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Effects of Pretreatments on the Drying Characteristics and Chemical Composition of Garlic Slices in a Convective Hot Air Dryer.

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ABSTRACT

The study investigated the effect of different pretreatments of citric acid (CA), potassium metabisulphite (KMS), and ethylenediamine Tetraacetic acid (EDTA) on the drying characteristics and chemical composition of garlic slices in a convective hot air dryer at drying temperatures of 45, 50 and 55 ^oC. From the results obtained, the moisture diffusivity coefficients varied from 6.84×10^{-8} to 10.10×10^{-8} m^2/s, 5.47×10^{-8} to 10.9×10^{-8} m^2/s, 5.47×10^{-8} to 15.0×10^{-8} m^2/s, and 6.84×10^{-8} to 9.94×10^{-8} m^2/s, for the control and the various garlic slices pretreated with CA, KMS, and EDTA respectively. EDTA pretreated garlic slices chelated more metal ions in the garlic than the other pretreatments and resulted in a significant decrease in ash content from 2.66% to 2.02% in the fresh and dried garlic slices respectively at 55^oC . The allicin content of the EDTA pretreated samples increased significantly from 22.6 to 24.2µg/mL as drying air temperature increased from 45 to 55 ^oC. However, the KMS pretreated dried garlic slices showed the greatest brightness (85.95) in colour compared with the fresh (61.86), whereas the EDTA pretreated samples were yellower (17.43) than the others. On the other hand, the control dried garlic slices were harder (64.5N) than all the pretreated samples. Overall, KMS pretreated samples performed better in terms of moisture diffusivity, ash and allicin content, colour and texture at all drying temperatures investigated.
Keywords: Garlic slices, Drying pretreatments, Hot air dryer, Allicin, Ash, Colour, Texture, Diffusion coefficient.

1.0 INTRODUCTION

Garlic (Allium sativum L.) is a nutritional herbaceous plant known for its medicinal as well as 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). The bulb is a very good source of calcium, phosphorus, selenium, manganese, and low in saturated fat, cholesterol and sodium. It is also rich in vitamins C and B6. A very important health promoting substance in the garlic is allicin, which is formed by an enzymatic reaction on activation of the bulb such as cutting and crushing. 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 recently provided strong evidence that most of these biological functions of garlic are attributed to allicin (Li & Xu, 2007; Krest *et al*., 2000; Mousa, 2001). Li & Xu (2007) reported that no compound outside the thiosulphate, of which allicin is about 60-80% has been found that accounts for a significant portion of the pharmaceutical activities of crushed garlic at levels representing normal human consumption (2-5 g/d). And these biological effects of thiosulphates can be related to their strong SH-modifying and antioxidant properties (Rabinkov *et al*, 1998; Prasad *et al*., 1996). Garlic products have been popular and marketed in recent years as health food for human in many western countries. The relatively high moisture content of fresh garlic (about 70%, w.b) shows that it is unfit for long term storage without sprouting or rotting. Consequently, the majority of the garlic supplements sold today is dried garlic powder tablets that are standardized on allicin (Sovova 2000; Lawson *et al*, 2001). The allicin and other volatile compounds in garlic have to be preserved during processing in order to ensure its medicinal and culinary benefits.

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*, 2000; Piga *et al* 2004; Tharrington *et al*,

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2005, 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 & Gupta, 2006; Singh *et al*, 2008;). Researchers such as (Xiao et al, 2009: Davoodi *et al*, 2007; Gazanfer & 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. The effect of microwave and combined microwave and vacuum drying methods on the allicin content of garlic slices have been investigated by many researchers including (Li & Xu, 2007, Ciu *et al*, 2003, Sharma and Prasad, 2001). However, few research results are available on the effects of different pretreatments on drying and nutritional characteristics of garlic slices. Therefore, the objective of the research was to investigate the effect of different pretreatments such as Ethylenediamine Tetraacetic acid (EDTA), Potassium Metabisulphite (KMS), and Citric acid (CA) on the drying kinetics and chemical composition of garlic slices, and some quality attributes of dried garlic such as colour and texture.

2.0 MATERIALS AND METHODS

2.1 Materials

Fresh garlic of good quality was procured from a Qin Hua garlic company in Xu Zhou, China. The garlic was stored in a refrigerator at a temperature of 5℃ . Prior to drying, the white thin papery coverings were removed from the whole bulb and the cloves. The individual cloves were cut into thickness of 3 mm slices using a cutting machine. Three Pretreatments of 0.5% citric acid (CA), 0.5% potassium metabisulphate (KMS), and 0.75% ethylene diamine Tetraacetic acid (EDTA), were prepared and given to the samples. 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).

2.2 Drying equipment and drying method

The controllable cabinet oven dryer used in the study (Shanghai Experimental Apparatus Company Limited, 101C-3B) has the technical features of 230/380V 50Hz and 59 kW, with a maximum temperature of 300 °C. The velocity of the drying air was kept constant throughout the whole experiment. 50g 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 hrs and later changed to 4 hrs until constant mass was observed. The electronic balance used to monitor the mass of drying samples was of 0.01g precision. The moisture contents of the samples during drying were calculated using the mass balance approach. The garlic slices were put in a thin layer on a round stainless steel meshed bowl and dried to a final moisture content of 4.61-9.53 percent (w.b). The initial moisture content of the fresh garlic was determined using the oven dry method at 105 °C for 24 hrs. The average moisture content was used to plot the drying characteristic curves for the various pretreated garlic slices with dimensionless moisture ratio versus drying time.

2.3 Estimation of effective diffusivity during hot air drying of garlic slices

In drying, diffusivity is used to indicate the flow of moisture from the material. In the falling rate period of drying, moisture removal is controlled mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of the material (Singh *et al*, 2008). The falling rate period of biological material is best described by Fick's diffusion model on the assumption that there is a uniform initial moisture distribution and negligible external resistance. The equation is in the form:

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{L^2} \right) \qquad (1)$$

Where, MR is the moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s), and L is half the thickness of slice of the sample (m), M is the moisture content at any time t, M_e is the equilibrium moisture content, and M_0 is the initial moisture content. Many researchers (Singh *et al*, 2008; Alibas, 2008; Erbay & Icier, 2008; Tunde-Akintunde, 2010) used this model to predict the moisture diffusivity of dried button mushrooms, nestle leaves, olive leaves, and chill pepper respectively.

The moisture diffusivity of the different pretreated garlic slices was obtained from the slope of the graph of *InMR* against the drying time. *InMR* versus time results in a straight line with negative slope (K) and the slope of the line can be used to predict the effective moisture diffusivity according to the equation:

$$K = \frac{\pi^2 D_{eff}}{4L^2} \qquad (2)$$

2.4 Determination of ash content

The ash content of the fresh and dried garlic was determined using the AOAC method. Two grams of powdered dried samples was weighed into porcelain crucibles and ashed in a furnace at a temperature of 560°C for 24 hrs. The ash content in percent was determined by the ratio of the final mass after ashing to the initial mass.

2.5 Determination of allicin content

The allicin content of the garlic during drying was determined using the modified Lawson's method (Lawson *et al*, 1995). Many workers have used similar methods to quantify the allicin content in fresh garlic, garlic powder and microencapsulated garlic powder (Miron *et al*, 2002; Li & Xu, 2007). One gram of fresh garlic cloves, were homogenized in 5mL of Hepes (50 mM, pH 7.5). The homogenate was allowed to stand for 5-10 min to ensure complete enzymatic conversion to thiosulphates, and the garlic juice was obtained by centrifuging at 3000 rpm for 5 min. The 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. 5mL of L-cysteine solution was added to 1mL distilled water. 1mL of the reacted mixture was taken to 100mL flask and diluted to the mark. 4.5 mL 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 UNIC 7200 spectrophotometer after the incubation and denoted as A_o. 5mL of L-cysteine was added to 1mL of garlic juice and the mixture was incubated for 15 min. Reaction mixture of 1 mL was diluted to 100mL. 4.5 mL 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 15min and denoted as A. The allicin content was determined using the equation

$$c = \frac{\beta\left(A_0 - A\right)\times 0.7\times 162}{28300} \tag{3}$$

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 above.

2.6 Determination of Colour

The colour of the fresh and dried garlic slices pretreated with various pretreatments was measured 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, 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 4) and hue angle (equation 5) were calculated from the values of L*, a*, and b*, and used to describe the changes in colour after drying.

$$C = \sqrt{a*^2 + b*^2} \tag{4}$$

$$\alpha = \tan^{-1}\left(\frac{b*}{a*}\right) \tag{5}$$

2.7 Determination of Textural properties

The textural property of the dried garlic slices was evaluated by a compressive test using a texture analyser (TA-XT2i; Stable Microsystems, Godalming, Surrey, UK) employing the method suggested by Nourian et al (2003). A dried garlic sample was placed on a hollow planar base. A compressive force was applied to the sample by a 2 mm spherical probe at a constant speed of 0.5 mm/s until the sample is fractured. The maximum compressive force at rupture of each sample was used to describe the sample texture in terms of hardness. The test was replicated five times and the average values taken.

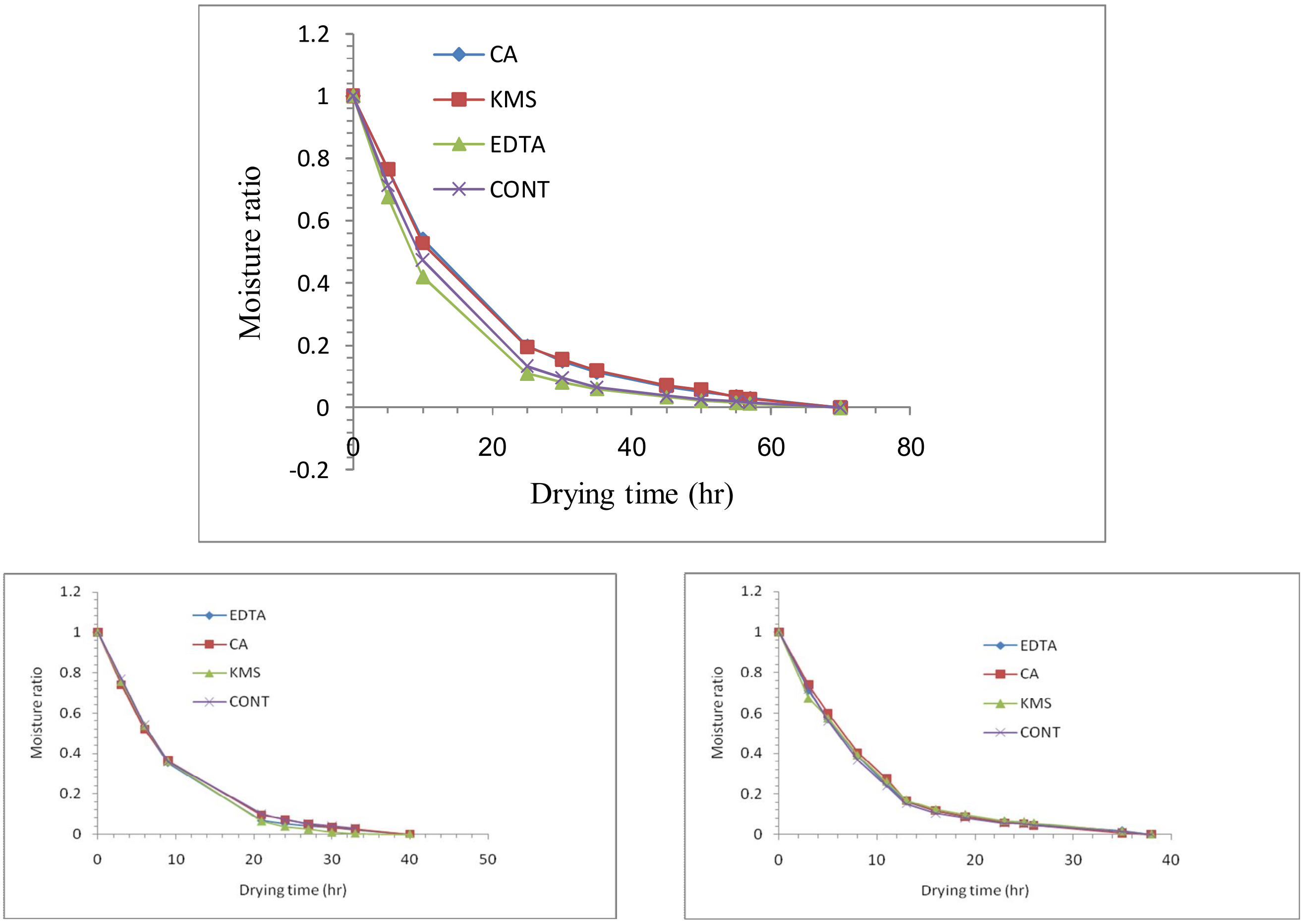
2.8 Statistical analysis

All the experiments except texture were performed in triplicate and conducted using the completely randomized design. Analysis of variance (ANOVA) was carried out using the SPSS 16.0 software. The results were expressed and plotted as the mean value ± standard deviation and standard error of estimates (SD and SEE). ANOVA tests were performed for all experiments at 95% confidence interval. Linear regression analyses to determine moisture diffusivity were also carried out by Excel software. Mean differences in the treatments were tested for significance using the Least Significance Difference (LSD) and where significant differences were observed, the Duncun Multiple Range test (DMRT) was used to separate the means.

3.0 RESULTS AND DISCUSSION

3.1 Hot-air drying curves

The variations of dimensionless moisture ratio with drying time for different pretreatments for the garlic slices dried at various drying temperatures are as shown in figures 1 (a, b, and c). Table 1 displays the statistical analysis of the final moisture content of the dried garlic slices at the various temperatures. The moisture content of the fresh garlic (both the control and treated samples) was found in range of 71.86 and 72.15 per cent (w.b), which reduced to 4.61-9.53 per cent 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 70hrs of drying to reduce moisture content from 71.95 to 5.76 percent for the control garlic slices at 45 drying air temperature. As temperature increased from 50 to 55°C, it took about 40 hrs and 38 hrs respectively to accomplish the same purpose. Therefore, it can be observed from the drying characteristic curves that temperature of drying air has a significant effect on the drying time. As the drying air temperature increased from 45 to 50, there was approximately 43 percent 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.



(b) (c)

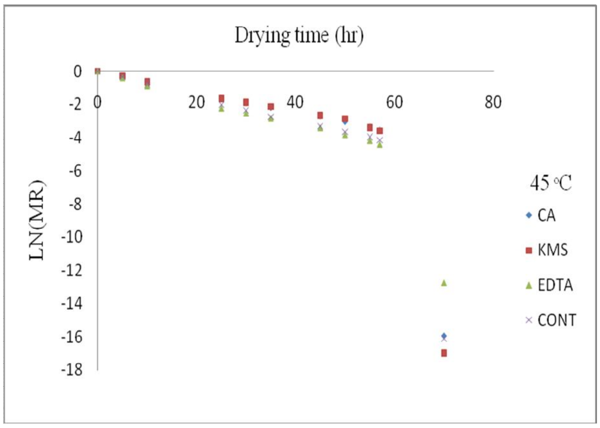
Figure 1: Variation in moisture ratio with drying time for different pretreatments on the drying characteristics curves of (a) garlic slices dried at 45 °C hot air temperature (b) garlic slices dried at 50 °C hot air temperature and (c) garlic slices dried at 55 °C hot air temperature.

A similar trend was observed for CA, KMS, and EDTA treated samples. There was a significant effect of pretreatment on the drying rate of garlic slices at 45°C drying temperature. EDTA and KMS treated samples significantly increased the drying rates as compared to the Control. However, as temperature increased to 55°C , the CA, KMS, and the control were significantly better than the EDTA pretreated samples. This shows that in terms of the final moisture content of the dried garlic, the pretreatments 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.

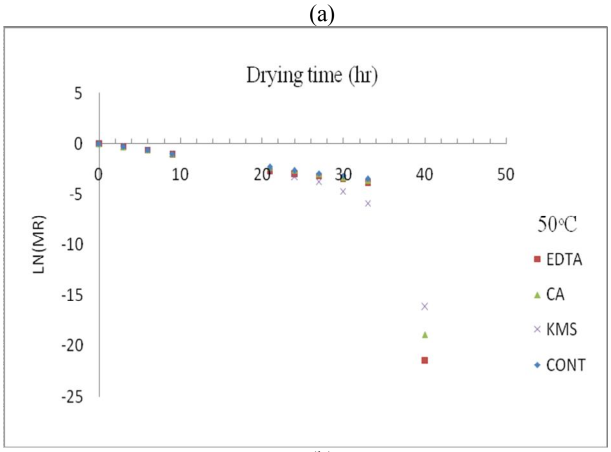
3.2 Moisture diffusivity during drying of garlic slices

Fig. 2 (a, b, and c) shows the variation in Ln(MR) against drying time for the various pretreatments of garlic slices at 45, 50, and 55°C drying air temperatures. The result allowed us to calculate the moisture diffusivity for the various pretreatments at the different temperatures used in this study. The values of the correlation coefficient varied from 0.966 at 55°C to 0.999 at 45 °C, and the diffusivity increased with drying air temperature from a minimum of 5.47 E-08 at 45°C to a maximum of 15.0 E-08 at 55°C. In general, it was observed that Ln(MR) against time followed a straight line equation with negative slope almost throughout the drying process, but at the later stages of drying the curves did not follow the straight line.

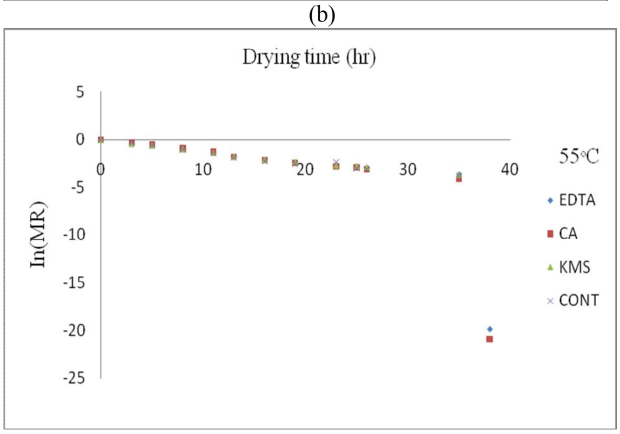
It was found that moisture diffusivity varied from 6.84×10^{-8} to 10.10×10^{-8} m^2/s, 5.47×10^{-8} to 10.9×10^{-8} m^2/s, 5.47×10^{-8} to 15.0×10^{-8} m^2/s, and 6.84×10^{-8} to 9.94×10^{-8} m^2/s, for the control and the various garlic slices pretreated with CA, KMS, and EDTA respectively. The relatively high values of coefficients of correlation found show good fitness between predicted and observed values. The values of coefficient of moisture diffusivities obtained from this study lie in the general range of 10^{-12} to 10^{-8} for drying of food material (Zogzas et al, 1996) and were consistent with what (Mota et al, 2010, Doymaz, 2010; Vega et al, 2007; Singh et al, 2008, Kaya and Aydin, 2009; Erbay and Icier, 2008) reported for drying of onion slices, thyme, aloe vera, mushrooms, Mexican tea, and olive leaves respectively.



(a)



(b)



(c)

Figure 2: Variation in ln(MR) against drying time for different pretreatments of (a) garlic slices dried at 45 °C hot air temperature (b) garlic slices dried at 50 °C hot air temperature and (c) garlic slices dried at 55 °C hot air temperature.

3.3 Effect of pretreatments and drying temperature on the ash and allicin contents

Table 1 displays the chemical composition of garlic, fresh and dried under different pretreatments and different temperatures (45, 50, and 55°C). From the result obtained, it is possible to see that ash and allicin are influenced by the pretreatments and temperatures used. EDTA pretreated garlic slices resulted in the highest significant reduction of ash content and was significant as temperature increased. Generally, there was no significant difference ($p=0.05$) in the ash content of the CA and CONT treated garlic samples at all the drying temperatures. KMS treated samples showed significant increase from 2.75 to 2.95 percent in ash content and later decreased to 2.64 per cent at 55°C. The greatest increase in ash content by KMS might have resulted from the formation of sulphates by the potassium metabisulphates as temperature increased to 50 °C. The highest reduction in the ash content by the samples treated with EDTA was expected because EDTA when added to food has chelating effect resulting in a ring structure that include the metal ions in the food material (Owen, 1996). This could be from the fact that ethylenediamine tetraacetate ion (EDTA) is an hexadentate ligand and are capable of forming six-membered ring in the complex reactions with metal ions for stable chelation (Miller, 1996). Therefore, Ethylenediamine tetraacetate ion (EDTA) provides more dramatic chelates effect than citric acid. The increase in temperature might have accelerated the chelating effect of EDTA than the citric acid. Citric acid forms less stable chelates than EDTA and this might have accounted for its relatively higher ash content than EDTA in the dried garlic at 45 and 55°C drying temperatures. The chelates are very important in foods and all biological systems (Owen, 1996). They are added to foods to sequester mineral ions, such as iron or copper, to prevent them from acting as prooxidants. Chelating agents such as EDTA and CA are not antioxidant in the sense that they arrest oxidation by chain termination or serve as oxygen scavengers. They are, however, valuable antioxidants synergists since they remove metal ions which catalyze oxidation (Lindsay, 1996). 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 24.2µg/mL as drying air temperature increased from 45 to 55°C. At drying temperatures of 45°C and 55°C, the control and KMS pretreated samples were significantly higher in allicin content than the CA and EDTA pretreated samples. This is consistent with a report by Davoodi et al (2007) for dehydration of tomato slices with KMS and $CaCl_2$ using a tunnel dryer. 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 increased significantly from 22.6 to 24.2µg/mL as drying air temperature increased from 45 to 55 °C.The general 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). Li and Xu (2007) however, reported 90.2 per cent retention of thiosulphates with microwave-vacuum and freeze drying.

Table1: Chemical composition of garlic, fresh and dried under different Pretreatments and temperatures

	Treatment	Moisture (% w.b)	Ash (%)	Allicin (mg/mL)
Fresh	CA	72.15(±0.71*)	2.78(±0.060)^{c}	133E-4(± 2 E-5)a
	CONT	71.95(±0.48)	2.81(±0.044)^{bc}	86E-4(±4 E-5)a
	EDTA	71.75(±0.45)	2.66(±0.064)^{c}	123 E-4(±0.00)a
	KMS	71.86(±0.06)	2.81(±0.058)^{bc}	119 E-4(±1 E-5)a
Dried at 45 °C	CA	9.53 (±0.105)c	2.55(±0.09)^{b}	209 E-4(±2 E-5)c
	CONT	5.76(±0.035)b	2.73(±0.115)^{b}	250 E-4(±2 E-5)d
	EDTA	4.95.0(±0.045)a	2.35(±0.031)^{b}	226 E-4(±4 E-5)c
	KMS	4.61(±0.026)a	2.75(±0.106)^{ab}	246 E-4(±1 E-5)d
Dried at 50 °C	CA	4.63(±1.254)a	2.83(±0.015)^{c}	208 E-4(±5 E-5)b
	CONT	4.94(±0.282)a	2.94(±0.040)^{c}	208 E-4(±2 E-5)b
	EDTA	6.40(±1.66)a	2.85(±0.045)^{d}	196 E-4(±1 E-5)b
	KMS	7.72(±1.83)b	2.95(±0.042)^{c}	204 E-4(±13E-5)b
Dried at 55 °C	CA	7.07(±0.006)b	2.40(±0.010)^{a}	224 E-4(±0)d
	CONT	4.83(±0.88)b	2.48(±0.10)^{a}	235E-4(±4E-5)c
	EDTA	7.01(±0.85)a	2.02(±0.09)^{a}	241 E-4(±1 E-5)d
	KMS	6.58(±1.12)b	2.64(±0.02)^{a}	234 E-4(±4 E-5)c
Means bearing the same letters in column are not significantly different at p = 0.05 *Values are means± standard deviation (SD)				

3.4 Colour parameters

The results of colour parameters obtained from the hot air drying processes of various pretreatments at different temperatures are shown in Table 2 for L (brightness), a (redness), and b (yellowness) values. 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, a significant increase in colour 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 temperature 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 showed improvement in brightness than what Li and Xu, (2007) and Kose and Erenturk (2010) reported in the drying of garlic and mistletoe respectively. They investigated the colour change of garlic at combined microwave-vacuum drying at powers of 282, 188 and 94W and freeze drying for 48hrs and reported brightness of 73.74 and 72.24 for combined microwave and freeze drying respectively. Sharma and Prasad (2001) studied the colour change of fresh garlic in a hot air dryer at 70°C and microwave hot air drying and reported brightness values of 79.32 for hot air drying and microwave drying respectively. 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 improve the brightness better than the control.

The redness of dried garlic slices compared with the fresh ones 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 of 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)

Table2: Comparison between pretreatments for colour parameters during garlic drying (L: brightness, a: redness, b: yellowness, C: chroma, αº: hue angle, SEE: standard error of estimate)

	Treatment	*L*	*a*	*b*	*C*	*αº*
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)cd	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 ºC	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 ºC	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 ºC	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

3.5 Textural properties

The texture of the dried garlic subjected to the various pretreatments in terms of hardness is shown in figure 3. It is evident that the fresh garlic slices subjected to the various pretreatment recorded hardness values of 5.0, 5.31, 6.58, and 5.91 N for the control, CA, EDTA, and KMS respectively. At the end of drying to the final moisture content in the range of 4.61 to 9.53 % (w.b) the hardness of the slices increased tremendously. The control (64.5N) recorded the highest increase in hardness, followed by the garlic slices treated with KMS (52.60N), EDTA (49.82N) and CA (35.26N). On the average, the control dried garlic were the hardest whereas the citric acid pretreated samples were the softest. Overall, all the pretreatments resulted in much lower texture in terms of hardness compared to the control, indicating the pretreatments might have caused case softening during drying (Leeratanarak et al, 2006). The control and the CA, EDTA, and KMS dried garlic samples were 12.91, 6.64, 7.57, and 8.91 times harder than their respective fresh samples. The general trend in increase in hardness was expected because as moisture is being removed from food materials, the material becomes harder. In the case of the garlic slices, the porous structure might have collapsed during the hot air drying resulting in a low transport rate of water, prolonged time and therefore tough texture (Cui et al, 2003). The results obtained agree with those reported by Xiao et al (2009), Funebo et al (2002) and Cui et al (2003) for dried sweet potato, apple and garlic slices respectively. Texture is one of the important characteristics indicating product quality (Vadivambal and Jayas, 2007). Textural properties are usually related to mechanical tests, which examine the visco-elastic behavior of the material (Krokida and Maroulis, 2001a). Textural properties of dehydrated products are normally measured as puncture force, which is a measure of the hardness of the product surface and is an indicator of the extent of case hardening that has occurred during drying (Kim and Toledo, Lin et al., 1998)

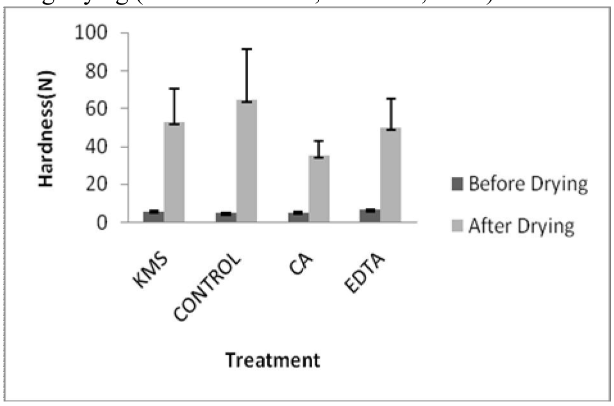


Figure 3: Effect of pretreatment on the hardness of the dried garlic compared to the fresh one.

Conclusion

A hot air drying experiment was carried out for garlic slices pretreated with three different treatments such as citric acid, KMS, and EDTA, and control (treated with distilled water) under three drying air temperatures of 45, 50 and 55 ºC. The results obtained showed that pretreatments significantly improve the drying rates of the garlic slices at 45 ºC drying temperature but not at 50 and 55 ºC . There were also significant differences (p=0.05) in the allicin and ash content of the garlic slices under the different pretreatments. EDTA pretreated samples resulted in the greatest chelating effect on the ash content with a corresponding increase in the allicin content. While the control dried samples were harder than all the pretreated dried samples, KMS pretreated samples were significantly brighter than the other samples. Overall, KMS pretreated samples performed better in terms of moisture diffusivity, ash and allicin content, colour and texture at all drying temperatures investigated.

REFERENCES

Ade-omowaye, B.I.O., Talens, P., Angersbuch, A. and Knorr, D.,2003. Kinetics of osmotic degydration of red bell pepper as influenced by pulse electric field pretreatment. Food Res. Int. 36, 475-482.

Alibas, I., 2008. Determination of drying parameters, ascorbic acid content, and color characteristics of nettle leaves during microwave-, air- and combined microwave-air-drying. Journal of Food Process Engineering 33, 213-233

AOAC, 1990. Official Methods of Analysis. Association of Official Analytical Chemists, Arlington, VA.

Arslan, D., Özcan, M.M, 2008. Evaluation of drying methods with respect to drying kinetics, mineral content, and colour characteristics of rosemary leaves. Energy Conversion. Manage. 49 (5), 1258-1264.

Ciu, Z., Xu S; Sun, D. 2003. Dehydration of garlic slices by combined microwave-vacuum and air drying Technology, 21 (7), 1173-1184.

Davoodi, M.G., P. Vijayanand, S.G. Kulkarni, K.V.R. Ramana, 2007. Effect of different pre-treatments and dehydration methods on quality characteristics and storage stability of tomato powder. LWT (40): 1832-1840.

Doymaz, I, 2010. Drying of thyme (Thymus Vulgaris L.) and Selection of a suitable thin-layer drying model. Journal of Food Processing and Preservation. Wiley Periodical. Doi:10.1111/j.1745-4549.2010.00488.x

Doymaz, I., 2004. Pretreatment effect on sun drying of mulberry fruits (Morus alba L). Journal of Food Engineering. 65, 205-209.

Erbay, Z. and F. Icier, 2008. Thin-layer drying behaviors of Olive leaves(Olea Europaea L.). Journal of Food Process Engineering 33. Wiley Periodicals. Pp287-308.DOI:10.1111/j.1745-4530.2008.00275.x

FAO, 2005. FaoStat Database. Available from http:faostat.fao.org (accessed January, 2011)

Funebo T, Ahrne, L., Prothon, F., Kidman, S., Langton M, Skjoldebrand, C, 2002. Microwave and convective dehydration of ethanol treated and frozen apple-physical properties and drying kinetics. Internal Journal of Food Science and Technology, 37 (6), 603-614.

Gazenfer, E. and Sefa, T., 2006. Colour retention of red peppers by chemical pretreatment during greenhouse and open sun drying. Journal of Food Engineering, 76, 446-452.

Jayaraman, K.S. and Gupta, D.K.D., 2006. Drying of fruits and vegetables. In Mujumdar, A. S. (Ed.), Handbook of Industrial Drying (third edition). Pp 606-634. UK: Taylor & Francis.

Kaya, A. and Aydin, O., 2009. An experimental study on drying kinetics of some herbal leaves. Energy Conversion Manage. 50, 118-124.

Kim, M. H., Toledo, R. T., 1987. Effect of osmotic dehydration and high temperature fluidized bed drying on properties of dehydrated rabbit eye blueberries. Journal of Food Science, 52, 980-989.

Kose, B. and S. Erenturk, 2010. Drying Characteristics of mistletoe (Viscum album L.) in convective and UV combined convective type dryers. Industrial Crops and Products 32. Pp 394-399.

Krest I, Glodek J., Keusgen M., 2000. Cysteine sulfoxides and alliinase activity of some Alliumn species. Journal of Agricultural and Food Chemistry, 48, 3753-3760.

Krokida, M. K., Maroulis, Z. B., 2001. Quality Changes during drying of food materials. In. Drying Technology in Agriculture and Food Sciences (Mujumdar A. S, ed). Oxford IBH, Delhi, India.

Lawson L D., Han G, Han P., 1995. A spectrophotometric method for quantitative determination of allicin and total garlic thiosulfinates. Analytical Biochemistry, 225, 157-160.

Lawson, L. D., Wang, Z. J., Papadimitriou D., 2001. Allicin release under simulated gastrointestinal conditions from garlic powder tablets employed in clinical trials on sterum cholesterol. Planta Medica, 67, 13-18.

Leeratanarak, N., Devahastn, S., and Chiewchan, N., 2006. Drying kinetics and quality of potato chips undergoing different drying techniques. Journal of Food Engineering, 77, 635-643.

Li, Y. and Xu Shi-ying, 2007. Preparation of Garlic Poweder with high allicin content. Agricultural Sciences in China. 6(7): pp 890-898.

Lin, T. M., Durance, T. D., Scaman, C. H., 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. Food Research International, 31 (2), 111-117.

Lindsay, R. C, 1996. Food Additives. In Food Chemistry by Owen R. Fennema**.** Third edition. Marcel Dekker, Inc. New York, USA pp 768-821.

Miller, D. D., 1996. Mineral Composition of Foods. In Food Chemistry by Owen R. Fennema**.** Third edition. Marcel Dekker, Inc. New York, USA pp 618-647

Miron, T., Rabinkov, A., Mirelman, D., Weiner, L., and Wilchek, M., 2001. A spectrophotometric assay for allicin and allinase(Alliin lyase) activity: Reaction of 2-Nitro-5-thiobenzoate with Thiosulphates. Analytical Biochemistry, 265, 317-325

Mota, C.L., C. Luciano, A. Dias, M.J. Barroca, R.P.F. Gine, 2010. Convective drying of onion: Kinetics and nutrional evaluation. Food and Bioproducts Procesing 88. Pp 115-123

Mousa, A. S., 2001. Discovery of angiogenesis inhibition by garlic ingredients: Potential anti-cancer benefits.FASEB Journal, 15. A117.

Nourian, F., Ramaswamy, H. S., and Kushalappa, A.C., 2003. Kinetic changes in cooking quality of potatoes stored at different temperatures. Journal of Food Engineering, 60, 257-266.

Owen R. Fennema, 1996. Food chemistry. Third edition. Marcel Dekker, Inc. New York, USA

Piga, A., Pina, I., Ozer, K.B., Agabbio, M. and Aksoy, U., 2004. Hot air dehydration of figs (Ficus caracal L.): Drying Kinetics and quality loss. Int. Journal of Food Sci. Technolo.,39, 793-799.

Prasad K. V. A., Laxdal M., Yu, B.L., 1996. Evaluation of hydroxyl radical-scavenging property of garlic. Biochemistry, 154, 55-63.

Rabinkov, A. T, Miron L. Konstrantinovski M, Wilchek D, Mirelaman L., 1998. The mode of action of allicin: trapping of radicals and interaction with thiol containing proteins. Biochemistry Biophysics, 1379,233-244.

Senadeera, W., Bhandari, B., Young, G., and Wijesinghe, B., 2000. Physical property changes of fruits and vegetable during hor air drying. In A.S. Mujumdar (Ed.), Drying technology in agriculture and food sciences (pp. 159-161). United Staes: science Publishers.

Sharma, G. P., Prasad, S., 2001. Drying of garlic (Allium sativum) cloves by microwave-hot air combination. Journal of Food Science, 46 (1), 410-413.

Singh, U., S.K. Jain, A. Doshi, K.H. Jain and K.V. Chahar, 2008: Effects of Pretreatments on Drying Characteristics of Button Mushroom. *International Journal of Food Engineering*, Volume 4, Issue 4. The Berkeley Electronic Press.

Sovova, 2000. Effect of allicin from garlic powder on serum lipids and blood pressure in rats fed with high cholesterol diet. Protaglandins Leukotrienes & Essential Fatty Acids, 62, 253-259.

Tharrington, E.D., Kendall, P.A. and Sofos, J.N., 2005. Inactivation of Escherichia coli)157:H7 during storage or drying of apple slices pretreated with acidic solutions. Int. Journal Food Microbiol. 99, 79-89.

Tunde-Akintunde, T.Y., 2010. Effect of pretreatment on drying time and quality of Chilli pepper. Journal of Food Procesing and Preservation. Vol 34, Issue 4:pp 595-608. DOI:10.1111/j.1745-4549.2010.00360.x

Vadivambal, R. and D.S. Jayas, 2007. Changes in quality of microwave-treated agricultural products-a review. Journal of Biosystems Engineering, 98, pp1-16

Vega, A., Uribe, E., Lemus, R. and Miranda, M., 2007. Hot air drying characteristics of aloe vera (aloe barbadenis Miller) and influence of temperature on kinetic parameters. Lebensm.-Wiss. Technol. 40, 1698-1707.

Xiao, H.W., H. Lin, X. D. Yao, Z. L. Du, Z. Lou., Z. J. Gao, 2009. Effects of different pretreatment on drying Kinetics and Quality of sweet potatoes bar undergoing air impingement drying. International Journal of Food Engineering Vol 5. Issue 5, Article 5.

Zogzas, N. P.,Maroulis, Z.B. and Marinos-Kouris, D., 1996. Moisture diffusivity data compilation in foodstuffs. Dry Technol. 14, 2225-2253.