Storage stability of dried tomato slice

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Abstract: Unlike fresh farm produce, processed fruits and vegetables such as sun dried tomatoes can be categorized as ambient temperature shelf stable products. However, large quantities of these products yet easily go bad most especially when the appropriate conditions for their storage are not offered. To minimize these losses, it is important to know and exploit the optimum environmental conditions and moisture content range for the storage of the products. The present study through systematic theoretical assertions employed by other researchers on other crops seeks to establish the storage stability of dried tomato slice at three probable temperatures of 10, 30 and 45℃. Results showed that in this temperature range, upper limit moisture content varied between 6%-7.5% and 6.5%-8.3% d.b. for adsorption and desorption, respectively. The corresponding lower limit moisture contents varied between 4.29%-5.52% and 5.15%-6.29% d.b. In order to minimize moisture migration into or out of dried tomato slice during storage, the study revealed that the product should be stored within 29%-62% relative humidity.

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1 Introduction

Tomato *Solanum lycopersicum* is among the most widely grown, commercially important and highly consumed vegetable in the world. Owing to its demand there is yearly increase in the cultivation of tomato in Nigeria. Statistics showed that between 2007 and 2010 the estimated production of tomato in Nigeria has increased from 1.079 to 1.861 million metric tones[1]. Currently, excessive supply of tomato usually occurs at the peak period of production while after a few weeks, scarcity set-in resulting in high prices of the fruit[2]. Since not all the fresh tomatoes produced can be consumed at the peak period of production, sun drying into dried slices and storage usually provides a larger market. Our informal survey on dried tomato slice production, packaging and storage in the Northwestern parts of Nigeria revealed that, over drying, bulk packaging inside polyethylene bags of any sort found in the market, storage of the packaged dried tomatoes slice on bare cemented ground and the display of the slices in an open container by the retailer in the market places, are common practices in the area. These conditions expose the product to the adverse weather conditions and dirt. Consequently, the product undergoes oxidation and moisture adsorption which cause mouldiness, discolouration, loss of nutrients and flavor. Therefore, the objective of the present study was to establish the suitable environmental conditions, and moisture content range at which dried tomato slice is the most stable for storage.

2 Materials and methods

2.1 Theoretical background

2.1.1 Determination of moisture content range

It has been noted that water in biomaterials serves as reactant, solvent and vehicle for the transportation of

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other soluble constituents in the material[3]. The knowledge of moisture content of food materials is very important. Because water is the major ingredient in many foods and it has a significant effect on food microbial, chemical and structural stability[4]. Consequently, drying of food materials is usually done to reduce its water content thereby minimizing microbial, chemical and enzymes activities during the storage of the materials. The idea used to be that the lower the moisture content, the better. Hence, dried food materials are usually stored at very low moisture content. In contrast, optimum moisture content for storage of dried food materials is the safe storage moisture content of the material. This is normally the maximum moisture content (upper limit moisture content) of dried food which discourages the growth of food pathogens such as moulds and bacteria. Igbeka[5] stated that the critical estimation of optimum moisture content is complex. A method which has been applied by some researchers that yielded satisfactory result is the "stability isotherm"[3,5,6]. The method that was initially reported by Rockland in 1969 involves plotting $\Delta M/\Delta RH$ against M and its integral form is given in Equation (1). The stability isotherm was developed from free energy change equation presented in equation (2).

$$\frac{\Delta M}{\Delta RH}=\int_0^\infty \frac{M}{RH}dM \tag{1}$$

$$\Delta F=\frac{RT}{18}\int_0^1 \frac{M}{RH}d(RH) \tag{2}$$

where, ΔF = free energy change (J/(kg mol)) during the transfer of 1 g water in an isotherm process; R = Universal gas constant (8314 J/(kg mol K)); T = Temperature (K); RH = Relative humidity (%); M = Moisture content (%, d.b.).

The free energy change equation was derived from the combination of the first law of thermodynamics and the ideal gas law in Equations (3) and (4) respectively.

$$\Delta F=-pdV \tag{3}$$

$$pV=nRT \tag{4}$$

Derivative of Equation (4) with respect to p yields

$$dV=-nRT\frac{\mathrm{d}p}{p^2} \tag{5}$$

Substituting Equation (5) into Equation (3) is given as follows:

$$\Delta F=nRT\frac{\mathrm{d}p}{p} \tag{6}$$

$$\Delta F=\frac{RT}{M_w}\int_{p_0}^{p}\frac{\mathrm{d}p}{p} \tag{7}$$

where, V = volume of gas, n = number of molecules of gas; M_w = 18, molar mass of water; p = vapor pressure of water vapor in a system and p_0 = saturated vapor pressure of pure water in the air in Pascal (Pa) at a given temperature T.

Equation (7) is written as Equation (2) since the pressure in this case is usually due to difference in relative humidity.

Rockland[6] explained that, the free energy required to transfer water molecules from vapor state to solid surface is a quantitative measure of the affinity of the solid for the vapor. Since the expression $RT/18$ in Equation (2) is a constant, the equation can therefore be represented by the plot of $\Delta M/\Delta RH$ against RH which is very similar to the stability isotherm in Equation (1). The only difference is Equation (2) is integrated with respect to RH while Equation (1) is with respect to M. The free energy equation is minimized when M/RH has a minimum value. It is therefore asserted that maximum product moisture stability occurs at M:RH coordinates where minimum change of moisture content M takes place per change in RH. This is because at this point, M is least sensitive to a change in RH. The optimum moisture content of product can therefore be read from the plot of $\Delta M/\Delta RH$ against M as the moisture content that corresponds to the minimum point on the curve.

As oppose to the view that food products moisture stability increased with the decrease moisture content (without limit), a study discovered an automatic deterioration resulting in typical rancid flavor and odor at a low moisture content[7]. This explained the need to determine the lower limit moisture content. The Brunauer-Emmett-Teller (BET) model presented in Equation (8) was used to determine the monolayer moisture contents (Mm) which corresponds to the least moisture or lower limit moisture content and this is described as the moisture at which food is most stable[3,5,7,8]. According to Oyelade[9] monolayer moisture content is the least moisture content required of food material for it safe storage and it is not the optimum moisture content.

$$\frac{aw}{(1-aw)M}=\frac{1}{M_m}+\frac{(C_b-1)}{M_mC_b}aw \tag{8}$$

where, M = equilibrium moisture content (%, d.b.); M_m = monolayer moisture content (%, d.b.); aw = water activity (decimal).

2.1.2 Determination of storage environment

Local isotherm concept (LI) applied[5,9,10] was adopted in relating the isotherm curves of dried tomato slice to the storage environment at various temperature. This involves linearization of the Henderson Equation (9) to obtain Equation (10).

$$(1-aw)=e^{-KTM^n} \tag{9}$$

$$\lg[\text{-}\ln(1-aw)]=\lg KT+n\lg M \tag{10}$$

where, aw = water activity (decimal); M = moisture content (%, d.b.); n and K =constants.

Then, $\lg[\text{-}\ln(1-aw)]$ is plotted against log M to determine the moisture content M, water activity aw, and constants n and K. The plot usually group aw into three ranges through lines y_1, y_2 and y_3. Figure 1 shows a typical plot of $\lg[\text{-}\ln(1-aw)]$ against $\log M$ where arrows I_{12} and I_{23} indicate the points of intersections between lines y_1:y_2, and y_2:y_3 respectively.

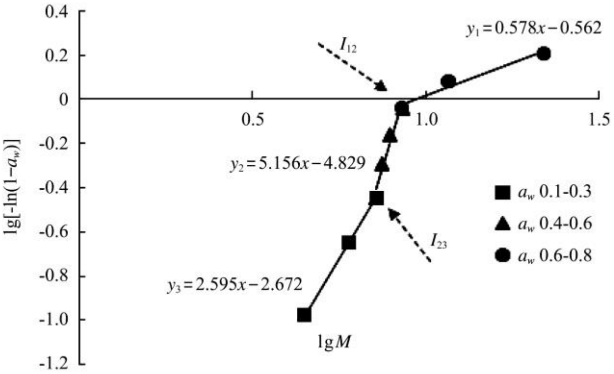

Figure 1 Typical plot of log[-ln(1−*aw*)] versus lg *M* at a given temperature

2.1.3 Tomato sample preparation

Freshly harvested full red tomato fruits of Roman VF which is one of the most widely grown varieties in the Northwestern part of Nigeria were collected from a single grower’s field at Kudingi in Giwa Local Government Area of Kaduna State, Nigeria. The fruits were transported in open baskets to the Crop Processing Laboratory of the Institute for Agricultural Research (IAR) Samaru Zaria, where the experiment was conducted. The fruits were sorted to remove the damaged ones and undamaged were washed, drained and sliced 20 mm thick to obtain a uniform drying. The slices were dried using IAR forced convection solar dryer.

The major components of the forced convection solar dryer include blower system, solar collector, drying chamber and the frame. The blower system consists of 45 Watts Newclime axial flow fan mounted on a hollow trapezoidal air duct tapered at inclination of 15°. The air duct has an inlet opening of 0.35 m × 0.35 m and outlet opening of 0.07 m × 0.8 m. It directs the airstream from the fan into the solar collector unit which is a blackbody 1 m × 1.5 m in size. Hot air from the solar collector is then channeled into the drying chamber. The drying chamber 1 m × 3 m in size contains drying beds on which the slice tomatoes are spread in thin layer. Both the solar collector and drying chamber were equipped with Perspex cover to guide against dust and other contaminants. The dryer is mounted on wooden frames that give it support and raised it 0.4 m above the ground level. The drying of tomato slice used for this experiment was carried out between the months of December and January under the following weather conditions: average incident solar radiation of 473 W/m^2; average ambient temperature of 20.8℃; average relative humidity of 20% and Sunshine hours of 7.3 h per day. Drying of the sample to an average moisture content of about 5% (d.b.) was achieved in 60 h.

2.2 Weather simulation

The gravimetric method described[7,9,11] was used to obtain the various relative humidity levels used in the moisture sorption study. This method involves preparation of various concentrations of sulfuric acid (H_2SO_4) to vary the relative humidity in the range of 10% to 80% in airtight glass bottles. Triplicate samples of 10 g dried tomato slices (5% d.b. moisture content) were weighed into a sample basket made from wire mesh and the weights of the baskets together with the samples were recorded as the initial masses of the replicates. The triplicate samples were placed on a plastic stand in the glass bottles over the H_2SO_4 solutions contained in the bottles. Sets of bottles containing the samples and the H_2SO_4 solution at relative humidity of 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% were arranged in three different environments maintained at temperatures of 10^{O}C, 30^{O}C and 45^{O}C. These temperature ranges were chosen because they were probable temperature in tropical region. For instance, 13.6℃ and 43.0℃ were maximum and minimum monthly mean temperature data for 10 years (1999-2008) in Zaria[12]. During the experiment, the temperature control was achieved by using a LG refrigerator model GR B282VPL set at 10℃ and two Panasonic cooled incubator model MIR154 set at 30℃ and 45℃. The samples were weighed every day until constant weights were attained. Constant weight is attained when the sample mass remained the same for three consecutive days. The weighing was done as quickly as possible to prevent sorption from atmosphere. When the constant weights were reached, sample equilibrium moisture contents were determined by oven drying method at 110℃.

The above experiments were also carried out on a reconditioned sample of dried tomato slice. The reconditioning was achieved by using the method described[13-15]. This involves, soaking 0.5 kg of tomato slices at an initial moisture content of 5% d.b. in clean water for thirty minutes. At the end of the soaking, the tomato was spread out in thin layer to dry in natural air for about eight hours. The tomato was then packaged in polyethylene bags and stored in this condition for a further twenty four hours. The polyethylene bags were kept in a refrigerator to enable uniform moisture content. Then, the tomato was allowed to equilibrate in ambient condition for six hours. At the end, the moisture content of the reconditioned sample was determined as 29.5% d.b. The equilibrium moisture contents from the experiments using 5% d.b. and 29.5% d.b. moisture contents were used to plots for adsorption and desorption respectively.

3 Results and discussion

3.1 Upper limit moisture content

Some physical changes noticed during the experiment include variation in the time taken for the equilibration to reach. Some samples attained the constant weight before the others. Equilibrations of samples were found to be between 9th and 13th day of the experiment. Although there was no condensation of moisture noticed in the airtight glass bottles during the experiment, but samples subjected to 70% and 80% of relative humidity especially those stored at 45℃ become darker in color and soggy after the experiments. From the experiment, equilibrium moisture contents were obtained for each level of relative humidity. The ΔRH has a constant value of 10 this is obtained as the difference between each successive level of relative humidity 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% employed. Corresponding values of ΔM were obtained by finding the difference between successive equilibrium moisture contents of the corresponding relative humidity levels. Figures 2 and 3 represent the plots of the moisture stability quotier $\Delta M/\Delta RH$ against moisture content M at various temperatures for adsorption and desorption processes respectively. From the plots, the points of minimum change in M per unit change in RH which correspond to lowest point on the curves were read and presented in Table 1 as the upper limit moisture contents.

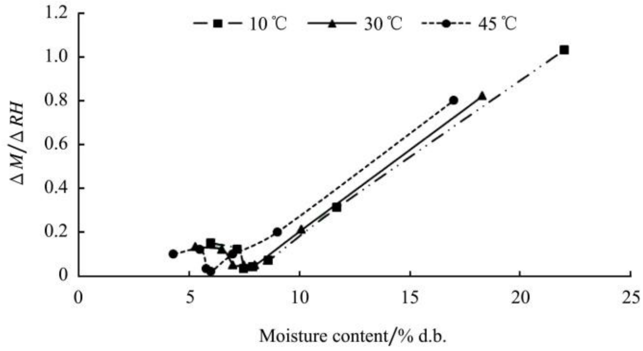

Figure 2 Moisture stability curve of dried tomato slice at adsorption

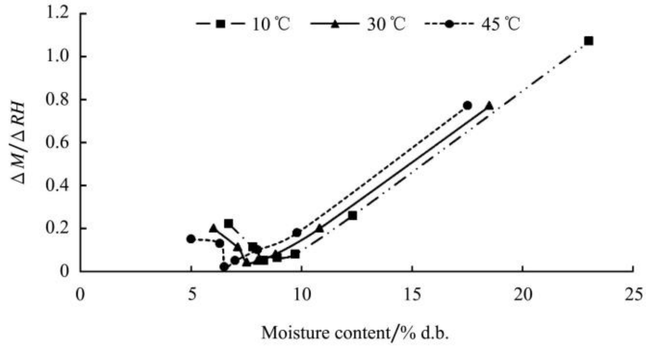

Figure 3 Moisture stability curve of dried tomato slice at desorption

From Table 1 it can be deduced that upper limit moisture content otherwise called the optimum moisture content decreased with the increase in the temperature and its values range between 6.0%-7.5% d.b. and 6.5%-8.3% d.b. for adsorption and desorption respectively. In the variety of temperature chosen, the upper limit moisture contents at desorption were higher than adsorption. This implies that, the dried tomato slice need to be dried further if it is to be stored at higher temperature than it is required when it is to be stored at a lower temperature. This is in order with the assertion that the kinetic energy of water molecule is high at higher temperature[16]. Therefore, smaller moisture should be left in the product to be stored at higher temperature to prevent free water that can make the product to be susceptible to spoilage. The trend of the above results were in agreement with those reported for other food materials[3,5].

Table 1 Upper limit moisture contents of dried tomato slice

Temperature/°C	Upper limit moisture content/%, d.b.	
	Adsorption	Desorption
10	7.5	8.3
30	7.5	7.5
45	6.0	6.5
Mean ±SD	7.0 ±0.87	7.3 ±0.90

3.2 Lower limit moisture content

Monolayer moisture contents which correspond to the lower limit moisture content required in the dried tomato slice determined using the Brunauer-Emmett-Teller (BET) model equation are presented in Table 2. The results showed that lower limit moistures range between 4.29%-5.52% d.b. and 5.15%-6.29% d.b. for adsorption and desorption, respectively.

Table 2 Lower limit moisture contents of dried tomato slice at adsorption and desorption

Temperature/°C	Lower limit moisture content/%, d.b.	
	Adsorption	Desorption
10	5.52	6.29
30	5.05	5.81
45	4.29	5.15
Mean ±SD	4.95 ±0.62	5.75 ±0.57

In general, values of the lower limit moisture contents were found to be higher for desorption than adsorption. The values of lower limit moisture content decreased with increase in temperature for both adsorption and desorption processes. These trends were similar to those reported for other food materials[7,17,18]. The results were in accord with the affirmation that, the higher the temperature, the lower the moisture level must be in order to reduce deterioration of biological materials[19]. It is interesting to note that all the lower limit moisture contents determined using the BET model were lower than their corresponding upper limit moisture contents earlier determined using the "stability isotherm".

3.3 Storage environment

Apart from the inherent moisture content of food, another important factor that determines its storage stability is the storage environment. The storage environment is a function of relative humidity and temperature under which the food material is stored. Using the linearized Henderson equation, the Local Isotherm (LI) plots of lg[-ln(1−aw)] against lg$M$ yielded linear equations and corresponding lg$M$ values of the intersection point as presented in Table 3.

Table 3 Storage environment models and intersection points demarcating dried tomato slice into local isotherms

Temp/ ℃	Adsorption			Desorption		
	Models	R^2	Intersection	Models	R^2	Intersection
10	$y_1 = 0.578x - 0.562$	0.968	$I_{12} = 0.9345$ $I_{23} = 0.8573$	$y_1 = 0.614x - 0.620$	0.945	$I_{12} = 0.9868$ $I_{23} = 0.8921$
	$y_2 = 5.156x - 4.829$	0.949		$y_2 = 4.290x - 4.253$	0.983	
	$y_3 = 2.595x - 2.672$	1.000		$y_3 = 2.149x - 2.391$	0.985	
30	$y_1 = 0.642x - 0.596$	0.948	$I_{12} = 0.9031$ $I_{23} = 0.8129$	$y_1 = 0.713x - 0.688$	0.945	$I_{12} = 0.9445$ $I_{23} = 0.8513$
	$y_2 = 4.535x - 4.130$	0.999		$y_2 = 4.320x - 4.094$	0.966	
	$y_3 = 2.521x - 2.489$	0.998		$y_3 = 2.074x - 2.235$	0.989	
45	$y_1 = 0.600x - 0.522$	0.949	$I_{12} = 0.8451$ $I_{23} = 0.7404$	$y_1 = 0.671x - 0.618$	0.937	$I_{12} = 0.9031$ $I_{23} = 0.7993$
	$y_2 = 3.630x - 3.072$	0.860		$y_2 = 3.598x - 3.256$	0.889	
	$y_3 = 2.392x - 2.201$	0.987		$y_3 = 2.077x - 2.106$	0.999	

When lg*M* coordinates of the intersection points were substituted as '*x*' in the models, corresponding values of '*y*' were determined and equate to the term lg[-ln(1−*aw*)] in order to calculate the values *aw*. Using the procedure described above, ranges of water activity *aw* required for storing dried tomato slice were estimated to be 0.30-0.61 and 0.29-0.62 for adsorption and desorption, respectively. These values were therefore used in the demarcation of the isotherms into LI-I, LI-II and LI-III for dried tomato slice as illustrated in Figures 4 and 5 for adsorption and desorption respectively. Bond water properties in each of the LI's have been described as: LI-I is monolayer, frozen, hydrate, localized, polar site water that strongly attached to substrates; LI-II is the multilayer, intermediate, chemisorbed water usually the stable region and; LI-III is mobile, free, capillary water that support microflora growth[3,5,20]. It is remarkable to note that, the upper limit and the lower limit moisture contents that were previously determined fall within the equilibrium moisture contents of the LI-II in both adsorption and desorption that are described as the stable region.

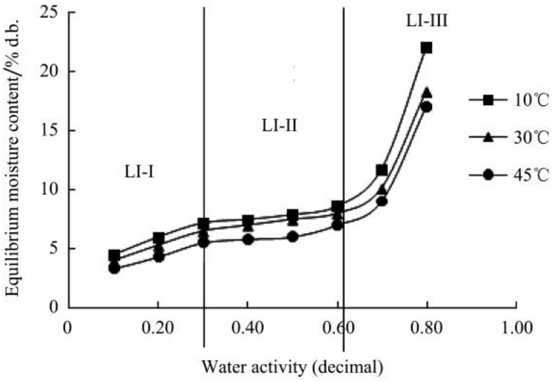

Figure 4 Moisture isotherm of dried tomato slice at adsorption

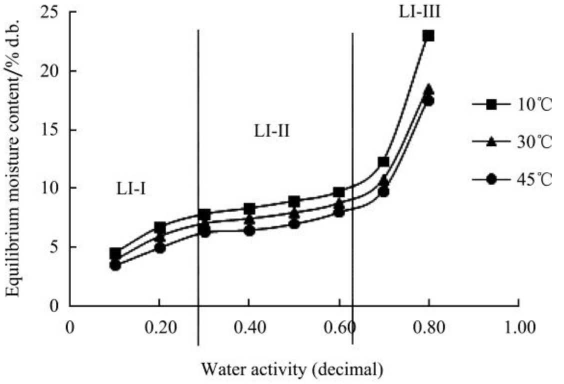

Figure 5 Moisture isotherm of dried tomato slice at desorption

4 Conclusions

Inferences from the present study showed the existence of upper and lower limit moisture contents and water activity range at which stability of dried tomato slice is at its maximum. The study showed that in the temperature range of 10℃ to 45℃ dried tomato slice should not be dried below moisture content of 4.29% d.b. in order to avoid automatic deteriorations or above 8.3% d.b. moisture content to avoid microflora growth. Dried tomato slice was found to be the most stable in the region of local isotherm II (LI-II) and the product should be stored within 29%-62% relative humidity to minimize moisture migration into or out of the product.

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