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Comparative Analysis of Shrinkage of Pineapple during Convective Drying in Sun, Solar and Electric Tray Drying

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Abstract: **- In this study, a comparative analysis was done on the shrinkage behaviour of pineapple slices under three different drying treatments namely solar, open sun and convective electrical tray drying. Pineapple slices were cored and dried under the above mentioned conditions. The diameters and thickness was measured using a vennier calliper and the volume and density were calculated from the collected data. it was noted that there was more shrinkage in tray drying followed by sun drying. Solar drying had the least shrinkage. The reduction in density followed a non-linear exponential reduction. All three drying treatments exhibited the same phenomenon. An exponential function was best in describing the reduction in density in solar drying. For sun and tray drying, the density reduction followed a power function decline. By comparing the volume of water removed versus the fractional volume decrease of pineapple samples in solar drying, sun drying and tray drying respectively it was noted that again a linear relationship prevailed in all three cases. The linear correlation coefficient (R2) showed that the shrinkage was more linear in sun and tray drying with a similar R2 value of 0.978 and 0977 while that for solar drying was least at 0.956.**

Key words: **Shrinkage; Fractional volume; Density; Drying; Dehyadration**

I. INTRODUCTION

Drying or dehydration of foods is an age old practice used to preserve food. This is achieved by removal of water in part or all from the food matrix. This ensures microbial and enzymatic stability of the food. Drying usually refers to the process of liquid water being evaporated from the surface of the product or from the pores within the product, the water vapour subsequently being removed by, e.g., hot air. Being one of the oldest methods of food preservation, drying has been known to protect food against microbiological spoilage as well as pathogens. Drying helps to maintain the edible status of foods and, generally speaking, extends their shelf life. The required level of moisture content to prevent spoilage achieved in a drying process depends on the micro-organisms present and inhibition of biochemical reactions. Additional heat is usually required to accelerate the drying process. The heat can be supplied in many ways, such as solar energy, microwave/radio-frequency radiation, hot gas stream (including superheated steam), etc. [1], [2]. According to Senedeera [3], dried foods have a number of advantages which include stability under ambient conditions, ease of handling by volume reduction, extended shelflife and easily incorporated into other food formulations. Abasi et al, [4] also reported the advantages of reduced transport and handling costs as well as reduced storage costs due to reduced volume.

The mechanisms of water transfer in the product during the drying process can be summarized as follows: water movement due to capillary forces, diffusion of liquid due to concentration gradients, surface diffusion, water vapor diffusion in pores filled with air, flow due to pressure gradients, and flow due to water vaporization–condensation. In the pores of solids with rigid structure, capillary forces are responsible for the retention of water, whereas in solids formed by aggregates of fine powders, the osmotic pressure is responsible for water retention within the solids as well as in the surface [1], [2].

The drying process of a material can be described by a series of stages in which the drying rate plays a key role. Fig 1 shows a typical drying rate curve in which points ***A*** and ***A'*** represent the initial point for a cold and hot material, respectively. Point *B* represents the condition of equilibrium temperature of the product surface. The elapsed time from point *A* or *A′* to ***B*** is usually low and commonly neglected in the calculation of drying time.

The section ***B*** to ***C*** of the curve is known as the constant drying rate period and is associated with the removal of unbound water in the product. In this section, water behaves as if the solid were not present, that is, it moves freely. Initially, the surface of the product is very wet, with a water activity value close to one. In porous solids, the water removed from the surface is compensated by the flow of water from the interior of the solid. The constant rate period continues, while the evaporated water at the surface can be compensated for by the internal water. The temperature at the surface of the product corresponds approximately to the wet bulb temperature.

The falling rate period starts when the drying rate cannot be kept constant any longer and begins to decrease and the water activity on the surface becomes smaller than one. In this case, the drying rate is governed by the internal flow of water and water vapor. Point *C* represents the start of the falling rate period, which can be divided into two stages. The first stage occurs when the wet points on the surface decrease continuously until the surface is completely dry **(point *D*)**, while the second stage of the falling rate period begins at point ***D***, where the surface is completely dry and the evaporation plane moves to the interior of the solid. The heat required to remove moisture is transferred through the solid to the evaporation surface, and the water vapor produced moves through the solid in the air stream going towards the surface. Sometimes there are no marked differences between the first and second falling rate periods. The amount of water removed during this period may be small, while the time required may be long since the drying rate is low [5].

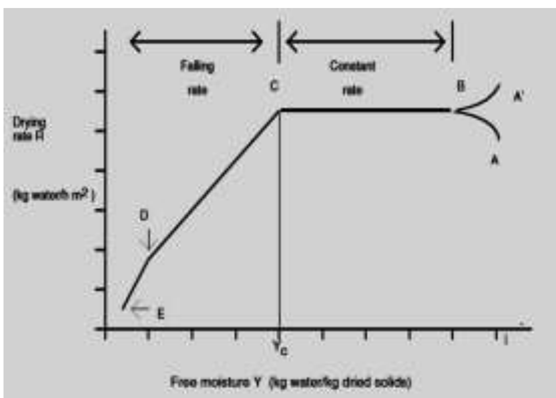


Fig 1: Drying rate curve [5].

The process of drying or dehydration is however accompanied by physical and structural changes to the food such as shrinkage. Shrinkage can be defined as the change in volume due to removal of moisture in the viscoelastic matrix leading to a contraction of the matrix as it collapses into the voids left by water [2] or simply reduction in external volume leading to change in shape and decrease in dimension [6]. In most reported cases shrinkages is detrimental to the quality of dried foods save for instances where it is a desired characteristic as is the case with resins, plums and dates [6]; [4]. The loss of volume, crispiness, surface cracking are often considered poor quality characteristics and reduce overall acceptance by consumers. Abasi et al [4] further elaborated on the significance of shrinkage on the drying in drying operations by stating that it is a phenomenon that cannot be ignored in studying the drying kinetics of foods. Zogzoz et al [7] stated that shrinkage was a function of size, surface area and volume or dimension reduction. As such mathematical shrinkage models have been proposed to describe shrinkage. they are either empirical or fundamental models. Empirical models take into account the amount of shrinkage and how it relates to the operational parameters of the drying process. On the other hand the fundamental models take into account the porosity, density, volume and mass transfer.

Pineapple slices which were centre cored were dried in three conditions namely open sun, indirect cabinet solar dryer and convective electrical dryer. The Pineapple (*Ananas comosus*) is one of the common non-citrus tropical and subtropical fruit, largely because of its attractive flavour and refreshing sugar-acid balance and a very rich source of vitamin C and organic acids [8].

II. MATERIALS AND METHODS

2.1 Fruit Selection and Preparation

Mature pineapples *(Ananas comosus)*of green-yellow colour were obtained from the fruit market in Chennai area with an average weight of 150g ±7g, a moisture content of 87% ± 5% [9]. The initial moisture content was determined by gravimetric measurement method where a sample was placed in a hot air oven at 105^{o}C and measuring the moisture until a constant weight was obtained [10]. The fruits were peeled, sliced to an average thickness of 10mm ±3[11] and cored. They were divided into two lots and the lots were dried in the solar dryer and in open sun drying simultaneously.

2.2 Laboratory scale solar dryer prototype design

A laboratory scale solar dryer was designed and fabricated for this study. It had a capacity of 1kg. The dryer was constructed using sheet metal of thickness 4mm which had an insulated drying cabinet to prevent secondary heating from the walls. The dryer was intended to dry products from an average moisture content of 90% to 10% or less which caters for a wide range of fruits and vegetables.

2.3 Open Sun Drying

Pineapple slices were spread (uni-layer) on a flat wooded surface and exposed to direct solar radiation. The drying process involved heat transfer by convection from the surrounding air and by direct absorption of solar incidence and diffuse radiation on the surface of the pineapples which caused the drying to occur. A dry bulb thermometer was mounted to record the ambient air temperatures.

2.4 Gravimetric Analysis

Periodic sampling and weighing was used to record the reducing weights of both the samples in open sun and solar dryer. An electronic weighing balance was used to measure the weights which were taken at half hour intervals. Gravimetric analysis is based on the principle of loss of water due to drying (evaporation) which directly translates to a decrease in the sample weight. The change in weight over time was recorded and the data was analysed [12].

2.5 Volume Measurement

The shrinkage phenomenon was analysed by monitoring of samples total volume and apparent density during drying. Pineapple samples with cylindrical ring shape geometry were measured for shrinkage. The outer diameter, inner diameter and thickness were measured using a digital vennier callipers at one hour intervals. The formula for volume of a cylinder was used and the inner diameter volume was subtracted from the outer diameter volume to obtain the true volume of the pineapple rings. Equation 1 shows the formula for volume of the pineapple rings [13].

$$\textbf{\textit{Ring Volume}} = \frac{\pi D^2}{4}h - \frac{\pi d^2}{4}h \ (mm^3) \qquad \text{(Equation 1)}$$

Where D is outer diameter, d is inner diameter and h is the thickness of the pineapple ring.

2.6 Density measurement

The density of the pineapple rings was determined at one hour intervals. The density was obtained by dividing the volume by the recorded mass for drying kinetics as shown in equation 2.

$$\textbf{\textit{Density}} = {}^{m\,(g)}\!\big/_{V(mm^3)} \qquad \text{(Equation 2)}$$

Where m is the mass of samples in grams and V is the volume of the samples in mm^3.

2.7 Volume of Water Removed (VR)

The dimensionless ratio of water removed (VR), was calculated using equation 3

$$VR = {}^{V}\!\big/_{V_o} \qquad \text{(Equation 3)}$$

where VR is the dimensionless ratio of water removed, V is the volume removed at time t and V_o is the volume at time t = 0 [6].

2.8 Fractional volume decrease of sample (SV)

The fractional decrease of sample volume was obtained from equation 4

$$SV = {}^{(V_o - V)}\!\big/_{V_o} \qquad \text{(Equation 4)}$$

III. RESULTS AND DISCUSSION

3.1 Shrinkage and Density

Shrinkage was monitored by taking the decreasing dimensions of the pineapple rings. From the diameter and thickness of the rings, the volume and density were calculated using equations 1 and 2 for solar sun and tray drying.

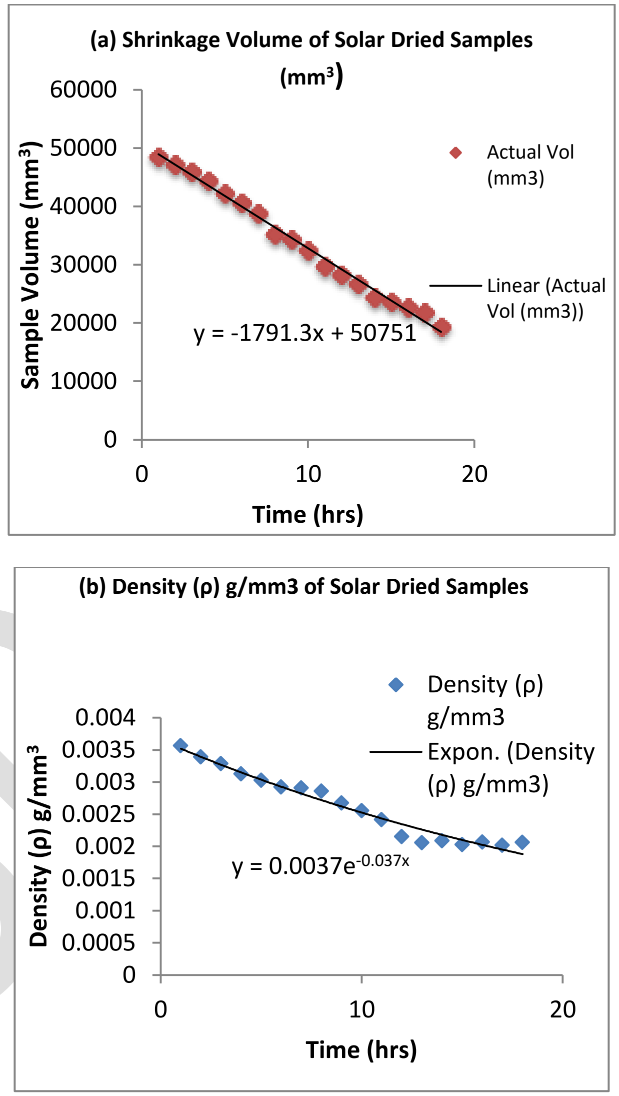
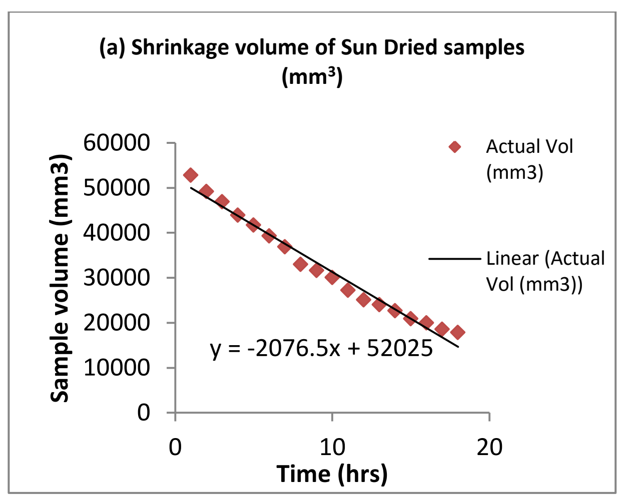


Fig 2: (a) Shrinkage and (b) Density vs Time for Solar Dryer Kinetics



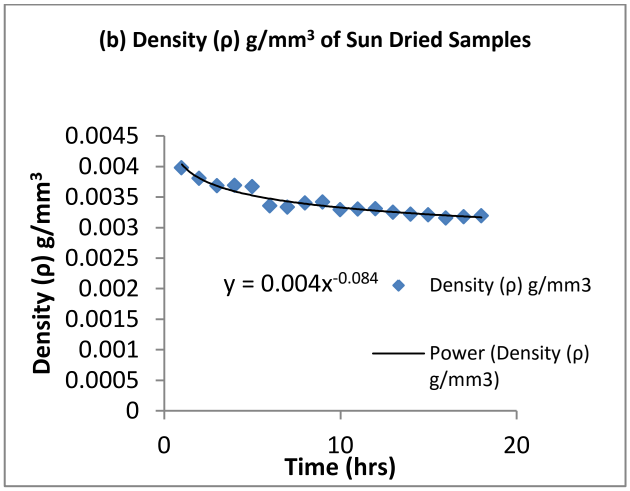
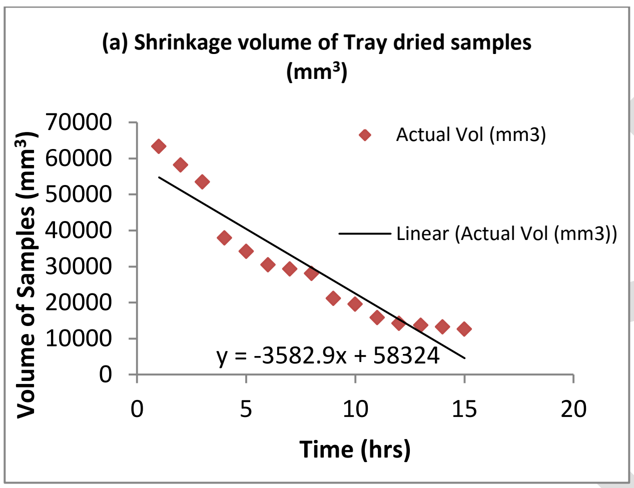


Fig 3: (a) Shrinkage and (b) Density vs Time for Sun Dryer Kinetics



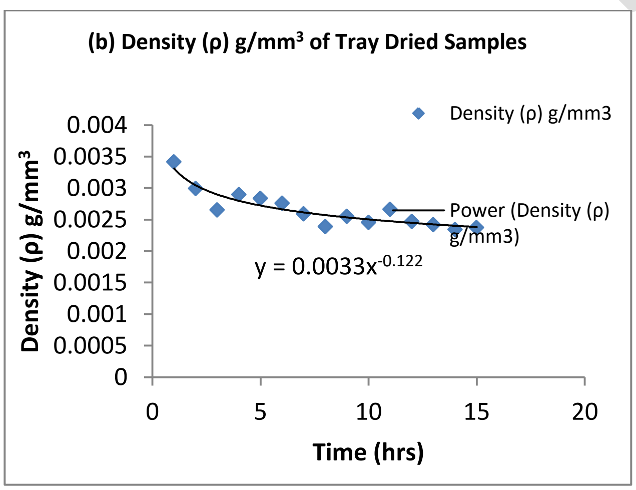


Fig 4: (a) Shrinkage and (b) Density vs Time for Tray Dryer Kinetics

From the graphs of volume vs Time Fig 2a, 3a and 4.a, a linear relationship was established during all the three drying treatments. By comparing the gradients, these can be taken as shrinkage rate constants [13]. It was noted that there was more shrinkage in tray drying followed by sun drying. Solar drying had the least shrinkage. The reduction in density followed a non-linear exponential reduction. All three drying treatments exhibited the same phenomenon. An exponential function was best in describing the reduction in density in solar drying. For sun and tray drying, the density reduction followed a power function decline (Figs 2B, 3b and 4b). A model equation was generated for all three changes in density (Table I).

Table I: A summary of the shrinkage data and model equations

Sr No.	Treatment	Shrinkage Rate constant	Model Equation (density decrease)
1	Solar Drying	-1791.3	$y = 0.0037e^{-0.0037x}$
2	Sun Drying	-2076.5	$y = 0.004x^{-0.084}$
3	Tray Drying	-3582.9	$y = 0.0033x^{-0.122}$

3.2: Water Removed versus the Fractional Volume Decrease

Figs 5, 6 and 7 showed the volume of water removed versus the fractional volume decrease of pineapple samples in solar drying, sun drying and tray drying respectively. it was noted that a linear relationship prevailed in all three cases. The linear correlation coefficient (R^2) showed that the shrinkage was more linear in sun and tray drying with a similar R^2 value of 0.978 and 0.977 while that for solar drying was least at 0.956. These findings were similar to the work done by Krokida & Maroulis [14] and Lazano et al [15]. In explaining this linear phenomenon, it was noted that the shrinkage occurred throughout the drying process, the volume of water removed may be larger in the final stages than the volume reduction of the sample due to increased rigidity of the solid matrix as moisture content decreases [16]. The results of the linear phenomenon of volume of water removed versus fractional volume decrease of pineapple samples are shown in Table II.

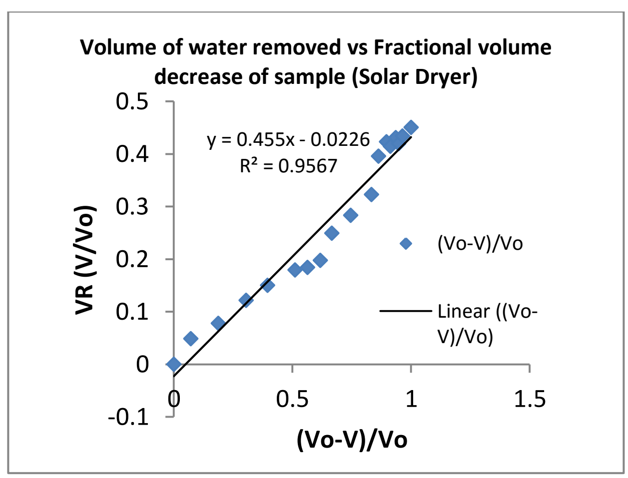


Fig 5: Volume of water removed vs Fractional volume decrease of sample (Solar Dryer)

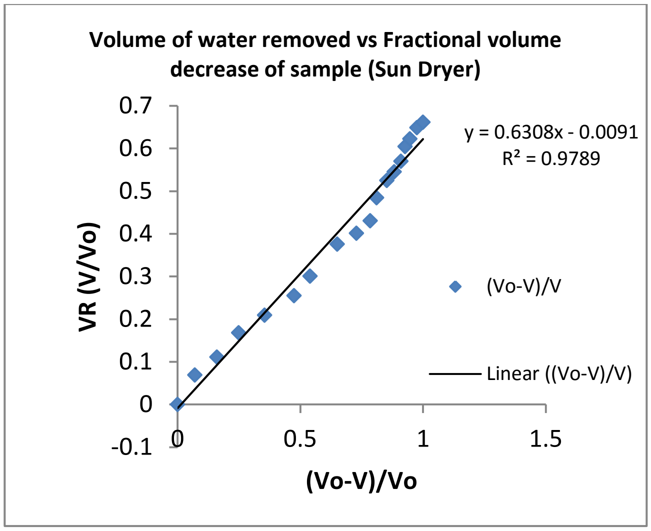


Fig 6: Volume of water removed vs Fractional volume decrease of sample (Sun Dryer)

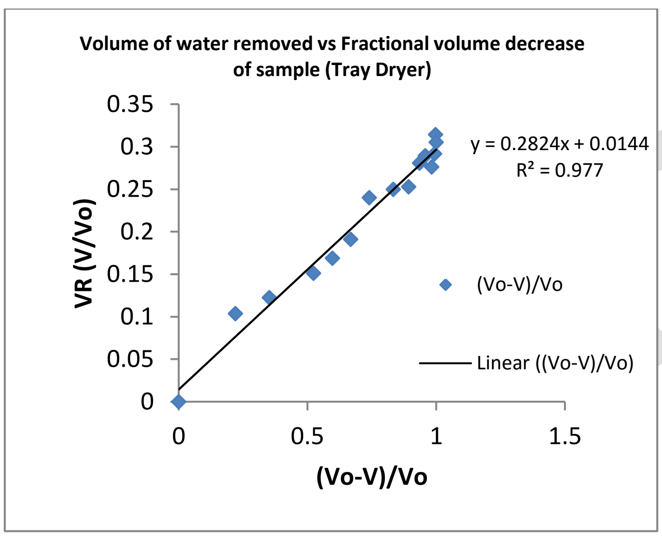


Fig 7: Volume of water removed vs Fractional volume decrease of sample (Tray Dryer)

Table II: Summary of volume of water removed versus fractional volume decrease of pineapple samples

Sr No.	Treatment	R^2	Model Equation (VR vs SV)
1	Solar Drying	0.956	*y = 0.455x - 0.022*
2	Sun Drying	0.978	*y = 0.630x - 0.009*
3	Tray Drying	0.977	*y = 0.282x + 0.014*

IV. CONCLUSIONS

From the results obtained, it was noted that shrinkage occurred in all three treatments namely solar, sun and tray drying but was more pronounced in sun and tray drying. Solar drying had the least shrinkage. This could be attributed to the high temperature used in the tray dryer (60°C) which resulted in a more rapid heat transfer. in the case of sun drying the though the avarage temperatures were lower than both tray and solar drying, the mass transfer due to unhindered air flow may have contributed to increased shrinkage when compared with solar drying.

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