

## Effect of Selected Factors on Drying Process of Tomato in Forced Convection Solar Energy Dryer

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**Abstract:** The effect of air velocity, slice thickness and glazing materials in drying process of tomato in forced convection solar energy dryer was evaluated. The result is to serve as an input for solar energy development for drying of vegetable and fruit products in North West Ecological zone of Nigeria. In order to evaluate the effects of the above factors in drying operation, a split-split-plot experimental design was used. Differences among the treatments and their interactions were tested with orthogonal contrast test to access their significance while further analysis were done to compare all possible pairs of treatment means using Duncan's Multiple Range Test (DMRT). The results showed that there is no significant difference, at 95% probability level, between the means of the three glazing materials used. However, the variations in mean slice thickness and in mean air flow rate are highly significant at 99% probability level. The results further revealed that drying rate increasing with decrease in slice thickness and increase in air flow rate. Drying of 15, 20 and 25 mm slice thickness of tomato was achieved in time range of 21-24, 27-29 and 30-50 h, respectively.

**Keywords:** Air flow rate, drying time, glazing, slice thickness, solar dryer, tomato

### INTRODUCTION

Drying involves the removal of moisture from agricultural products. It is a process of simultaneous heat and mass transfer. That is, it involves two fundamental physical processes: the transfer of heat to evaporate moisture and the transfer of mass or moisture within and from the drying product. The heat transfer may be in form of conduction, convection or radiation while the mass transfer may be in form of liquid as it diffuses to the surface and/or as a gas diffusing outward from the product (Kays, 1991).

Generally, moisture removal from agricultural products may be by thermal or low temperature drying. When the product is subjected to thermal drying, two processes occur simultaneously:

- The transfer of heat energy from the surrounding environment to evaporate the surface moisture
- The transfer of internal moisture to the surface of the material and its subsequent evaporation from the surface

According to Kays (1991) and Joshi *et al.* (2004), the rate at which the above processes are accomplished in convective solar energy drying operation is governed mainly by the properties of the drying medium (heat

energy, air movement, humidity, atmospheric pressure and vacuum) and that of the product properties (moisture content, thickness, surface area and nature of the material). Others are the geometrical arrangement of the product in relation to the heat transfer surface or medium (for example, tray loading) and the characteristics of the drying equipment-heat transfer efficiency. However, the specific factors affecting drying rate include: heat energy; equilibrium moisture content; humidity; air velocity; surface area of material; atmospheric pressure and vacuum; and nature of material size. Preliminary evaluation has shown that air velocity and product size are very crucial in tomato drying operation, especially during the cold dry period when tomato drying is at its peak.

Heat energy has a pronounced effect on the rate of drying. It provides the drying force for moisture removal. According to Abdullahi (2003) the greater the temperature difference between the drying medium and the material being dried, the greater will be the rate of heat transfer into the material. Kays (1991) also reported that increasing the material temperature increases the free energy of the water molecules, which increases their movement and potential for exchange. Therefore, the higher the temperature of air and the greater the temperature drop, the faster the rate of drying will be.

Drying, in thin layer, is one in which individual particles or grains of material are fully exposed to the

drying air (Henderson *et al.*, 1997). Air serves as the vehicle to carry heat to the drying material and to carry away the evaporated water vapour. The greater the air flow in general, the greater the drying rate (FAO, 1995). In thin layer bed drying of wheat, air velocity has been reported to have a significant effect on drying rate (Cao and Yu, 1987). It has, also, been established that the heat gain or efficiency of flat plate solar energy collector increases as the air flow rate increases (FAO, 1987).

Evaporation is a surface phenomenon. This implies that the ratio of surface area to the volume of the product is of critical importance. Abdullahi (2003) reported that larger ratio of surface area to the volume of material provides more surface in contact with the drying medium for more moisture removal.

In investigation using natural convection solar energy dryer; Buhari (2000) and Aliyu (2000) individually evaluated 10, 15 and 20 mm tomato thickness cut transversely. The former recommended 10 mm based on dried quality while the later 15 mm as economic size in terms of drying space.

The objective of this study is to evaluate the effect of air velocity, slice thickness and grazing materials in drying process of tomato in forced convection solar energy dryer.

## MATERIALS AND METHODS

The study was conducted in 2009 at Department of Agricultural Engineering, Ahmadu Bello University, Zaria-Nigeria. Exhaust type axial flow fan was used for this study. Isiaka (2009) recommended this fan because of its high efficiency, compactness, structural durability, light weight, low power rating, simplicity of installation and low cost. A Newclime fan regulator with five speed levels was used to vary air velocity/flow rate. Roma VF (known locally as Dan Acre) tomato variety was used as experimental crop. The tomato was obtained from IAR Samaru Experimental farm. The tomato fruits were sorted to an average size of 80 mm length and 60 mm diameter. This was followed by removal of bad and unripe fruits. The sorted fruits were washed and allowed to drain. Then, the fruits were sliced transversely into thicknesses of 15, 20 and 25 mm, respectively. Samples of the fresh tomato were taken for moisture content determinations.

The experiment was conducted using a split-split-plot experimental design at three levels of air flow rate (3.28, 4.50 and 5.25 m<sup>3</sup>/s, respectively), three levels of slice thickness along transverse direction (15, 20 and 25 mm, respectively) and three types of glazing materials (polythene sheet, perspex and glass). Each experimental unit was subjected to three replications and thus bringing the total experimental units to 81.

Table 1: Analysis of Variance (ANOVA) for tomato drying data showing the effect of variables and their interaction on time

Source of variation	df	Sum of square	Mean squares	Computed F	Tabular F 1%
Replicate	2	1.3765	0.6883	1.32 ns	6.94 18.0
Cover (A)	2	0.3025	0.1512	2.58 ns	6.94 18.0
Error, a	4	0.2346	0.0586		
Thickness(B)	2	9196.6173	4598.3086	25467.60**	3.88 6.93
A x B	4	6.7716	1.6929	9.38**	3.26 6.41
Error, b	12	2.1667	0.1806		
Air flow (C)	2	39.8210	19.9105	38.28**	3.25 5.25
A x C	4	52.6790	13.1698	25.32**	2.63 3.89
B x C	4	5.6975	1.4244	21.97**	2.63 3.89
A x B x C	8	9.4136	1.1767	2.26*	2.21 3.04
Error, c	36	18.7222	0.5201		
Total	80	9373.8025			

Ns: Not significant; \*: Significant at 99% probability level; \*\*: Significant at 95% probability level

Nine dryers were used for the experiment and each of the dryer has nine sample trays. The trays were coded, weighed and recorded. The sliced samples were evenly spread on the trays to form a single layer and the loaded samples were re-weighed. This was followed by arrangement according to the layout of the experimental design inside the drying chambers. During the drying process the air flow rates, the ambient temperatures (wet and dry) around the dryer, the inlet and the outlet temperatures plus the relative humidity in and out of the dryer were monitored. The variations in samples weights were monitored using metler weighing balance with a sensitivity of 0.01. The first readings of the samples weights were taken and recorded 1 h into drying time. Subsequent readings of the samples weights were taken at 2 h intervals until constant weigh was reached for each of the samples. The initial and final moisture contents of the samples were determined according to the procedure detailed by ASAE (1996).

The statistical analysis was done using orthogonal contrast test (SAS, 1995) to determine the significant effects. Further analysis was done to compare all possible pairs of treatment means using Duncan's Multiple Range Test (DMRT).

## RESULTS AND DISCUSSION

**Effect of selected factors on drying process of sliced tomato:** The analysed results for experimental evaluation of the effect of grazing material, slice thickness and air flow rate on the drying process are as presented in Table 1. The result shows that there is no significant difference, at 95% probability level, between the means of the replicate plots, meaning that the experimental error is minima.

**Effect of grazing materials on drying time:** The result in Table 1 shows that the variation in mean drying time for three different types of grazing materials was not

statistically significant at 99% probability level. This implies that the effect of grazing materials, namely polythene sheet, Perspex and glass covers, does not affect the drying rate of sliced tomato in a forced convection solar dryer. This is evident from the mean drying time of 32.5, 32.6 and 32.6 h recorded for glass, Perspex and polythene leather, respectively.

**Effect of slice thickness on drying time:** The variation in mean drying time for slice thickness was found to be statistically significant at 95% probability level. Since evaporation is a surface phenomenon the significant nature of variation in drying time as related to slice thickness is as expected. In this case, the ratio of surface area to volume increases as slice thickness decreases. This implies that the smaller the thickness, the higher the ratio and as such more of the surface will be in contact with the drying medium thereby providing more surface area for moisture escape. In drying process, there is need to transport the internal moisture in product to the surface before evaporation can take place, therefore, the release of the moisture will be faster in products with small thicknesses as it is evident in these results.

The effect of slice thickness on drying time was ranked using Duncan's Multiple Range Test (DMRT). The results of the ranking revealed that the mean drying time for 15 mm slice thickness is significantly different from those for 20 and 25 mm. The mean for 20 mm slice thickness is also different from that for 25 mm slice thickness. That is, drying time decreased as the slice thickness is reduced. The result is in agreement with Abdullahi (2003) who found that products with enormous surface area relative to their volume loose moisture quickly when subjected to the same drying conditions. Mean drying time of 22.4, 27.9 and 47.3 h were achieved for 15, 20 and 25 mm thicknesses, respectively. This implies that, total drying time was increased to about 25 and 102% with 5 and 10 mm increase in thicknesses, respectively. However, the variation in drying time between 15 and 20 mm is low as compared with 20 and 25 mm. These variations could be seen from the differences in mean drying period of 5.5 h between 15 and 20 mm thicknesses as compared with 19.4 h for 20 and 25 mm thicknesses. These results indicate that drying rate does not vary linearly with variation in slice thickness. As the thickness increases, the resistance to moisture transfer becomes higher.

**Effect of air flow rate on drying time:** The effect of air flow rate was found to be statistically significant at 95% probability level. The significant difference in drying time as related to air flow rate is, also, in order since air serves as the medium to transfer heat to the drying material for

moisture evaporation and to carry away the evaporated water vapour. That is, the higher the air flow rate the more of the generated heat is moved to the product and the more of the evaporated moisture is removed, resulting in faster drying of the product.

The variation in air flow rate was also assessed using Duncan's Multiple Range Test (DMRT). The results show that the mean for 3.28 m<sup>3</sup>/s is significantly different from the means for 4.50 and 5.25 m<sup>3</sup>/s. The mean for 4.50 m<sup>3</sup>/s is also different significantly from the mean for 5.25 m<sup>3</sup>/s. In this case, increasing air flow rate means increase in latent heat energy needed to evaporate the product moisture and transport this moisture from the drying chamber. An average drying time of 31.6 h was recorded for the highest air flow rate of 5.25 m<sup>3</sup>/s while 32.7 h was achieved for the medium air flow rate of 4.50 m<sup>3</sup>/s. In the case of the low air flow rate of 3.28 m<sup>3</sup>/s, 33.3 h was obtained as the drying time. The results showed that drying time decreased with increased in air flow rate. It can, therefore, be said that the results are in agreement with FAO(1995) and Cao and Yu (1987) that both revealed that drying rate increases with increase in air flow rate.

**The interaction effects of the factors on drying time:** The result for cover/thickness interaction effect revealed that the difference in drying time is statistically significant at 95% probability level as shown in Table 1. However, the major controlling factor is the slice thickness. The drying time for 15 mm thickness is low when compared with 20 mm thickness and considerably low when compared with 25 mm slice thickness. The difference in mean drying times for 20 and 25 mm is equally high. The drying time ranges from 22.11-22.67, 27.61-28.39 and 46.89-47.67 h for 15, 20 and 25 mm thicknesses, respectively.

The interaction effect for cover/air flow rate was found to be statistically significant at 95% probability level. In this result, the effect of air flow rate is more pronounced when compared with that of the cover but no definite pattern was established. However, on the average, the mean for glass cover and 5.25 m<sup>3</sup>/s air flow rate is lower and differ from the other means. There is no significant difference in mean drying time for perspex/5.25 m<sup>3</sup>/s air flow rate; polythene cover/4.50 m<sup>3</sup>/s air flow rate; and perspex/4.50 m<sup>3</sup>/s air flow rate. There is also no difference in means for perspex/4.50 m<sup>3</sup>/s air flow rate; polythene cover/5.25 m<sup>3</sup>/s air flow rate; and glass/3.28 m<sup>3</sup>/s air flow rate. The mean drying time for glass cover/4.50 m<sup>3</sup>/s air flow rate is the highest and differs from the means for perspex/3.28 m<sup>3</sup>/s and polythene cover/3.28 m<sup>3</sup>/s air flow rate.

The thickness/air flow rate interaction also shows significant difference in mean drying time at 95% probability level. As expected, drying time decreased with decreased in thickness and increased in air flow rate.

However, the differences in means for 3.28, 4.50 and 5.25 m<sup>3</sup>/s are not significant at 15 and 20 mm slice thicknesses, respectively. This implies that, the influence of air flow rate is not significant at these levels of thicknesses. This could be attributed to the succulent nature of tomato. In this type of material, according to Kay (1991), drying rate does not increase linearly with increase in air flow rate.

For 25 mm thickness, the influence of air flow rate is significant and differs for all the three air flow rates under consideration. That is, increase in air flow rate resulted in decrease in drying time. The significant difference in results at different flow rate may be attributed to the fact that diffusion of internal moisture requires high pressure force and this can only be achieved by increase in air flow rate. The result is in agreement with FAO (1987) and Cao and Yu (1987) findings which show that, in thin layer drying, drying rate increases with increase in air flow rate.

For cover/thickness/air flow rate interaction, the difference in mean drying time is significant at 99% probability level. However, there is no significant difference in means for 15 mm thickness in combination with other factors. The same is true for 20 mm thickness. In the case of 25 mm thickness, the air flow rate plays a dominant role. At this level of thickness, drying time decreased with increased in air flow rate.

From the overall results, it can be stated that slice thickness and air flow rate are important factors for consideration in drying of sliced tomato under forced convection solar energy dryer. The results are in agreement with Abdullahi (2003) who noted that cutting of drying product into small pieces do enhance heat and mass transfer; and FAO (1987) and Cao and Yu (1987) findings that drying rate increases with increase in air flow rate.

### CONCLUSION

It can, therefore, be concluded from the study that under forced convection solar energy drying:

- Grazing materials have no significant effect on drying rate.
- The drying rate increased with decreased tomato slice thickness and increased air flow rate.

- Drying of 15, 20 and 25 mm slice thickness of tomato was achieved in time range of 21-24, 27-29 and 30-50 h, respectively.

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