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EFFECTS OF DIFFERENT PRETREATMENTS ON DRYING CHARACTERISTICS OF BANANA SLICES

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ABSTRACT

The effects of different pretreatments and temperature on the drying characteristics of ripe Gros Michel banana slices were investigated. 5 and 7 mm thick slices of bananas were pretreated with four different pretreatments such as ascorbic acid, lemon juice, salt solution, honey dip and a control for 10 minutes, each replicated three times. Pretreated banana slices were dried in a cabinet oven dryer using a completely randomized design at 60°C and 70^{o}C and their drying characteristics such as rate of drying, moisture diffusivity, re-hydration ratio, and coefficient of re-hydration were studied. The moisture content of the fresh ripe bananas for both the untreated and treated samples was found to be in the range of 75-77 % (w b) which reduced to 16.8 to 27% after oven drying for various thicknesses and temperatures of air drying for 16 hours. The moisture diffusivity during oven drying varied from 7.89E^{-5} to 14.94E^{-5} m/s^2, and increased with drying air temperature. The 5 mm thick slices at a drying air temperature of 70°C dried better than the others and resulted in about 13% savings in time. The minimum re-hydration ratio of 1.215 was obtained for 7 mm thick slices treated with ascorbic acid and the maximum re-hydration ratio of 1.716 was obtained for lemon juice samples. This means that the lemon juice treated dried bananas will reconstitute more moisture when exposed to air.

Keywords: banana slices, gros michel variety, drying characteristics, re-hydration ratio, re-hydration coefficient.

INTRODUCTION

Ripe bananas have been part of humans' diets for many years. Production and consumption of ripe banana have come to stay with many people around the globe. However, ripe bananas contain about 80% moisture and therefore very susceptible to post-harvest losses and considerable weight loss during transportation and storage. This in turn causes serious economic losses as a result of reduction in weight and quality. Post-harvest losses are a major challenge for tropical products such as mango, pineapple, banana, etc especially in Ghana. Usually, a fully ripened banana takes about 4-7days to deteriorate. In Ghana, tropical fruits produced in the peak periods are either consumed fresh, sold at relatively cheap prices, or are allowed to go waste due to inadequate processing facilities (Abano, 2010). Drying is one of the oldest methods for the preservation of food products. Newer techniques of drying such as heated air drying due to hygienic and economic considerations have been developed (Das *et al*., 2004; Motevali *et al*., 2010). Little attention is given to drying of tropical fruits for consumption and improving their storage life, even though enormous markets exist for dried fruits in Ghana. Dried food could be consumed directly or treated as secondary raw material (Menges and Ertekin, 2006). The hot-air drying of food materials has advantages such as control of product quality, achievement of hygienic conditions, and on reduction of product loss (Corzo *et al*., 2008). Food scientists have found that by reducing the moisture content of food to between 10 and 20%, bacteria, yeast, mold and enzymes are all prevented from spoiling it. The flavour and most of the nutritional value is preserved and concentrated (Dennis, 1999). When drying foods, the key activity is to remove moisture as quickly as possible at a temperature that does not seriously affect the flavour, texture and colour of the food. If the temperature is too low in the beginning, micro-organisms may grow before the food is adequately dried. If the temperature is too high and the humidity is too low, the food may harden on the surface. Temperature ranges between 37°C and 71^{o}C will effectively kill bacteria and inactivate enzymes, although temperatures around 43^{o}C are recommended for solar dryers (Kendall and Allen, 1998). Shrinkage of the cells, browning, loss of redrying ability, wettability and case hardening are some common problems associated with drying of tropical fruits, which reduce their market value and general acceptability (Dalgleish and Andy, 1988; McMinn and Magee, 1997; Singh *et al*., 2008).

Different pre-treatment methods have been developed for fruit drying, among which are lemon juice, salt solution, honey dip, ascorbic acid, sulfuring, osmotic pretreatment, and blanching (Karim, 2005). If no pre-treatment is done, the fruits will continue to darken after they are dried. For long-term storage of dried fruits, sulfuring or using a sulfite dip are the best pre-treatments. However, sulfites may cause asthmatic reactions in a small portion of the asthmatic population (Susan and Williams, 1993). Dried fruits are a good source of energy because they contain concentrated fruit sugars. Dried foods are high in fibre and carbohydrates and low in fat, making them healthy food choices. This study was conducted to assess the effects of different pretreatments and temperature on drying characteristics of banana slices. Specifically, the work aimed to investigate the effect of different pre-treatment method on the rate of drying, the moisture diffusivity, and rehydration ratios and coefficients. In addition, the work was expected to provide a cost effective way of processing ripe banana for human consumption, curtail post-harvest loss of fresh ripe banana,

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and promote entrepreneurial opportunities through the sale of dried ripe bananas in Ghana.

MATERIALS AND METHODS

Fresh ripe Gros Michel banana variety were procured from the University of Cape Coast "Science Market" on March 2010 and brought to the laboratory to determine the initial moisture content using the oven dry method (Aghbashlo *et al*., 2010). Primary processes such as cleaning, washing, peeling, and cutting were done. The peeled bananas were sliced into 5 and 7 mm thicknesses with a sharp knife manually prior to pretreatment. The completely randomized design (CRD) was used for the experiment with four treatments, one control, each replicated three times. 3000 mg (30 tablets) of ascorbic acid was dissolved in 660ml of water in a bowl. Also, 7.25 g of salt was dissolved in 660ml of water in another bowl. In addition, 255ml of lemon juice was mixed with 255ml of water in a third bowl and finally 40ml honey and half cup sugar was measured and added to a 495 ml lukewarm water to mix.

Samples of the sliced bananas were soaked in the different pretreatments for 10 minutes and allowed to drain according to recommended guidelines. Each of the pretreated samples was divided into three equal weights of 120 g for drying. Another 360g of the sliced bananas were divided into three and used as the control. The pre-treated bananas were put on trays and placed onto the racks in the Gallenkamp (Sanyo OMT oven) cabinet dryer. The 5 and 7 mm thick slices were dried at temperatures of 60 and 70 till the constant mass was observed. The weights of the drying bananas were determined every one hour until drying was complete. When drying was completed the samples were allowed to cool and packed into a transparent tightly zipped bag and labeled for further analysis and storage.

Moisture diffusivity during oven drying

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 drying of biological materials is best described by Fick's diffusion model as:

$$\frac{\partial M}{\partial t} = D\frac{\partial^2 M}{\partial X^2}$$

Where, D is the moisture diffusivity, m^2/s, M is the moisture content, L is the distance from the centre line and t is the time elapse during the drying. Assuming uniform initial moisture distribution and negligible external resistance, the solution of equation above as proposed by crank, 1975) is:

$$\frac{M - M_e}{M_0 - M_e} = MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{2n+1}e^{-(2n+1)^2\pi^2\frac{Dt}{L^2}}$$

Where
MR is the moisture ratio
M_e = the equilibrium moisture content (wet basis)
M_0 = the initial moisture content (wet basis)
M = the moisture content at time (wet basis)
L = the thickness of the slice
t = the time, s
D = the moisture diffusivity, m^2/s
Re arranging the equation above gives

$$\ln [MR = \ln[\square] \frac{8}{\pi^2}] - [\pi^2 \frac{Dt}{L^2}]$$

If the Ln (MR) is plotted against time it will result in a straight line with a negative slope and the slope of the line can be used to predict the moisture diffusivity. Singh *et al*. (2008) used this model to predict the moisture diffusivity of dried button mushrooms.

Re-hydration characteristics

The re-hydration tests were conducted to assess the reconstitution qualities of the dried banana slices. 5 g of the dried samples was soaked in enough amount of water for 10 minutes at room temperature. The ratio of mass of re-hydrated and dried samples was used to determine the re-hydration ratio and coefficient of re-hydration.

Re-hydration Ratio = $RR = \frac{C}{D}$; Coefficient of Re-hydration $COR = \frac{C}{D} \times \frac{100 - A}{100 - B}$ where,

A = Moisture content of samples before drying (%w b)
B = Moisture content of dried samples (%w b)
C = Mass of sample after soaking (g)
D = Test mass of sample before soaking (g)

RESULTS AND DISCUSSIONS

Oven air drying of banana slices

The moisture content of the fresh ripe bananas for both the untreated and treated samples was found to be in the range of 75-77% (w b) which reduced to 16.8 to 27% after oven drying for various thicknesses and temperatures of air drying for 16 hours. Figure-1 shows the drying rates of different thicknesses of untreated Banana slices at different drying air temperatures. It can be observed from the Figure that as the time of drying increases the moisture content of the samples decreases. Also, it took nearly 15 hours of drying to reduce the moisture content of the control banana slices of 5 mm thickness at 60°C drying air temperature from 75 to 20%. As the temperature was increased to 70°C for the same thickness of slices, it took nearly 13 hours to reduce to the same moisture. Besides, the 60, 5 mm thick slices dried almost at the same rate as the 70°C, 7 mm thick banana slices. At about 9 hours of drying time, the rate of moisture removal from the 60°C, 5 mm thick slices was equal to 70°C, 7 mm thick banana slices.

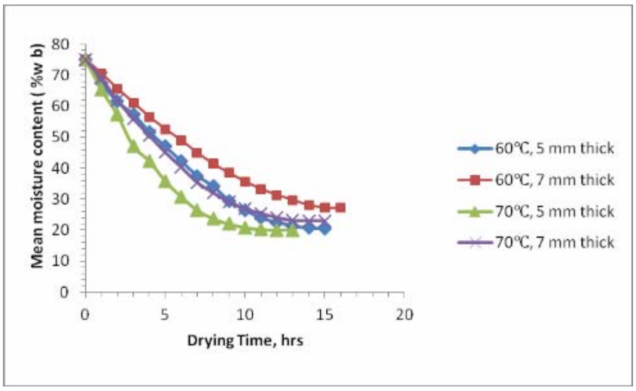

Figure-1. Drying rates of different thicknesses of untreated (control) banana slices at different drying air temperatures.

Therefore, it can be observed from the curves that temperature of drying air has significant effect on the drying time. As the drying temperature increased from 60°C to 70°C for the 5 mm thick control banana slices, there was approximately 13% savings in time. These results agreed with drying of potato slices by Akpinar *et al.*, (2003), pistachio by MIdilli and Kucuk, (2003), banana by Nguyen and Price, (2007), Wang *et al.*, (2007) and apple pomace by Motevali *et al.* (2010)

A similar trend was also observed for the other pretreated samples such as salt solution, lemon juice, honey dip and the ascorbic acid as shown in Figures 2, 3, 4, and 5 respectively. Generally, moisture removal from the banana slices was steadily until equilibrium moisture content was reached. However, the 70°C, 5 mm thick slices lost moisture rapidly compared with the others. In the ascorbic acid treated samples, the 60°C, 5 mm and 70°C, 7 mm thick slices started the drying process at the same rate until the seventh hour where the drying rate became faster in the 60°C, 5mm thick slices than the 70°C, 7 mm ones as shown in Figure-2. Moreover, for the thickness of 5 mm banana slices, the drying rate of the 60°C drying air temperature was the same as the 70°C drying air temperature for the ascorbic acid treated samples in the 13th hour. This shows that, at the initial periods of drying, more moisture was removed from the 70°C drying environment till such a time that there was very little moisture removal thereafter. Conversely, in the 60°C drying environment there was a steady moisture removal throughout the drying process.

In the lemon juice treated samples for different thicknesses and drying air temperatures, the initial rate of drying was the same (Figure-3). A similar trend occurred in the salt solution and honey treated samples as indicated in Figures 4 and 5. However, the 70°C drying air temperatures for the various thicknesses differed in drying rates early on, than the 60°C. Whereas the higher drying air temperature took about 3 hours, the lower drying air temperature took about 6 hours. In addition, the lemon juice treated samples took 11 hours of drying for the rate of moisture removal in the 60°C, 5mm slices to be equal to that of the 70°C, 7mm thick slices. This duration was the same in the salt treated samples but was about 8 hours in the honey dipping treated samples. It is interesting to note that even though the untreated and the ascorbic acid treated samples showed the same trend, the trend occurred at the initial periods of drying over longer drying periods as shown in Figures 1 and 2.

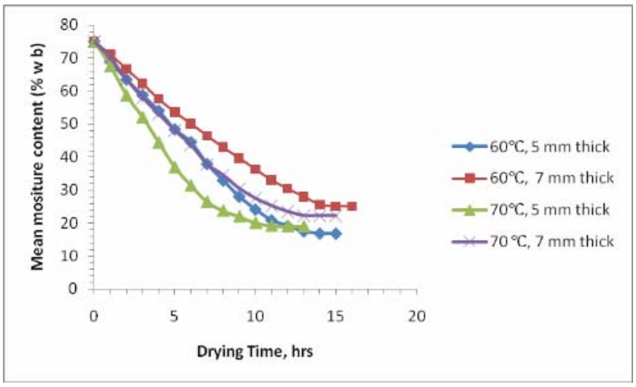

Figure-2. Drying rates of different thicknesses of ascorbic acid treated banana slices at different drying air temperatures.

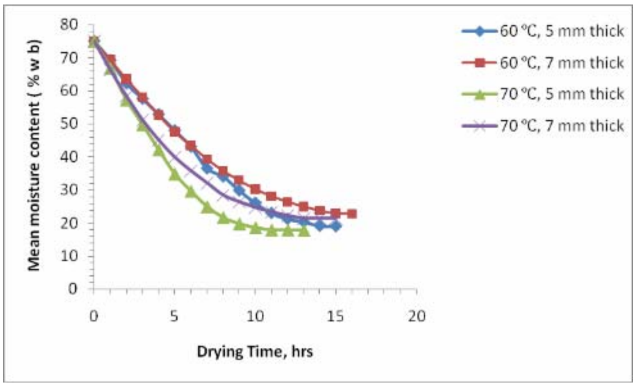

Figure-3. Drying rates of different thicknesses of lemon juice treated banana slices at different drying air temperatures.

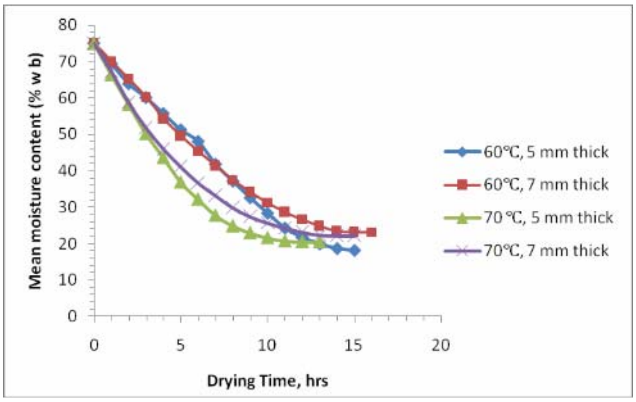

Figure-4. Drying rates of different thicknesses of salt solution treated banana slices at different drying air temperatures.

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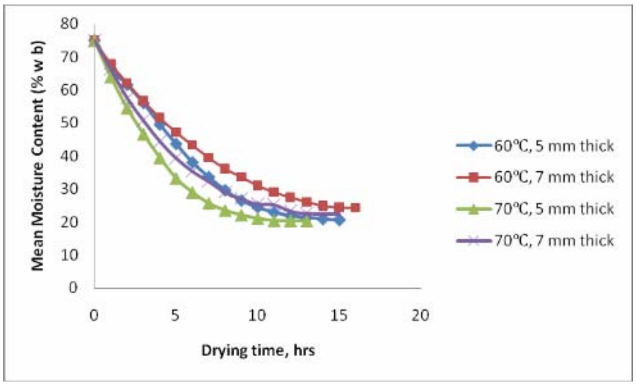

Figure-5. Drying rates of different thicknesses of honey dip treated banana slices at different drying air temperatures.

Figures 6 to 9 show the drying rate curves at various thicknesses and drying air temperatures of both the control and the treated banana slices. At lower thickness and drying air temperature, honey dip treated samples dried faster than the control, followed by lemon juice/ascorbic acid, and then salt treated samples in the first 10 hours. However, after 10 hours of drying, ascorbic acid dried faster than salt solution treated samples, followed by lemon juice/control and then the honey dip as revealed in Figure-6.

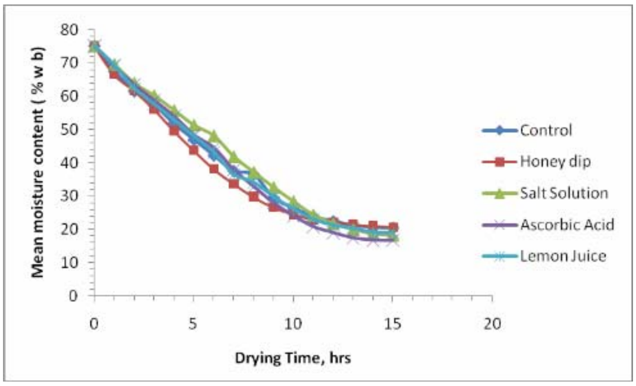

Figure-6. Drying rates of 5 mm thicknesses of control and treated banana slices at 60°C drying air temperatures.

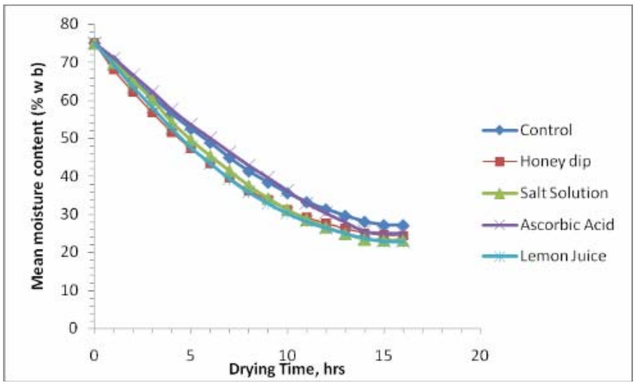

Figure-7. Drying rates of 7 mm thicknesses of control and treated banana slices at 60°C drying air temperatures.

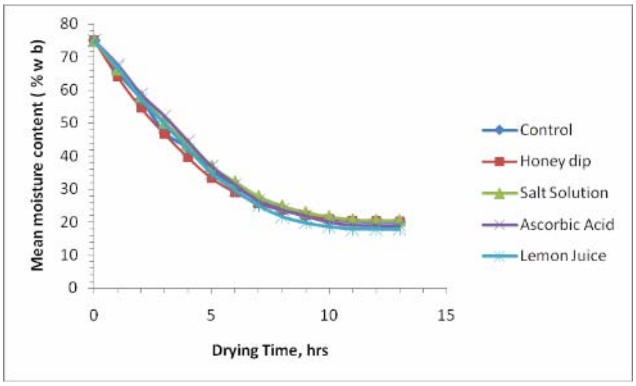

Figure-8. Drying rates of 5 mm thicknesses of control and treated banana slices at 70°C drying air temperatures.

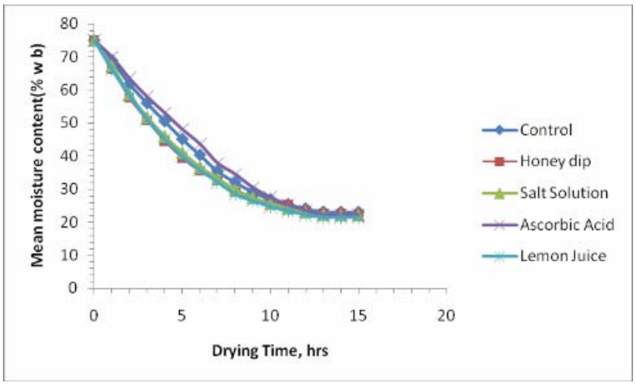

Figure-9. Drying rates of 7 mm thicknesses of control and treated banana slices at 70°C drying air temperatures.

At higher thickness and drying air temperature honey dip dried faster than lemon juice followed by salt solution, control and ascorbic acid treated samples in the first 10 hours of drying but after 10 hours, salt solution dried faster than lemon juice followed by ascorbic acid, the control, and honey dip treated samples as shown in Figure-9. Similarly, at higher thickness and lower temperature of drying air, a decreasing order of drying rates was observed: honey dip, followed by lemon juice, salt solution, control and ascorbic acid samples in the first 8 hours. Nevertheless, after 10 hours of drying the decreasing order of drying rates became salt solution, lemon juice, honey dip, ascorbic acid treated samples and the control as indicated on Figure-7. Finally, at lower thickness of slice and higher drying air temperature, the decreasing order of moisture removal was honey dip, the control, lemon juice, salt solution, and ascorbic acid samples in the first 6 hours. However, after 10 hours the decreasing order of drying rate was lemon juice, ascorbic acid, control, and salt solution/honey dip samples.

These recorded trends might be attributable to the fact that as honey dip is exposed to heat for a long period of time it forms a sticky coat around the banana slices and the slices do not lose moisture any longer. These results resemble those reported by (Kostaropoulos and Saravacos, 2006) and Motevali *et al*. (2010) for drying of raisins and pomegranate arils. Coupled with an increased thickness of banana slices; the honey dip treated sample will lose

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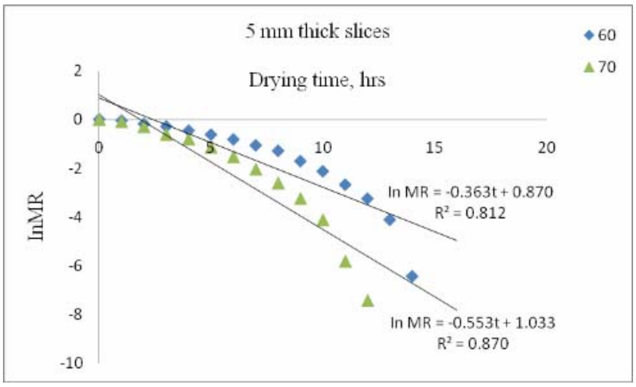
moisture at a far slower rates with extended drying time. However, the ascorbic acid pretreatment tends to loosen the water molecules in the banana slices when exposed to prolonged heat and thereby aid drying. Salt solution and lemon juice although seem to lose moisture in the early stages of drying, did not really loosen as much water molecules as ascorbic acid did when exposed to long hours of heat and hence insensitive to prolonged heat. The evaporation rate of salt solution could also account for its sharp fall in the initial hours of drying. Common salt made of sodium chloride in an acidic and basic reaction on heating evaporates rapidly. This may have resulted in the relatively high loss of moisture in the samples pre-treated with the salt solution at the final stages of drying. The delay in drying for honey might be due to its hygroscopic nature, which when exposed to air naturally forms a coat that impedes moisture loss. It is also possible that the delay in the honey treated sample could be due to the increased sugar to acid ratio. Sugar when heated forms a gelatinous coat around the banana, which is impermeable to moisture loss. This sticky coat also prevented moisture loss from the products treated with honey. Sugar also becomes more viscous when melted, and this viscous fluid expanded to fill the pore spaces in the banana slices on heating, which prolonged the rate of moisture removal from samples pre-treated with honey dip. Since samples pretreated with honey exhibited a viscous rather than an elastic behavior, it indicates that infusion of sugars caused plasticity of the banana slices. The degree of increased sugar impregnation by the samples pre-treated with honey dip also might cause the delay in drying. These results fully agree with those reported by Panagiotou *et al* (1998) for osmotic dehydration of banana, apple and kiwi pieces in sucrose solution.

Also, it can be seen from Figures 6 to 9 that, as the temperature of drying air increase for a particular thickness, the time of drying decreases. Similar results were expected also as increment of drying air temperature increases the drying potential, therefore it requires less time for the moisture to be removed. In addition, the total drying time was dependent on the pretreatment given for a particular thickness and drying air temperature within the early stages of drying but not significantly dependent on delayed time. This means that it requires a different time to dry the samples at the same thicknesses and temperatures of drying air. Hence, it can be concluded that the drying time depends on the temperature of drying air, thickness of the slices, and the pretreatment given to a certain limit beyond which the drying time is independent of the treatment given.

Moisture diffusivity during drying

The variations in In (MR) with drying time for the control and various pretreatments, drying air temperature and thicknesses of banana slices are shown in Figures 10 to 14 (a and b). The calculated data were statistically analyzed and regression equations were predicted. In general, it was found that In (MR) against time followed straight line equations with negative slopes. However in the later part of the drying, the curves did not follow the straight line behavior. It can be observed that for a particular treatment and thicknesses, the variations in In (MR) depend on the temperature of the drying air. At a given thickness of banana slices, the moisture diffusivity was found to increase with increase in temperature. The moisture diffusivity was found to vary from 9.55 E^{-5} to 14.0 E^{-5} m^2/s, 10.17 E^{-5} to 14.0 E^{-5} m^2/s 9.05 E^{-5} to 14.94 E^{-5} m^2/s, 7.89 E^{-5} m^2/s to 13.8 E^{-5} m^2/s, 9.22 E^{-5} m^2/s to 12.50 E^{-5} m^2/s for the control and various banana slices pretreated with ascorbic acid, lemon juice, salt solution and honey dip respectively. The range of moisture diffusivity was highest in salt solution (5.91 E^{-5} m^2/s), followed by lemon juice (5.89 E^{-5} m^2/s), the control (4.45 E^{-5} m^2/s), ascorbic acid (3.83 E^{-5} m^2/s), and then honey dip 3.28 E^{-5} m^2/s. In addition, the values of coefficients of co-relation for the various curves were 0.825$\pm$ 0.07. This relatively high value of co-relation coefficient shows good fitness between predicted and observed values. The various moisture diffusivities obtained were relatively higher than what Singh *et al*. (2008), Kar and Gupta (2003) reported for drying of button mushrooms of the same thicknesses of slices at 40 to 55. In addition, the moisture diffusivities recorded were higher than what Jadhav *et al*. (2010) reported for drying of bitter gourd. The comparatively high moisture diffusivities recorded in this study might be attributable to the high temperatures of drying air used in this study (60°C and 70°C) and the different cell arrangements in bananas. However, the moisture diffusivities were lower than what Aghbashlo *et al*. (2010) recorded for drying 5 mm thick slices of apple at 50°C, 60°C, and 70°C.



(a)

Figure-10 (a). Variation in LnMR with time for the control banana slices of 5mm thickness at different drying air temperature.

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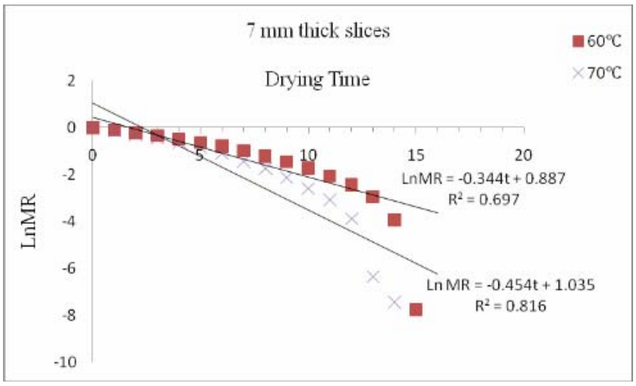
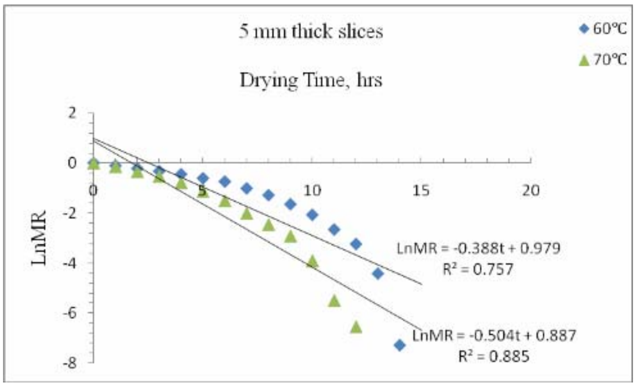
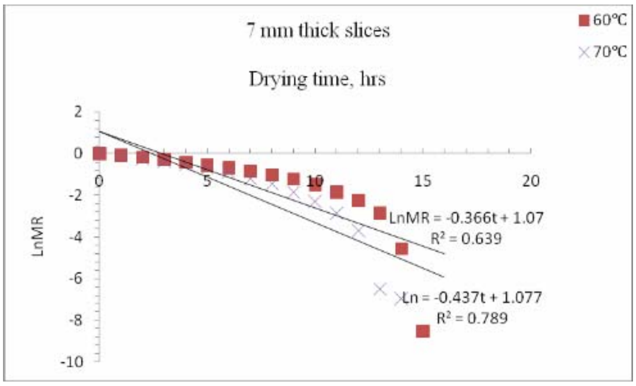


(b)

Figure-10 (b). Variation in LnMR with time for the control banana slices of 7mm thickness at different drying air temperature.

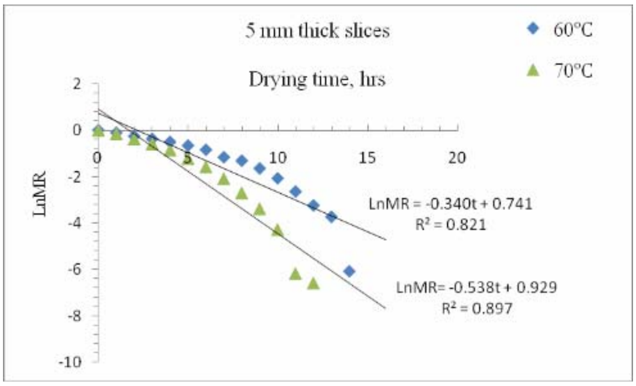


(a)



(b)

Figure-11 (a, b). Variation in LnMR with time for the ascorbic acid treated banana slices of various thicknesses at different drying air temperature.



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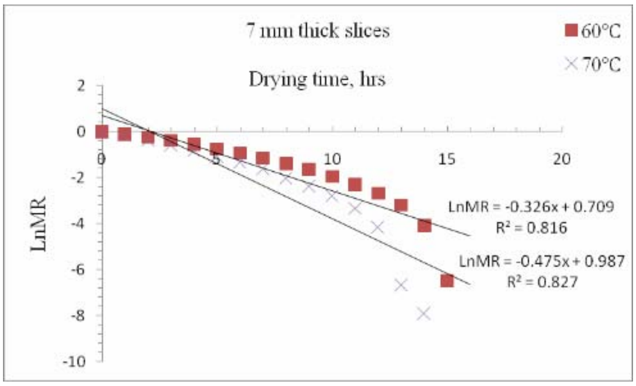
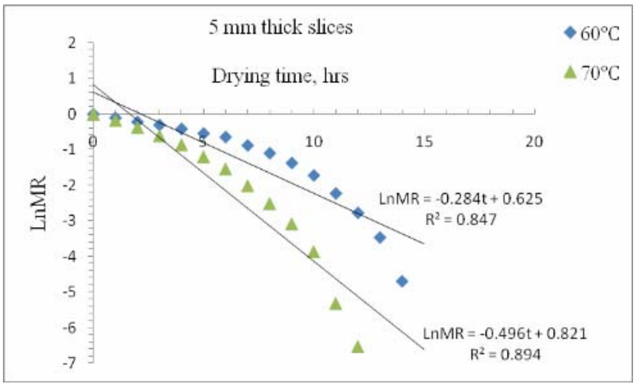


(b)

Figure-12 (a, b). Variation in LnMR with time for the lemon juice treated banana slices of various thicknesses at different drying air temperature.



(a)

Figure-13 (a). Variation in LnMR with time for the salt solution treated banana slices of 5mm thickness at different drying air temperature.

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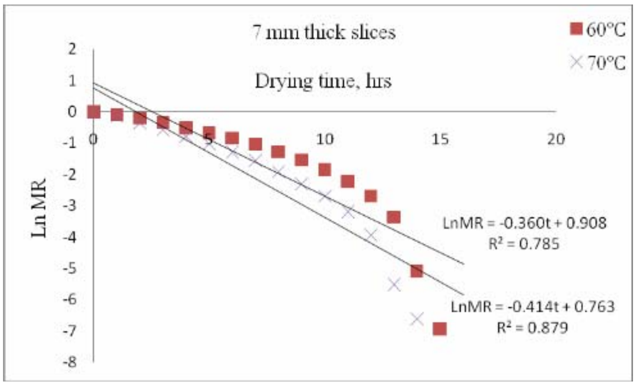
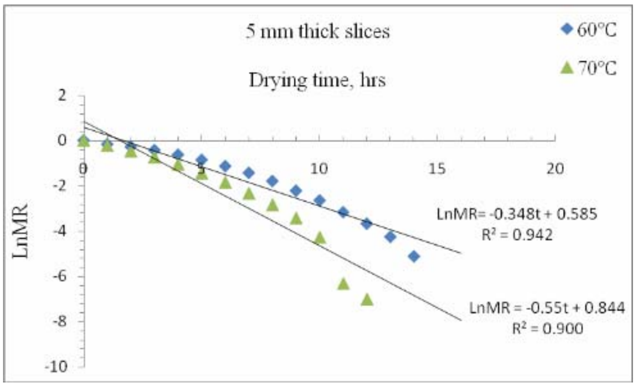
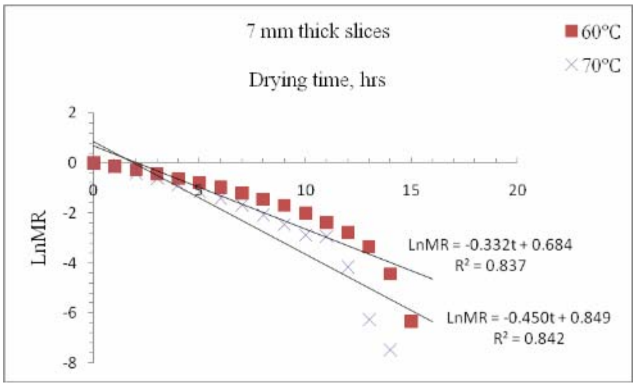


(b)

Figure-13 (b). Variation in LnMR with time for the salt solution treated banana slices of 7mm thickness at different drying air temperature.



(a)



(b)

Figure-14 (a, b). Variation in LnMR with time for the honey dip treated banana slices of various thicknesses at different drying air temperature.

Re-hydration studies

The 5 g samples of dried banana slices were re-hydrated by soaking them in cold water at room temperature for 10 minutes. The minimum re-hydration ratio of 1.215 was obtained for 7 mm thick slices treated with ascorbic acid and the maximum re-hydration ratio of 1.716 was obtained for lemon juice samples. Re-hydration ratio and coefficient of re-hydration are presented in Table-1. It can be seen that there is not much difference in the re-hydration and coefficient of re-hydration for the samples treated with different pretreatments.

Table-1. Re-hydration ratio of dried banana slices in oven drying.

Treatments	Temperature	Thickness (mm)	Re-hydration ratio (RR)	Coefficient of re-hydration (COR)
Ascorbic acid	60	5	1.658	0.497
Control	60	5	1.645	0.517
Honey dip	60	5	1.647	0.517
Lemon juice	60	5	1.716	0.528
Salt solution	60	5	1.621	0.494
Ascorbic acid	60	7	1.215	0.404
Control	60	7	1.247	0.427
Honey dip	60	7	1.231	0.406
Lemon juice	60	7	1.339	0.433
Salt solution	60	7	1.297	0.420
Ascorbic acid	70	5	1.423	0.438
Control	70	5	1.511	0.471
Honey dip	70	5	1.357	0.425
Lemon juice	70	5	1.693	0.514
Salt solution	70	5	1.451	0.455
Ascorbic acid	70	7	1.300	0.417
Control	70	7	1.271	0.412
Honey dip	70	7	1.255	0.404
Lemon juice	70	7	1.276	0.404
Salt solution	70	7	1.269	0.406

CONCLUSIONS

The following conclusions may be derived from the study:

- It requires approximately 16±1 hours for completion of the drying in the cabinet oven dryer;
- The moisture diffusivity varies from 9.55 E-5 to 14.0 E-5 m2/s, 10.17 E-5 to 14.0 E-5 m2/s 9.05 E-5 to 14.94 E-5 m2/s, 7.89 E-5 m2/s to 13.8 E-5 m2/s, and 9.22 E-5 m2/s to 12.50 E-5 m2/s for the control and various banana slices pretreated with ascorbic acid, lemon juice, salt solution and honey dip, respectively;
- The drying time depends on the temperature of drying air, thickness of the slices, and the pretreatment given, up to a certain limit beyond which it is independent of the treatment given; and
- The minimum and maximum rehydration ratio of 1.215 and 1.716 was obtained. There was not much difference in the re-hydration ratio and coefficient of re-hydration for all the treated samples.

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