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EFFECTS OF SULPHITING AND OSMOTIC PRE-TREATMENTS ON THE EFFECTIVE MOISTURE DIFFUSION COEFFICIENTS D_{EFF} OF AIR DRYING OF PINEAPPLE SLICES

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ABSTRACT

Air dehydration of fruits has been reported to be limiting in some factors especially on the drying kinetics and quality of the dried fruits. Removal of moisture during drying is attributed to these. This study was designed to evaluate the effects of sulphiting and osmotic pretreatments on effective diffusion coefficient (D_{eff}) of air drying pineapple slices at 50^o and 70 ^oC temperatures. *Smooth cayenne* pineapple obtained from Ajanla farms, Ibadan, Nigeria was used for the study. The fruits were hand peeled and sliced to spherical slices of 5 cm radius and 0.5 cm thickness. Pineapple fruit slices were pretreated at three levels of sulphiting and sucrose/osmosis and two conditions of drying (50 ^oC at 16 h and 70 ^oC at 10 h), resulting in 18 treatments in a factorial experimental design. Changes in moisture were monitored hourly and Fick's second law was used to describe the rate of moisture transfer to determine the D_{eff} as the slices were dried using a cabinet dryer. Results showed that the D_{eff} was strongly affected by sulphiting at 2500 ppm equalling $9.10 \pm 0.13 \times 10^{-6}$ and $6.78 + 0.53 \times 10^{-6}$cm/s for 70 ^oC and 50 ^oC drying temperatures, respectively. The osmotic pretreatment at 40% sucrose recorded $4.91 \pm 0.15 \times 10^{-6}$cm/s and $6.93 \pm 0.03 \times 10^{-6}$cm/s for 70 ^oC and 50 ^oC drying temperature respectively. The control samples had $3.14 \pm 0.23 \times 10^{-6}$ and $4.19 \pm 0.21 \times 10^{-6}$ at 70 ^oC and 50 ^oC drying temperature, respectively. The high values obtained from the pretreated samples may be due to the restructuring of the cell walls. The combination of sulphiting and osmotic pretreatments also exhibited significant impact on the D_{eff} value, ranging between 5.13 to 8.42×10^{-6}, though not as pronounced as with the single pretreatment method. Furthermore, drying at 70 ^oC influenced the D_{eff} value more than drying at 50 ^oC with both pretreatment methods. The study, therefore, showed that pretreatment methods improved the D_{eff} of the pineapple slices, with the sulphiting pretreatment at 2500 ppm having the highest value.

Key words: Sulphiting, osmotic, pretreatment, drying, kinetics

INTRODUCTION

Air dehydration of fruits reportedly affects the quality of the dried fruits, though the method has been suggested as a way of developing dry fruit to alleviate huge fruit losses after harvesting [1, 2]. Furthermore, the process has reportedly affected the rate of heat and mass transfer, which consequently affects the quality of the dried fruits [1, 2]. The deterioration of quality is nutritional, physical and chemical in nature [3, 4, 5].
The rate of drying is determined by the rates heat energy transfers to the material to provide the latent heat, though, under some circumstances the rate of mass transfer (removal of the water/or the D_{eff}) can be limiting. This mostly depends on the nature of the food. With possible exception of freeze drying, animal and vegetable tissues undergo some amount of shrinkage during drying, especially at the later stage of drying [6]. A hard impermeable skin often forms on the surface usually causing lower drying rates [7]. This is called case hardening. The mechanisms of case hardening are not fully understood, because they are probably influenced by a number of factors, including migration of soluble solids to the surface and high surface temperature, towards the end of drying process, resulting in complex physical and chemical changes in the surface layer [1,8,9].

Drying temperature is of more importance, mostly regarding the substantial effect it has on the texture of fruits. In general, rapid drying and high temperature cause greater changes than do moderate rates of drying and lower temperatures. High air drying temperature causes complex chemical and physical changes to the surface, and the formation of a hard impermeable skin, which also affects the rate of drying [9, 10].

Alteration of food cell structure prior to drying could influence the drying rate and consequently the dried product quality. Different pretreatment methods have been reported like sulphiting and osmotic pretreatment to alleviate some of these problems [1, 4, 11, 12, 13, 14, 15]. Sulphur dioxide, which possesses antimicrobial properties and inhibits enzymatic and non-enzymatic darkening, was found to be useful for controlling browning of cut fruits during drying. Reports also indicate that the rate of moisture removal during drying of fruits is affected by these pretreatment methods [11, 13, 15, 16], like the possible effect of $S0_2$ on the pectolytic enzyme activity, which consequently affects the textural property of the fruit [1]. On the other hand, the effect of osmotic dehydration prior to convectional drying on the rate of moisture transport and product, show that moisture content in sugar beet root decreased as the sucrose content increased [17]. A similar report was also obtained for carrot slices with and without osmotic treatment when drying rates were expressed as a function of the original sample solids, concluding the uptake of solid in the osmosis process, though the report did not reflect the D_{eff} values for both types of carrot slices [15]. On the other hand, Mazza [1] observed that as the concentration of sucrose used for dipping carrot cubes was increased from 5-60%, the rate of moisture transport decreased, attributing to the depression of water vapour pressure in the product. Also, it applied to the crystallization of dissolved sugar impaired diffusion of water vapour and the rate of heat transfer.

Reports show that the influence of sulphiting and osmotic pretreatments on D_{eff} differs widely as the tissue properties change from one foodstuff to another with Fick's law being applied. More so, the combination of these pretreatment methods may pose a different result on the rate of moisture removal on fruit like pineapple. Effect of drying temperature was also noted [8]. This study was, therefore, developed to assess the influence of pretreatment methods (sulphiting and osmotic) on D_{eff} during dehydration of pineapple slices at 50 ^{o}C and 70 ^{o}C.

MATERIALS AND METHODS

Materials

Freshly harvested pineapple fruit (*Ananas comosus* L.) with good physiological maturity obtained from Ajanla farm, Ibadan, was used for the study. They were kept at 18 ^{o}C and 80-90% relative humidity up to the time of use, 48 h after arrival at the laboratory.

Experimental Design

A factorial experimental design was used. The factors were three levels of each of two pretreatment methods, sulphiting and sucrose – osmosis, and two levels of drying conditions (temperature/time) viz 70 ^{o}C for 10 h and 50 ^{o}C for 16 h. This resulted in (3x3x2 factorial experiment) 18 samples for the study. The experimental ranges of factors (Table 1) were established from preliminary experiments [11, 12].

Sample preparation

Fresh pineapple fruits selected with similar characteristics of ripening were hand peeled, cored, sliced and cut into spherical shape of 5 mm thickness and 20 cm radius. A batch of 5kg of pineapple slices was pretreated with sucrose solution and/or sulphited as shown in Table 1.

Pineapple slices were osmotically treated by immersing in aqueous solution of 40% w/w or 60% w/w of sucrose (Food grade of 98% purity) for 10 min at room temperature. The samples were drained on wire mesh and reweighed. The sulphiting pretreatment was done by dipping pineapple slices in 1500 ppm and 2500 ppm $S0_2$ solution made from potassium meta bisulphate (KMS) solution for 6 min at room temperature, drained on wire mesh and reweighed.

Pretreated pineapple slices were dried in a cabinet dryer (Gallenkamp hot box, Manufactured by Gallenkamp, Riley Industry Limited, United Kingdom, Model No:13426E-24). The slices were spread on perforated stainless steel trays, of 1kg pineapple slices. Tray loading and drying was done at 1.2 m/s per square metre tray area with through air flow. All the 18 samples were dried simultaneously in order to ensure uniform drying conditions. As drying progressed, the moisture content of dehydrated slices was determined by standard hot air oven method at every hour [18]. At the end of drying, the final product weight was recorded and its moisture content determined. The weight changes recorded during drying was used in calculating moisture in percentage dry weight basis and drying rate as a function of weight loss per unit dry matter per drying hours, respectively.

The method of Bruin and Luyben [8] was used to monitor the kinetics of moisture transport to obtain the D_{eff}. The volume of each pineapple slice (v) was measured using a pycnometer (Cole-Parmer Pycnometer) (with water as the fluid) and the equivalent spherical radius (Re) was then calculated from the formula for the volume of sphere ($V = 4\pi\ R^3e/3$) using the pineapple slice volume. It was assumed that the internal temperature of the fruit is uniform due to the low Biot number for heat transfer. Thus,

$$Bo = h^R/K \qquad (1)$$

where h = heat transfer coefficient

is usually found for convectional air drying of foods [13,19]. The process was assumed to be isothermal; therefore, the heat transfer effects were neglected and Fick's second law was used to describe the rate of moisture transfer during the first falling period of drying. However, the pineapple slices did not have a spherical shape. The diffusion problem for any geometry can be reduced to the analytical solution corresponding to a sphere, by modifying the

$$\text{Fourier Number, } Fo = D_{eff}\ t/_R{}^2 \qquad (2)$$

The expression of Fick's law for diffusion out of a sphere with boundary conditions of internal resistance controlling integrated over the volume of the sphere is

$$M = \frac{m - m_e}{m_O - m_e} = \sum_{n=1}^{n} Bn \exp(-\mu^2 n\ Fo) \qquad (3)$$

where, $Bn = 6\ \mu^2\ \mu_n = n\pi$

$$Fo = D_{eff}\ t/R^2e \qquad (4)$$

n= 1, 2, 3, ………..
t = time
mo = uniform initial moisture content
me = equilibrium moisture content
Re = sphere radius
D_{eff} = effective moisture diffusivity

The values of the effective diffusion coefficients D_{eff} (corrected by the shape factor) were calculated. The significance of the differences among the obtained D_{eff} values was analysed through a t parameter test with a 95% confidence level.

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Statistical Analysis

All statistical analyses were performed using the Statistical Analysis System [20]. Mean separation was obtained by Duncan Multiple Range test and Analysis of variance, ANOVA, was conducted on the mean values to determine the significance of any difference between samples [21].

RESULTS

The drying kinetics curves in Figures 1- 6 show drying rates versus drying time at 50 ^{o}C and 70 ^{o}C temperature. The drying rate on dry basis (DB) is plotted versus time t, for all the samples. All the samples exhibited unsystematic drying rates, which revealed a typical behavior of drying of biological materials. Drying rates were higher with samples at 70 ^{o}C drying temperature, reflecting the influence of high temperature on drying. The sample sulphited with 2500 ppm $S0_2$ on Figures 3 and 4 had 0.42 g water/kg dry matter h^{-1} at the 7th h and 0.78 g water/kg dry matter h^{-1} at the 4th h of drying at 50 ^{o}C and 70 ^{o}C drying temperature, respectively. The control sample showd a close drying rate behavior to the two sulphited samples at 70 ^{o}C drying temperature while at 50 ^{o}C drying temperature, the control did not exhibit a sharp fall in drying rate like the other sulphited samples. The effect of sulphiting pretreatment was significant on the drying kinetics, declining with increase in drying time.

The combination of the pretreatments also affected the drying kinetics. The sample pretreated with 60% sucrose and 2500 ppm $S0_2$ at the 5th h of drying recorded 0.51 g water/kg dry matter h^{-1}, while the average drying rate was 0.32 g water/kg dry matter h^{-1} at 50 ^{o}C drying temperature in Figure 5. At 70 ^{o}C drying temperature, in Figure 6, the average drying rate was 0.43g water/kg dry matter h^{-1}, with the highest rate of water removal being 0.90 g water/kg dry matter h^{-1}.

Results of the D_{eff} are shown in Table 2, with significance differences at 95% confidence level, indicating the effects of pretreatment and drying variables on the rate of moisture transport. Sample pretreated with 2500 ppm SO_2 at 70 ^{o}C drying temperature obtained the highest D_{eff} with $9.10 \pm 0.13 \times 10^{-6}$ cm^2/s while the control sample at 50 ^{o}C drying temperature had lowest value of $3.14 \pm 0.23 \times 10^{-6}$ cm^2/s.

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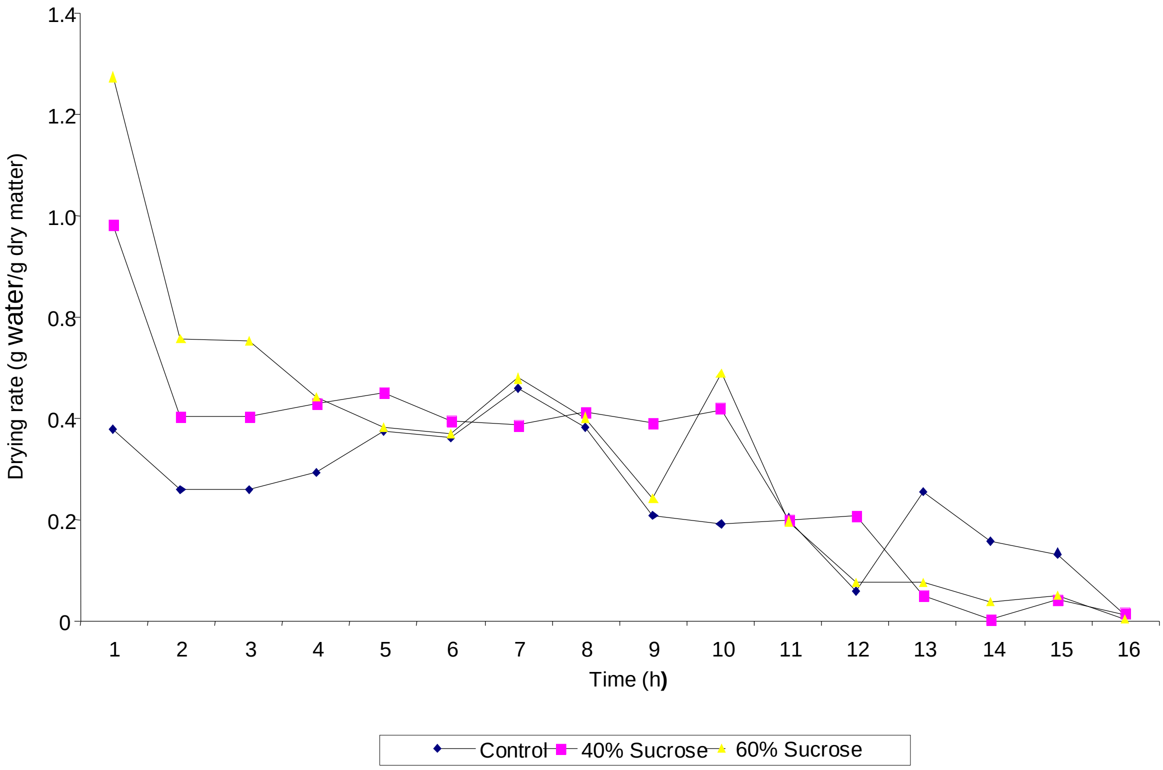

Figure 1: Effect of Sucrose pretreatment on drying rate of pineapple slices at 50 ^{o}C drying temperature

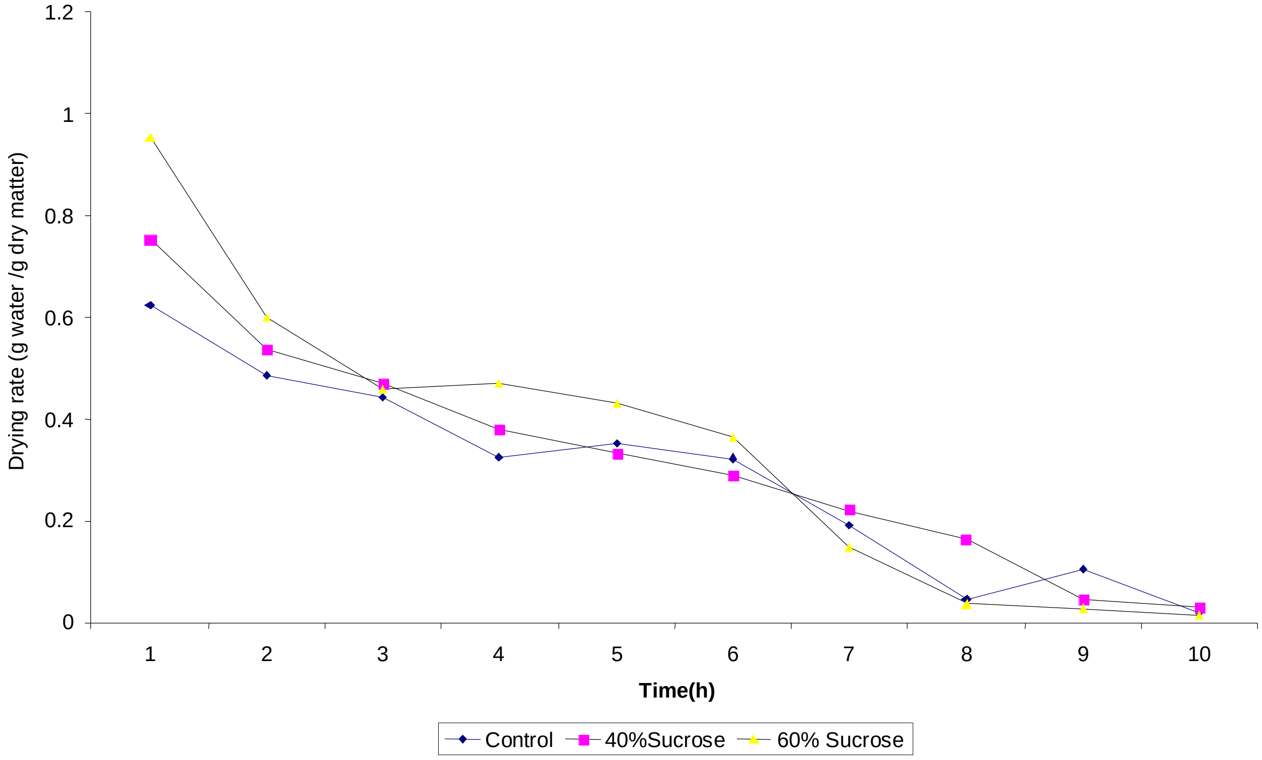

Figure 2: Effect of Sucrose pretreatment on drying rate of pineapple slices at 70 ^{o}C drying temperature

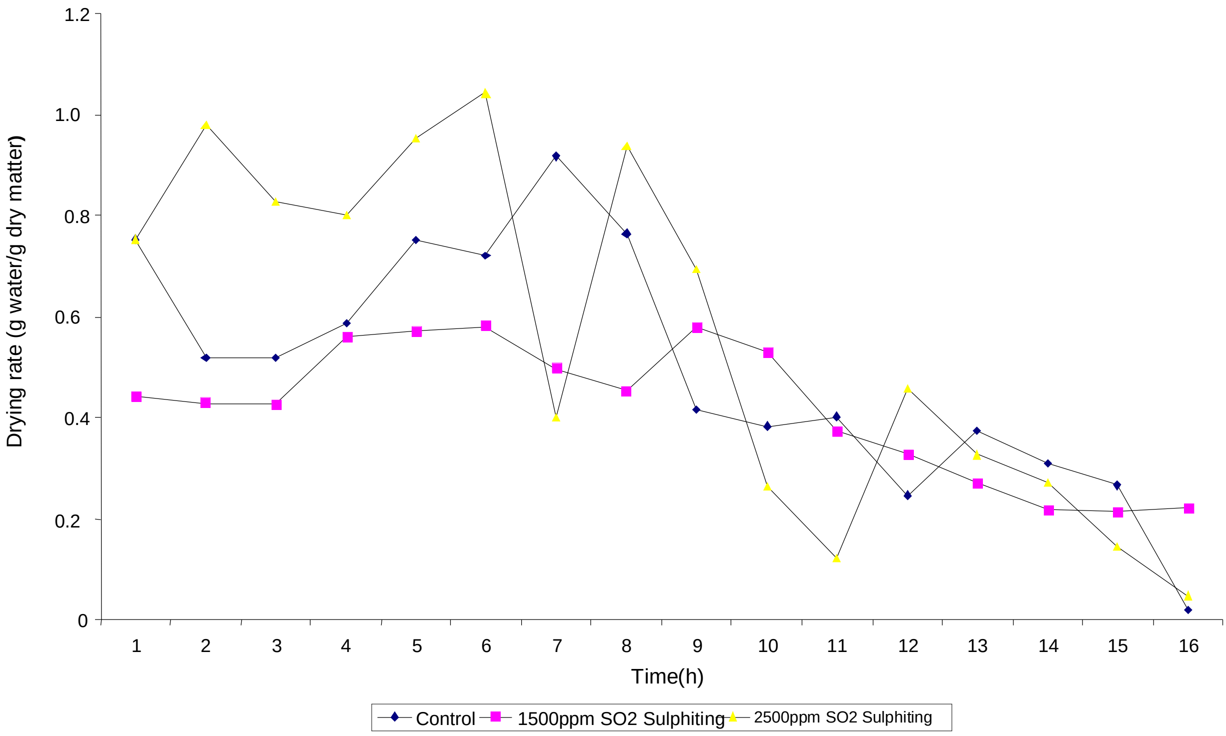

Figure 3: Effect of Sulphiting pretreatment on drying rate of pineapple slices at 50 ^{o}C drying temperature

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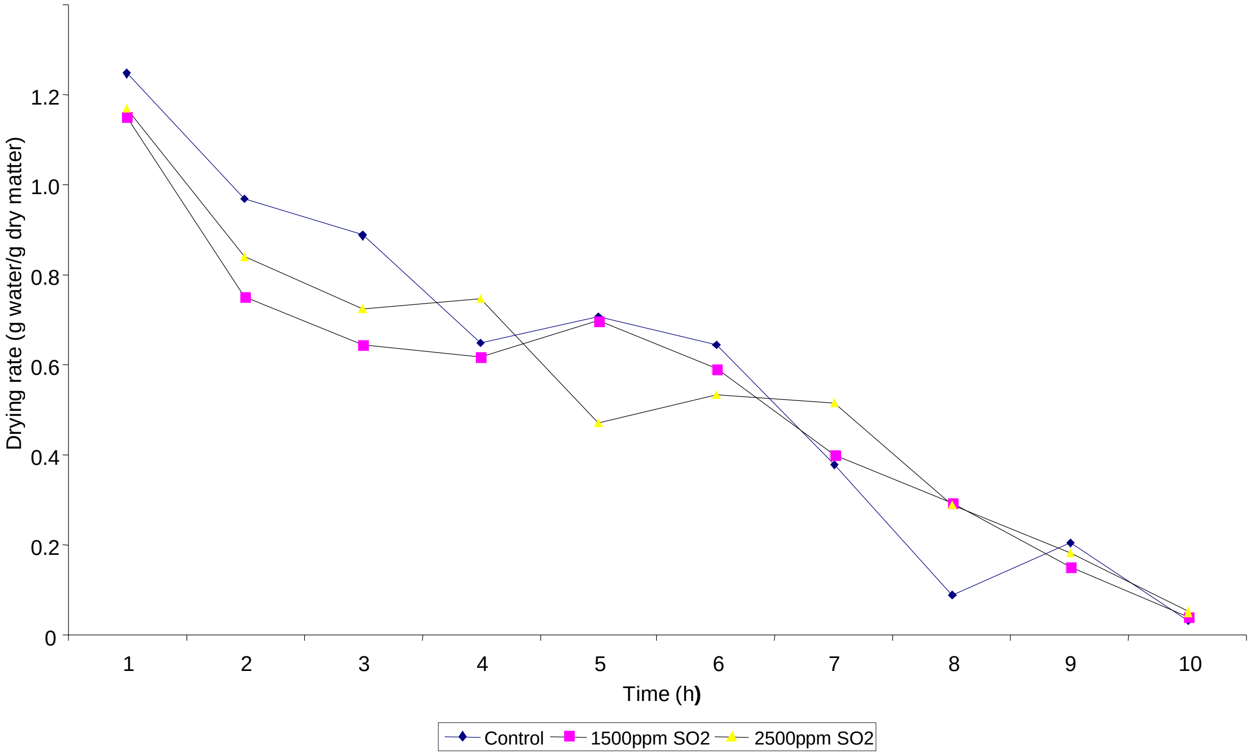

Figure 4: Effect of Sulphiting pretreatment on drying rate of pineapple slices at 70 ^{o}C temperature

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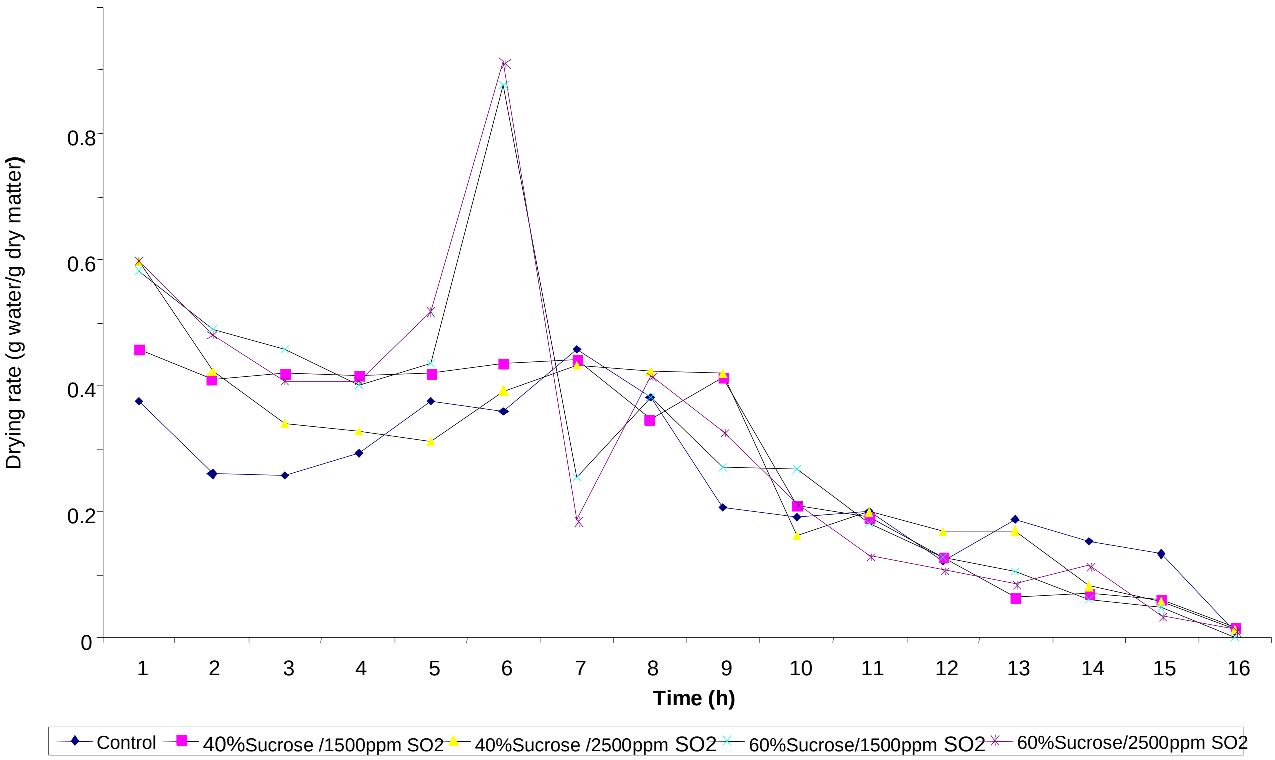

Figure 5: Effect of Sucrose and Sulphiting pretreatments on drying rate of pineapple slices at 50 °C drying temperature

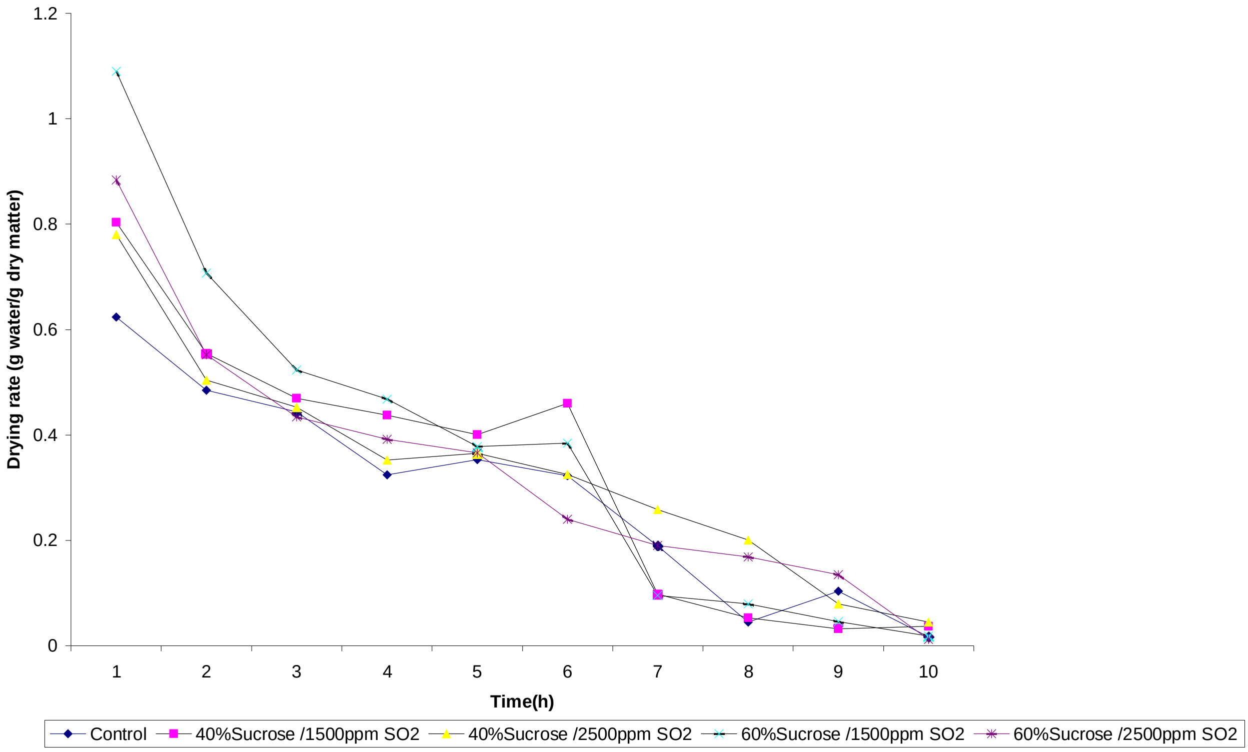

Figure 6: Effect of Sucrose and Sulphiting pretreatments on drying rate of pineapple slices at 70 ^{o}C drying temperature.

DISCUSSION

The unsystematic rate of drying of the samples revealed the influence of pretreatment methods on the permeability of the cell membranes, as well as their influence on the water binding capacity of the fibrous matter [11, 13]. The observed sudden drop in moisture content during drying at 70 ^{o}C showed higher diffusive transfer of moisture to the evaporation surface compared to the samples dried at 50 ^{o}C. The changes in the drying rates with no constant drying rate experienced were characteristic of most biological materials. According to Alvarez *et al.* [13], effects of blanching and sulphiting on the permeability of the cell membranes, as well as to their influence on the water binding capacities of the fibrous matter were responsible for the high rate of moisture removal observed with the samples. The variations in the intermediate values of water removal observed were probably caused by natural differences in the composition and structure of the raw pineapple slices, even at a uniform degree of ripeness and the variation of the pretreatment. The faster drying rate observed with samples dried at 70 ^{o}C, shows relevance of temperature on drying. The relative lower moisture content recorded with combinations of pretreatment method also corroborates the D_{eff} values obtained. The observed faster drop in moisture content during drying at 70 ^{o}C showed higher diffusive transfer of moisture to the evaporation surface compared to the samples dried at 50 ^{o}C. With appropriate control of air drying conditions, reduction of moisture content is possible at a rate dependent more in the air drying temperature and time. Ghaius *et al*. [18] also revealed the significant effects of time-temperature combination effect on convective drying of agricultural products.

It is apparent that drying rate decreases continuously with drying time. These results were in agreement with the earlier reports on food drying kinetics [22, 23, 24]. However, unlike the findings of Mazza [1] on effect of heat treatment on drying kinetics of fruits the obtained results showed that the pretreatment with SO_2 influenced the drying kinetics than the sucrose osmotic pretreatment. This deviation might be due to the effect of SO_2 pretreatment on physical and chemical changes on the water binding components of the pineapple slices and on the cellular membrane permeability.

All the pretreatment methods increased the D_{eff} significantly [17, 25]. The sulphiting pretreatment might have affected the permeability of cellular membrane of the slices, creating a faster drying rate at the two drying temperatures. Similarly, the osmotically pretreated samples exhibited high D_{eff} probably due to the severe ultra structural damage of the cell walls and solute uptake that increases water transport resistance and a reduces of the cell wall resistance. Furthermore, degradation of polysaccharides, and decrease in the amount of total pectin substances particularly the residual protopectin might have occurred during the osmosis process. This might have resulted in reduction of tensional and firmness of the slices, thereby causing an increase in D_{eff} when compared to the control samples, as also observed by Heng et al., [26] on papaya. Such materials exhibit a reduced optical density, which is due to the fact that the binding force between the cell wall, and that the higher concentration of hydrozium ions present in the high acid fruits may accelerate the breakdown of the binding materials [13]. This also explains the possible degradation of polysaccharides as well as leaching of pectin and other cell wall soluble components.

CONCLUSION

Sulphiting and osmotic pretreatments influenced D_{eff} of pineapple slices at 50^{o}C and 70^{o}C drying temperatures. The combination of the two pretreatments affected the D_{eff} as compared to a single pretreatment method. The pretreated samples recorded a faster rate of moisture removal. Microscopic description of the product may explain the effect of the pretreatment methods on the cell structure and its influence on the D_{eff} value.

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Table 1: Factors and Levels of Experimental design for the study

Factors		**Levels**	
	1	**2**	**3**
Sulphiting	O ppm	1500 ppm	2500 ppm
Sucrose/osmosis	0%	40%	60%
Drying condition (Temperature/Time)	70 ^{o}C/10 h	50 ^{o}C/16 h	

Table 2: Effective Diffusion Coefficients D_{eff} from Fick's Law on pretreated pineapple slices during drying

Pretreatment	**Drying temperature**	**D_{eff} x10^{6} (cm2/s)**
Control	50 °C	3.14a± 0.23
Control	70 °C	4.19b± 0.21
40% sucrose	50 °C	4.91b ± 0.15
40% sucrose	70 °C	6.87d ± 0.18
60% sucrose	50 °C	5.89c ± 0.35
60% sucrose	70 °C	6.93d ± 0.63
1500ppm $S0_2$	50 °C	6.12c ± 0.41
1500ppm $S0_2$	70 °C	8.24c ± 0.77
2500ppm $S0_2$	50 °C	6.78c ± 0.53
2500ppm $S0_2$	70 °C	9.10f ± 0.13
40% Sucrose/1500ppm $S0_2$	50 °C	6.13c ± 0.52
40% Sucrose/1500ppm $S0_2$	70 °C	7.27d ± 0.41
40% Sucrose/2500ppm $S0_2$	50 °C	6.12c ± 0.41
40% Sucrose/2500ppm $S0_2$	70 °C	8.42e ± 0.23
60% Sucrose/1500ppm $S0_2$	50 °C	5.13b ± 0.26
60% Sucrose/1500ppm $S0_2$	70 °C	7.22d ± 0.24
60% Sucrose/2500ppm $S0_2$	50 °C	6.16c ± 0.18
60% Sucrose/2500ppm $S0_2$	70 °C	8.24e ± 0.42

Each value represents means of three replicates. Mean value having the same letter are not significantly different at p>0.05)
± - *standard deviation of the mean value.*

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