (p = 0.05) in the allicin content of the garlic slices under the different pretreatments. KMS pretreated samples were significantly brighter than the other samples.

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