OPTIMIZATION OF OSMOTIC DEHYDRATION OF "AMBUL" BANANA FOLLOWED BY HOT AIR DRYING

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Abstract
Ambul banana (Musa mysore) is a popular variety in Sri Lanka and it has short postharvest shelf life. Postharvest losses of banana are estimated to be more than 25%. An optimum drying system for the preparation of quality dehydrated products is cost effective as it shortens the drying time and cause minimum damage to the product. The process of osmotic dehydration followed by hot air drying was studied and modeled for ambul banana preservation. Preliminary trials were done to identify the correct total soluble solid content, thickness and diameter of banana slices for the dehydration. Three antibrowning pretreatment were evaluated for banana slices. They are 0.1M ascorbic (A), 0.1M citric (B) and 0.1 M ascorbic citric (50:50) combination(C).Samples were immersed in 60° brix sucrose solution in 1:30 solid to solution ratio at room temperature (30°C) until it became equilibrium. The effective diffusion coefficients for water and sucrose transport were determined according to predictive mathematical model based on Fick's 2nd law. The osmotically pretreated banana slices of sucrose solution were convectively dried in a tray dryer at air temperatures of 50, 60 and 70°C at constant velocity. Color attribute of final dried banana slices were evaluated by "image J" software (version IE 6.0 java). Changes in vitamin C content with time were determined by using a titrimetric method. The moisture content in ambul banana was 75.47% in wet basis. Preliminary study showed the optimum thickness, diameter and soluble solid content of banana slices were, 5 mm, 21mm and 16° respectively. According to predictive mathematical model effective diffusion coefficients of A, B and C pretreated samples were 5.65 $\times 10^{-10}$, 5.86 $\times 10^{-10}$ and 6.74 $\times 10^{-10}$ m^2/s respectively. Solid gain observed in samples were not correlated linearly with the time, solid gain in nine hours osmotic process maximum in A and C pretreated samples (17.94%) whereas the lowest solid gain was observed in B pretreated sample (16.41%). In the hot air drying process moisture content decreased in a nonlinear manner with time at all three temperatures. It was faster in the initial period of drying and then the rate decreased. The surface color (browning index) increased with drying temperature while vitamin C content decreased when increased drying time and temperature. The dried banana prepared by 9 hours osmosis in 60° Brix with C pretreatment and subsequent drying at 50°C hot air for eight hours showed better color, appearance and moisture content.

Keywords: Ambul banana; effective diffusion coefficient; Fick's law; hot air drying; osmotic dehydration

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1. INTRODUCTION

Banana (*Musa* spp.) is one of the major crops which are cultivated all over the world. It is grown in more than 120 countries throughout the tropical and subtropical regions. It is one of the major fruits that have a higher nutritious value (Abiodun-Solanke and Falade, 2010). Ripen banana contain a number of vitamins, vitamins A and C but less in vitamins B. Banana has significant health benefits. It reduces risk of high blood pressure, reduces risk of stroke, cholesterol-lowering effect, great support to kidney health and has potential as a remedy for heart born and important to healthy teeth and bones, giving better contribution to body's immune system, promoting brain health and heart health (Dayananada *et al.*, 2015)."Ambul" (*Musa mysore*) is one of the most popular banana varieties in Sri Lanka. The main reason for this popularity is its sweet and sour taste. This characteristic flavor and relatively smaller has influenced in causing a great potential for increased production to service the export market. However the short storage life of banana is the major problem in exporting this commodity. Previous studies have reported that 20-30% of the banana harvest (9,000-13,500 tons) is going into waste annually in Sri Lanka mainly due to post harvest diseases and mechanical damages(Wasala *et al.*, 2015). It is clear that a considerable amount of the Banana production is wasted due to such reasons.

In the case of avoiding such problems, many processing techniques can be employed to preserve fruits and vegetables like drying. Dehydration is one of the most important operations that are widely practiced because of their technical and economical advantages, such as suitability for automatized mixing with other ingredients, and weight and volume reduction with consequent lowering of storage and transport cost.

Osmotic dehydration involves dehydration of banana slices in two stages, removal of water using as an osmotic agent (osmotic concentration) and subsequent dehydration in a dryer where moisture content is further reduced to make the product shelf stable. Osmotic concentration is the process of water removal from banana slices, because the cell membranes are semi-permeable which creates three types of counter current mass transfer. Water outflow, from the product to the solution , a solute transfer, from the solution to the product and a leaching out of the products own solute (sugars, organic acids, minerals, vitamins, etc.), which is quantitatively negligible compared with the first two types of transfer, but essential with regard to the composition of the final product.

During osmotic dehydration, the kinetics of water removal, the solid gain and the equilibrium moisture content are strongly affected by the kind of osmotic agent and its concentration. This could affect the quality of the final product and it should be minimized. Therefore, the characteristics of the product can be varied by controlling temperature, sugar syrup concentration, concentration of osmosis solution, time of osmosis, size and geometry of sample and sample to solution ratio to make osmotic concentration process faster (Riva *et al.,* 2005).Determination of the diffusion coefficient is essential for describing the mass transfer process, by the Fick's equation(Wadso, 2007), which is used for estimating effective diffusion coefficients of water in the food through different methods. Different methods were compared in order to determine the best coefficient to be used in the predictive models. The analytical solution of the diffusion equation has allowed estimating average values of coefficients between the initial moisture and the average sample moisture at a given instant. The numerical method allowed estimating how the effective diffusion coefficient varies with the moisture (Porciuncula *et al*., 2013).

Fruits are very rarely used as a whole for this process. In the case of bananas, if the fruit is cut in pieces or bits, enzymatic browning produces undesirable and deleterious changes in the appearance, thus sensory properties of fruit and control of enzymatic browning is recommended. For the purpose of minimizing such effects, ascorbic, citric and ascorbic citric combination is used as the anti-browning agents.

After osmotic process, water activity of sample was found to be higher than 0.60, allowing development of microorganisms (e.g. bacteria, fungi), and some undesirable reactions such as enzymatic and non-enzymatic browning reactions, fat oxidation, vitamin degradation and protein denaturation during storage (Bchir *et al.,* 2012).

Therefore, a complementary treatment like drying can enhance the conservation of banana slices. Drying is the most commonly used method for food dehydration since it is the most rapid process that inhibits enzymatic degradation, limits microbial growth and produces a uniform dried product (Mallikarjunaiah *et al.,* 2011). The modes heat and mass transfer are involved in hot air drying of foods. In hot air drying, heat transfer will occur through the flow of heat. Whereas, mass transfer will occur through two mechanisms: Firstly the movement of moisture internally within the foods.

Secondly, the movement of water vapor from the food surface as a result of external conditions of temperature, air humidity, air flow and area of exposed surface (Silva *et al.,* 2014).

One of the most important aspects of drying technology is the modeling of the drying process

2. MATERIALS AND METHODS

2.1 Sample preparation

This research was carried out in the laboratory of Department of Food Science and Technology of Wayamba University of Sri Lanka. Bananas were purchased from a local store in Makandura area, Sri Lanka. The fruits were selected based on their appearance and state of ripeness, which was evaluated from soluble solids content using a refractometer. The soluble solids content were 16° Brix (± 1.3). Selected fruits were peeled manually before use and sliced to 5 mm (± 0.243) of thickness with a diameter of approximately 21mm (± 0.375). Preliminary trails were conducted to optimize the osmotic dehydration conditions with respect diameter and thickness. The sample's dimensions were measured with a Venire caliper.

Banana slices were divided into three groups. The first group was kept in 0.1M ascorbic acid solution. The second group slices were kept in 0.1Mascorbic acid/ citric acid (1:1) mixture. The third group samples were dipped into 0.1M citric acid solution. Each pretreatment was applied 20 minutes in room temperature. The initial moisture content of the banana slices was determined by drying 5 g of pureed sample at 105°C until a constant mass was reached. Pretreatments did not affect the initial moisture content, which was 75.47% (±0.699) in wet basis.Osmotic solutions were prepared with commercial sucrose and distilled water mixed with 3:5 mass ratio. A mass ratio of 1:30 between fruit samples and osmotic solution was used in all experiments, in order to avoid significant changeson sugar solution concentration during the experiments.

2.2. Experimental procedure of osmotic process

Banana samples were weighed, and immersed in a sucrose solution (60°Brix) by thin nylon nets. The solution concentration was determined by a refractometer. The osmotic dehydration experiments were conducted for up to 9 hours in stirred solutions at room temperature.

The mass transfer after the treatment was quantified by determining dry basis moisture content (DMC) and solids gain (SG). The treated banana samples were removed from the chamber, drained and carefully dried on filter paper in order to reduce the solution adhered on their surfaces. Subsequently, these samples were weighed and their moisture content determined by the gravimetric method (AOAC, 2000). All determinations were performed in triplicate for each hour. The values of SG and DMC were calculated through:

$$SG = \frac{\{m_u - m_{uo}\}}{m_o} \times 100$$

$$DMC = \frac{\{m - m_u\}}{m_u} \times 100$$

m_u= dry solids mass in the sample after osmotic dehydration (kg)

m_{uo}= dry solids mass in the non-treated sample (kg)

m_o= mass of non-treated sample (kg)

m= sample mass after osmotic dehydration (kg)

2.3. Determination of effective diffusion coefficient

Diffusion coefficient wad determined by using following equation:

$$\frac{m_w}{m_{wo}} = \frac{\bar{\rho} - \rho}{\rho_i - \rho_s} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\,\pi^2\,\frac{Dt}{4L^2}\right)$$

m_w = Water content in the sample (kg)

m_{wo} =Water content of non-treated sample (kg)

ρ = Concentration of water in the sample (kg m^{-3})

$\bar{\rho}$ = Average concentration of water in the sample (kg m^{-3})

ρ_i =Initial concentration of water in the sample (kg m^{-3})

ρ_s =Water concentration in the surface of the samples in equilibrium with the osmotic solution (kg m^{-3})

D= Diffusion coefficient

L= Thickness of banana slices (m)

Water concentration in the banana (ratio of water mass by solid volume) was replaced by sample water content in dry basis (X), as a consequence of considering the non-shrinkage of samples. Analytical methods were used to estimate effective diffusion coefficients of water in banana.

D_x is the coefficient determined from an analytical solution and each pair of time-diffusion coefficient. The value of D_x is supposed to represent the coefficient between the initial moisture and the moisture after an elapsed experimental time.

$$D_x = a + bX$$

In which a and b are constants and X is the time (Seconds). D_x is the average value that best represents a set of experimental data, which was equal to effective diffusion coefficient.

2.4. Determination of moisture content in hot air drying process

The osmotic treated banana samples were removed from the chamber, subsequently, these samples were kept in dehydrator at three different temperatures (50, 60 and 70°C) for 8 hours. The weight of moisture can was recorded as (W1). Approximately 5g of bananaslices were weighted in to the moisture cans and allowed to dehydrating. Then each hour time interval weight of moisture cans and banana slices were recorded as (W2) and placed in an air drying oven at 105°C (Memmert-USA) to constant weight, allowing at least 24 h. it was cooled in a desiccator. The weight of the crucible plus contents was recorded after drying (W3).

$$DMC = \frac{\{m_1 - m_e\}}{m_e} \times 100$$

m_1= Sample mass after hot air drying (kg)

m_e=Dry solids mass in the sample after hot air drying (kg)

W1= Initial weight of empty moisture can (kg)

W2= Weight of moisture can + sample (kg)

W3= Final weight of moisture can + sample (kg)

m_1= W2- W1

m_e= W3- W1

2.5. Surface color evaluation

Osmotically and air dried banana slices were selected randomly and images were used and the mean value of RGB (red, green and blue) taken using the “image J” software (version IE 6.0 java). The data were plotted against color index (RGB mean value) and temperature.

2.6. Determination of vitamin C degradation during hot air drying

The 2,6-dichlorophenolindophenol titrimetric method(Okiei et al., 2009) was used to determine the total ascorbic acid content of dried banana.

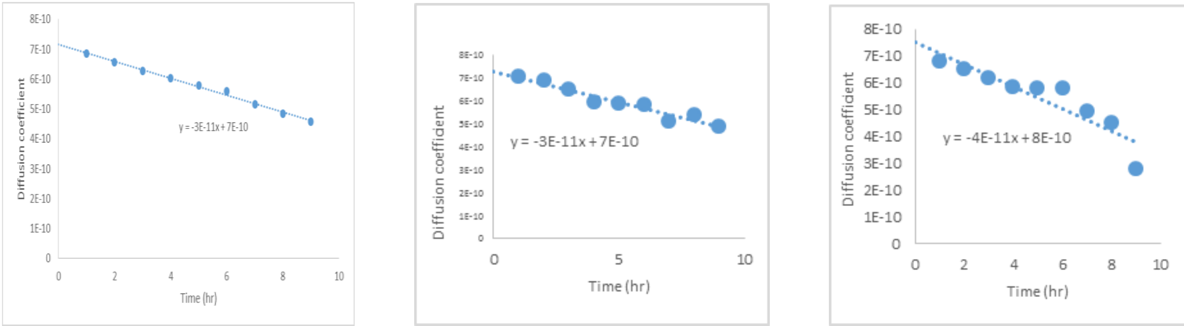
2.7. Statistical analysis

Significant differences between the results were calculated by analysis of variance (ANOVA) using SAS software. Differences at $p < 0.05$ were considered to be significant. Results were expressed as mean ± SD. Values were the average of triplicate experiments.

3. RESULTS AND DISCUSSION

Visual observation of dried banana slices is very important aspect to the consumer acceptance of the product, surface color depend on hot air drying temperature and pretreatments. Banana slices were white-yellowish at the beginning and developed a yellow-brownish color in the course of the drying. The discoloration was decreased with increasing temperature plan an enzymatic character of the browning (Demirel & Turhan,2003). Under the same conditions, the pretreated slices showed less discoloration than the untreated slices. In this experiment, citric and ascorbic acids were used in 1:1 ratio as the pretreatment and three hot air drying temperatures (50,60 and 70°C) were used. Reports on the effect of pretreatment on color of dried banana is mixed probably due to use of different varieties, pretreatment agents, concentration, time-temperature combination of pretreatments, drying conditions, determination methods of the discoloration.

3.1. Effective diffusion coefficient in osmotic process



A B C

Figure 1:Time evolution of Diffusion coefficient (DC) of 5 mm thick ascorbic acid (A), citric acid (B), ascorbic-citric acid (C) pretreated banana slices, during the osmotic process

About 5 mm thick pretreated banana slices during the osmotic process data has been plotted against the time and diffusion coefficient (Figure 1), it was calculated using predictive mathematical model. It shows there is an inverse relationship between diffusion coefficient and time. The diffusion coefficient in ascorbic acid pretreated banana was within the range of 6.86 $\times 10^{-10}$ m^2s^{-1} to 4.58$\times 10^{-10}$ $m^2s^{-1}$and the value of effective diffusion coefficient 5.65 $\times$ 10^{-10} m^2s^{-1}. The diffusion coefficient of citric acid pretreated banana was within the range of 7.07 $\times 10^{-10}$ m^2s^{-1} to 4.90$\times 10^{-10}$ m^2s^{-1} and the value of effective diffusion coefficient is 5.86 $\times$ 10^{-10} m^2s^{-1}. The diffusion coefficient of both ascorbic acid and citric acid pretreated was within the range of 6.77 $\times 10^{-10}$ m^2s^{-1} to 2.76 $\times 10^{-10}$ m^2s^{-1} and the value of effective diffusion coefficient is 6.74 $\times$ 10^{-10} m^2s^1.According to experimental data, highest effective diffusion coefficient was showed by ascorbic and citric acid combination (C) pretreated sample and the lowest effective diffusion coefficient was showed by ascorbic pretreated sample which gives the value of 5.65 $\times$ 10^{-10} m^2s^{-1}. The value of the effective diffusion coefficient of citric pretreated samples (B) is in between other two pretreatment applied samples which is 5.86 $\times$ 10^{-10} m^2s^{-1}. Pretreatments have an important effect on banana dehydration rate, which was used to find most suitable pretreatment.

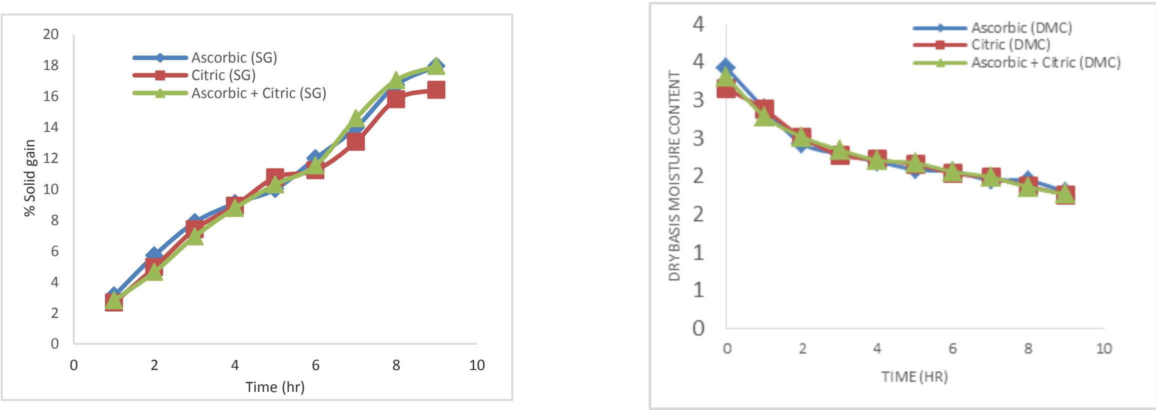
During the osmotic process a non-uniform moisture gradient is developed and the diffusivity is not constant, it varies with the position inside the sample and time of dehydration. It was observed lower values of the diffusion coefficients with decreasing moisture content of the samples (Porciuncula*et al.*, 2013).Besides the changes in moisture content, the state of the cell membrane may change from partially permeable to completely permeable, causing significant changes in tissue structure.

The most likely cause of cell damage can be attributed to the reduction of cells size, caused by the loss of water during the osmotic dehydration. These cellular changes can modify the water path during the dehydration and, as a consequence, the value of the diffusion coefficient was changed (Grunwald & Germany, 2000).

According to the Figure 2, banana slices in different pretreatments at room temperature on the percentage solid gain (Figure 2A) shows a nonlinear positive relationship.

After the completion of nine hours processing period, ascorbic and combination of ascorbic acid and citric acid pretreated samples was showed the highest solid gain by 17.94% and the citric acid shows the lowest solid gain by 16.41%.

Figure 2B shows changes in moisture content based on dry weight basis pretreated banana slices in different pretreatment at room temperature on dry basis moisture content which plotted against time and dry basis moisture and the results showed there were no significant difference (p>0.05) according to the pretreatments.



A B

Figure 2: Influence of different pretreatment at 30°C on % solid gain (A) and change in moisture content (B) of banana slices of 5mm thickness during osmotic dehydration

The effect of sucrose of different pretreatment on the solid gain with respect to time of osmosis at different temperatures is shown in Figure 2.After the completion of nine hours processing period, ascorbic and combination of ascorbic and citric acid pretreated samples was showed the highest solid gain is 17.94% and the citric shows the lowest solid gain is 16.41%.

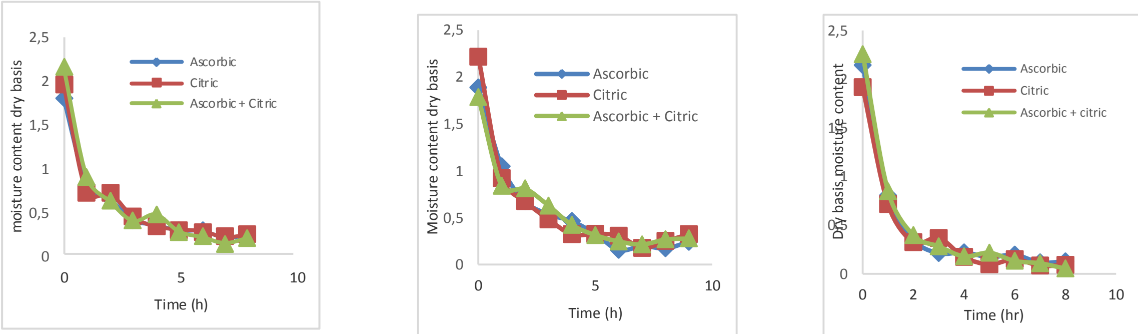
Solid gain also increases in a nonlinear manner with time at all pretreatments. Solid gain is faster in the initial period of osmotic dehydration and then the rate decreases. This is because the osmotic driving potential for solid transfer keeps on decreasing with time as the solids keep moving from solution to sample. Further, more solid uptake results in the formation of high solid subsurface layer, which interferes with the concentration gradients across the sample-solution interface and act as a barrier against uptake of solids(Khan *et al*.,2003).Also solid uptake is inversely correlated with the size of the molecule of osmotic agents.

The effects of different pretreatments on the dry basis moisture content with respect to time of osmosis at room temperature are shown in Figure 2B. It is observed from these figures that the moisture loss increases in a nonlinear relationship with time at all pretreatments. Moisture loss is faster in the initial period of osmotic dehydration and then the rate decreases. This is because osmotic driving potential for moisture transfer keeps on decreasing with time as the moisture keeps moving from sample to solution. After some period of osmotic dehydration, the rate of moisture loss is reduced, because of faster gain of solid at initial period in the banana slices that fill the path of evaporation; hence restricting the loss of moisture (Vasić *et al*., 2012).

3.2. Changes in moisture content during hot air drying

Figure 3 shows the changes in moisture content in osmotically treated samples with time at three different temperatures. At 50°C temperature (Figure 3A) about eight hours hot air drying final product which pretreated ascorbic, citric and ascorbic/citric combination contain 0.17kg•kg^{-1}, 0.25 kg•kg^{-1} and 0.26 kg•kg^{-1} dry basis moisture content respectively. At 60°C (Figure 3B) eight hours hot air drying, moisture content was 0.20kg•kg^{-1}, 0.21kg•kg^{-1} and 0.17kg•kg^{-1} in the same order. Whereas at 70°C (Figure 3C) eight hours hot air drying. Moisture content was 0.12kg•kg^{-1}, 0.09 kg•kg^{-1} and 0.06 kg•kg^{-1} dry basis at the same order. Each temperature all treated samples showed a rapid slope initially and then gradually decreasing trend.

The initial moisture content of samples was measured as 75.47% (±0.699) (wet basis). Moisture content of osmotically pre treated banana slices were decreased with increased air-drying temperatures, compared to osmotic dehydrated banana slices.



A B C

Figure 3: Changes in moisture content (dry basis) of osmotically pre-treated banana slices at 50°C (A), 60°C (B) and 70°C (C) temperature air drying process

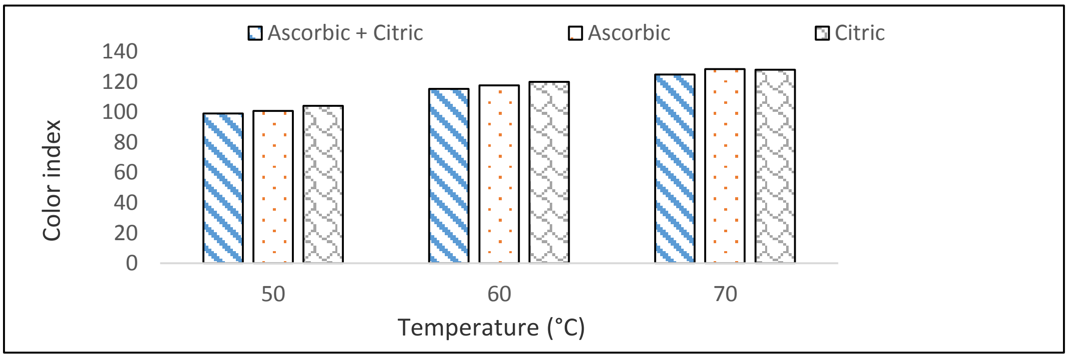


Figure 4: Effect of pre-treatment and temperature (ºC) on color measurement parameters after osmotic dehydration treatments

This is due to the loss of total free water fraction in banana slices during air drying process. The drying rate increased with temperature from 50 to 70°C. During drying at high temperatures, case hardening is expected for foods containing dissolved solutes in high concentration. The moisture content rapidly decreased and then gradual decrease with drying time (Fig.3 A, B, C). However, tested pretreatments were not significantly ($p<0.05$) affect on the drying rate during the hot air drying process. Increasing the drying temperature decreased the moisture content of final product. Reduction of drying rate might also be due to the development of the shrinkage which causes the reduction in porosity of the banana samples with advancement of the drying process (Sereno, 2003).

The moisture ratio reduced exponentially as the drying time increased. Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer (Rigi *et al.*, 2014). Moisture ratio is reduced during drying process at all temperatures investigated in this study but at higher temperature (70°C) this reduction is quicker (Fig.3C). This can be attributed to a high rate of evaporation from the surface of banana samples at higher temperatures which leads to higher mass transfer rate (Lima *et al.*, 2002). A higher drying air temperature decreased the moisture ratio faster due to the increase in air heat supply rate to the banana samples and the acceleration of moisture migration.

3.3. Surface color evaluation

Color index contains the mean values of combination of red, blue and green of the banana slices. Graph shows that color index increase when the temperature increases. Compare the other color index at 50°C is most suitable for all pretreatment which is less browning. According to the Figure 4, 50°C is the most suitable temperature for all pretreatment which gives less browning and

when the hot air drying temperature increases the color index also increases.
Through statistical data, only hot air drying temperature affects the color index significantly. Pretreatments did not affect significantly for the color index. But considering 95% confidence level, ascorbic pretreated sample shows lowest browning index. Under the given conditions, the banana samples which were treated with ascorbic acid and citric acid 1:1 ratio combination and 50°C hot air drying temperature is the most suitable considering surface color. The Figure 4 shows that combination of ascorbic acid and citric acid pretreated and hot air dried at 50°C are the most suitable temperature for hot air drying and the pretreatment to prevent browning.

3.4. Vitamin C degradation during hot air drying

The Figure 5 shows the changes in the amount of vitamin C content with the processing time period. It shows rapid slope initially and then gradually decreases within the range of 0.064 to 0.015 mg/ dry g. 75.65% of vitamin C destroyed in 8 hours hot air drying process. Vitamin C is a very sensitive indicator whose loss in dehydrated fruits can be attributed to osmotic treatment, dehydration and storage conditions, among other factors. Several authors have observed a high loss of vitamin C by leaching during osmotic dehydration of different fruits (Azoubel *et al.*, 2009). The effect of temperature during osmotic dehydration on the loss of vitamin C was also measured. The vitamin C content in fresh fruit was measured at 0.057 mg/g. The vitamin C content in banana was reported after the ascorbic citric combination pretreatment was 0.064mg/g. Initial vitamin C content of banana change by factors such as the extent of ripeness and the growing conditions of the fruit. As can be seen the drying temperature affected the decomposition of vitamin C so that the least amount of vitamin C was measured at 50°C. After the eight hours of hot air drying processing time vitamin C content was decrease to 0.015mg/g. This can be related to the irreversible oxidization of vitamin C during drying. From a functional point of view, vitamin C in combination with other antioxidants, including vitamin E, β-carotene, and phenolic compounds, provides a synergistic antihypertensive effect (Okiei *et al.*,2009). As banana is enriched with some of these compounds access to drying conditions that retains most of the vitamin C content. According to Figure 5, 75.65% of vitamin C destroyed in eight hours hot air drying process.
In order to prevent absorption of moisture from atmosphere and to prevent spoilage due to contamination, good quality, food grade and airtight containers can be used to store osmotically dried foods. Aluminum foil, laminated polypropylene pouches are suggested as ideal packing materials although use of high-density polyethylene pouches for osmotic dried banana is common. Based on a preliminary shelf life study (data not shown), the osmotic dried banana slices on storage for 6 months were microbiologically safe which could probably be because of addition of ascorbic, citrate, low moisture and high concentration of sugar.

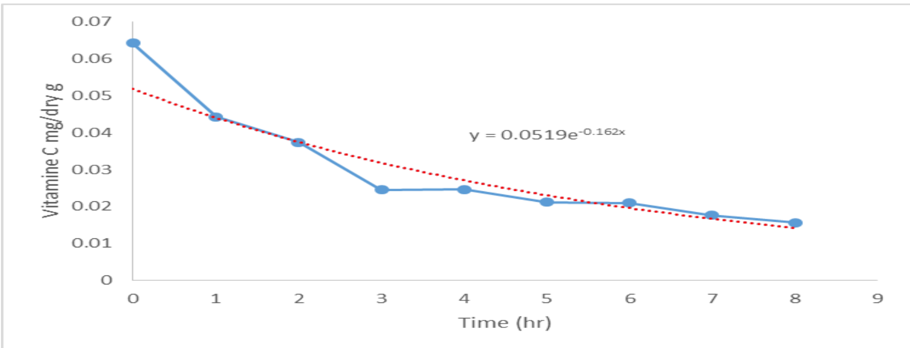


Figure 5: Vitamin C content versus drying time of ascorbic citric combination pre-treated banana slices at 50°C temperature air drying process

The higher total soluble solid and acidity of the product might have also played a role in preservation of the product.

4. CONCLUSIONS

From the results it can be concluded that solid gain by the banana slices increased non-linearly with duration of osmosis. The rate of moisture loss and solid gain both were higher in the initial period of osmosis than in the later period. The most effective pretreatment for hot air drying of osmotcally treated banana is use of combination of 0.1M ascorbic and citric acid at 1:1 ratio. Effective diffusion coefficient of 0.1M ascorbic and citric acid pretreated banana for osmotic process is 6.74×10^{-10} m^2/s. The most suitable temperature for hot air drying is 50°C. However, about 75% of vitamin C may destroy during 8 hours hot air drying process.

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