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Research Article

DEHYDRATION OF AMLA SEGMENTS IN A SOLAR TUNNEL DRYER

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Abstract- In this study, a solar tunnel dryer of 6 x 3x 2.7 m (LxWxH) constructed with galvanized frame structure and covered with 200 µ UV-stabilized LDPE sheet. Two fresh air inlets of 0.6 x 0.3 msize and two exhaust fans each of 9" diameter and 50 watt capacity were installed at the rear side and front side of the dryer, respectively. The amla segments pre-treated with 2% sodium chloride, 0.1 % potassium meta-bi-sulphite solutions and untreated slices were subjected for drying. Results obtained from this experiment showed that in solar tunnel dryer, the drying required 11-13 h for various pre-treated amla segments to reduce the initial moisture content ranging from 521.46 to 422.32% (dry basis) to final moisture content in the range of 17.39 to 17.01 % (dry basis) and in open yard sun drying, it required 15-18 h for various pre-treated amla segments to reduce from moisture content of 520.13 to 430.13 % (dry basis) to safe storage moisture content of 17.83 to 17.09% (dry basis) at different drying air temperatures and relative humidities. Two drying models were fitted to experimental drying data of amla segments namely Logarithmic model and Henderson-Pabis model and Logarithmic model was found to be the best fit to describe the drying behavior of amla segments. The use of solar tunnel dryer leads to considerable reduction of drying time in comparison to sun drying. The amla segments being dried in the solar tunnel dryer were completely protected from rain, insects and dust.

Keywords- Solar tunnel dryer, Drying, Moisture content, Amla Segments, Drying Models.

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Introduction

Amla tree having good fruit bearing capacity would yield 187 to 299 kg fruit per year. Amla fruit has richest source of vitamin 'C' compared to other all other fruits. It is highly nutritive witha great medicinal value. Amla is a seasonal and are highly perishable in nature as its storage in atmospheric conditions after harvesting is very limited i.e. 5-6 days. Indian gooseberry is highly acidic and astringent in taste which makes them unpalatable and unsuitable for direct consumption hence they are consumed in processed forms such as jams, jellies, candies etc. Amla is made available throughout the year by applying several techniques of processing such as freezing, pickling with salt, oil spices drying. Drying is an effective method to increase the shelf life of aonla fruit. Storage facilities such as cold storage, controlled/modified atmosphere storage, being very expensive, are not in the direct reach of poor farmers. Preservation of foodstuffs through dehydration is an ancient practice and has many advantages, such as reduced weight, inexpensive packaging, dry shelf stability and negligible deterioration in quality due to enzymatic changes compared to other processing techniques [1,2].

Among the various drying methods available, open-sun drying is the most common preservation practice followed where solar radiation is high. The solar radiation in Bangalore in the month of December increases from 2.6 $kWhm^{-2}$ day^{-1} to 4.5 $kWhm^{-2}$ day^{-1} whereas during summer i.e. March to May; this value ranges from 5.0 to 6.5 $kWhm^{-2}$ day^{-1}. Though electrical/fuel fired dryers help the farmers in drying their products at a relatively faster rate, they are not popular among the poor farmers of most developing countries. Reasons are the higher initial cost of the dryers. Moreover, electricity, though costly, is not available in the rural areas uninterrupted. Use of solar dryer is the solution in this situation. Keeping the above points in view, the present study was taken up with the following objectives:

- Design and development of a solar tunnel dryer
- Dehydration of amla segments in a solar tunnel dryer

Material and Methods

Experimental study

The experiment was carried out at the section of Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Hessarghatta, Bangalore North District, Karnataka. It is situated on the latitude of 13°58′ North, longitude of 78° East and at an elevation of 890 meters above mean sea level which is considered as the heart of the Mysore Plateau (a region of the larger Deccan Plateau) of Karnataka. Tunnel type solar dryer was designed and constructed. Amla segments were dried in the constructed solar dryer. The drying characteristics like moisture ratio and drying rate were recorded and analysed. The drying models were selected and the drying data were fitted in the models [3-5].

Experimental set up

A gable roof even span type solar tunnel dryer having a floor area of (6m x 3m) was designed for amla segments [Fig-1]. The height of solar dryer was 2.7 m which was convenient height for a person to enter into the dryer and carry out the operations such as loading and unloading of the material to be dried. The centre length of the dryer was 3.3m. The solar tunnel dryer was a galvanized iron framed structure and oriented in north-south direction. The structure was covered with ultra violet stabilized polythene sheet of 200 micron size. Two fresh air inlets, each of 0.6 m x 0.3 m were installed at the rear side of the dryer and at 0.15 m height from the ground level for entry of fresh air. Two each of 50 watt axial flow exhaust fans were fitted (9" diameter) at the front side of the dryer at 2 m height from the ground level, for easy escape of moisture ladden air from the dryer, for obtaining higher drying rate. The structure was raised on concrete floor [Fig-2]. Five platforms were fabricated to place the products filled in plastic tray. Each platform had a dimension of 2.7 m x 1 m x 0.96 m (LxWxH). Four platforms were kept inside solar tunnel dryer and one was used for open sun drying of product. The platforms were fitted with nylon caster wheels for mobility [6-8]. The instruments used for the present investigation were data logger for recording the hourly temperature and relative humidity during the drying period, digital vane type anemometer for recording the air velocity, electronic weighing balance for weighing onion samples, hot air oven to determine the initial and final weights of the samples.

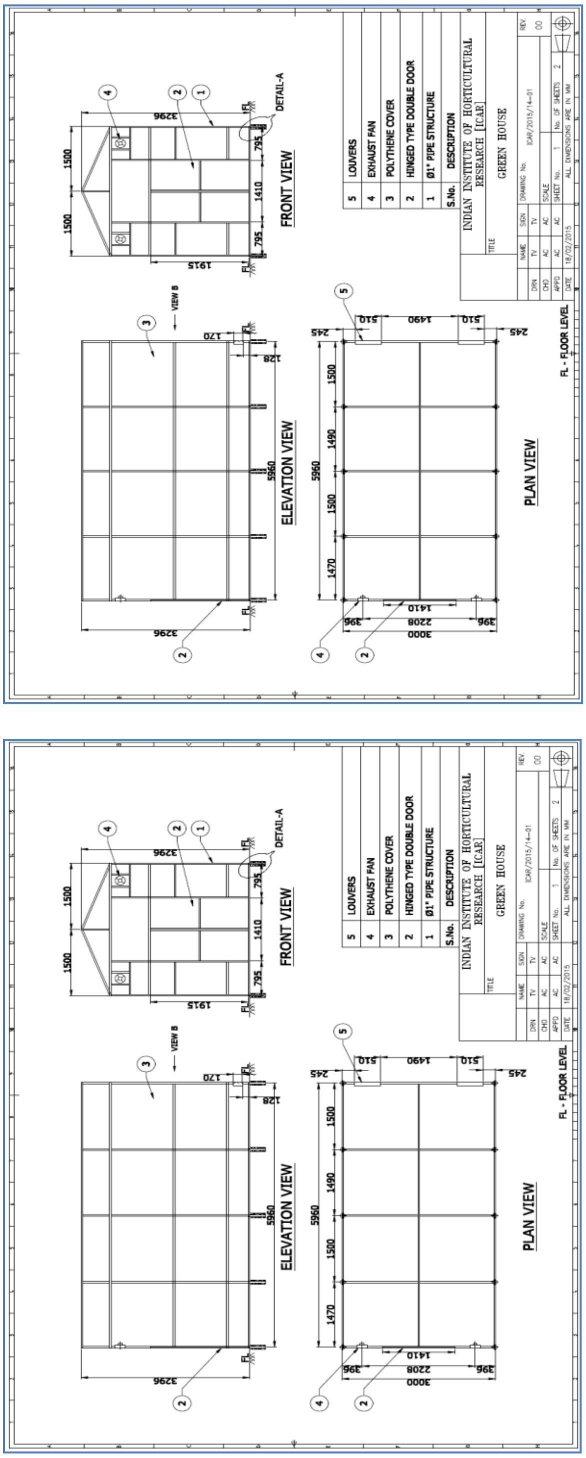

Fig-1 Structural details of solar tunnel dryer

Side view

Front view

Rear view

Fig-2 Solar tunnel dryer

Experimental procedure

Freshly harvested amla well matured, hard, greenish- yellow fruit free from physical damage and disease were selected were procured from local market of Bengaluru in Karnataka state. The raw materials were then thoroughly cleaned to remove any dirt or dust particles attached to the surface.

The cleaned amla was divided into three lots. The first lot of amla selected for dehydration without treatment was flaked using sharp stainless steel knife and weighed into plastic trays holding 350 grams of amla. Two lots were kept for pre-treatment with the selected chemicals. The second lot was weighed and blanched with 2 % sodium chloride solution in a stainless steel utensils for 8 minutes and then it is subsequently cooled in normal cold water for 3 minutes. The segments were removed and stones were separated. Then the segments were equally divided and weighed in trays each holding 350 grams of amla segments and kept for dehydration in solar tunnel dryer and open sun [Fig-3]. The treatment combinations were laid out in two factorial randomized block design with six replications. The pre-treated amla segments were placed on the drying platforms as per the experimental layout. The drying was started by 9.00 a.m. and discontinued at 4.00 p.m. for each day. The drying was continued on subsequent days until the desired moisture content of about 17 % (d.b) for amla was reached. The temperature of the ambient air and the air inside the solar tunnel dryer were recorded at every one hour during drying period using Data logger. The temperature inside solar tunnel dryer was recorded at two different positions i.e. both positions 1.5 m from rear side and another position from door entry. The relative humidity of the ambient air and the air inside the solar tunnel dryer were also recorded using Data logger at every one hour of interval during the drying process. The relative humidity inside solar tunnel dryer was also recorded at two different positions as explained above. The air velocities of ambient air were recorded by using vane type digital anemometer. The readings were recorded at one hour interval during the drying period. The weight of dried samples were taken at an interval of one-hour. Reduction in moisture content v/s drying time, temperature v/s drying time, relative humidity v/s drying time, moisture ratio v/s drying time, drying rate v/s drying time curves were plotted.

Fig-3 Drying of Amla segments in a solar tunnel dryer

Determination of parameters of drying kinetics

The physiological loss in weight of amla segments was recorded at an interval of one hour during drying process. The drying rate and moisture ratio were calculated by using the following equations.

$$\text{Drying rate }(\%\text{ d.b. } h^{-1}) = \frac{dM}{dt} \qquad [1]$$

where,
dM = Difference in moisture content (% d.b.)
dt = Difference in drying time (h)

$$\text{Moisture ratio }(\%\text{ d.b. } h^{-1}) = \frac{M - M_e}{M_0 - M_e} \qquad [2]$$

Where,
M = Moisture content at any specified time t (% d.b.)
M_e = Equilibrium moisture content (% d.b.)
M_0 = Initial moisture content (% d.b.)

Drying models

The mathematical models for amla segments *viz.,* Henderson-Pebis and Logarithmic models were selected for fitting the experimental data and these selected models were the best models to describe the drying curve equations of amla segemnts during drying. These are explained here under.

Henderson and pebis model: $MR = a*\exp(-k*\theta)$ [3]

Logarithmic model: $MR = a*\exp(-k*\theta) + c$ [4]

Where,

$$\left(\frac{M - M_e}{M_o - M_e}\right)$$

MR = Moisture ratio =
M_e = equilibrium moisture content, % (d.b.)
M = moisture content at any time θ, % (d.b.)
M_o = initial moisture content, % (d.b.)
k = drying rate constant
θ = drying time (min)
a, c = empirical constants in drying models

Before conducting an experiment, the experimental set up was allowed to run until steady drying temperature was attained. Amla segments was dried from an initial moisture content of 521.4629-422.3213 % (d.b.) to a final moisture content of 17.3902-17.0195 % (d.b.) for safe storage.

The constants of the selected models were estimated by non-linear regression (**Ramachandra and Rao, 2009**) [6]. The parameters of the models were estimated by using MATLAB version 8.0 software packages. The fit quality of the proposed models on the experimental data was evaluated using linear regression analysis using curve fitting tool in MATLAB 8.0 Software. The statistical parameters standard square error (*SSE*) and root mean square error (*RMSE*) were calculated employing the following equations.

$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}(MR_o - MR_p)^2}{df}} \qquad [5]$$

$$R^2 = \frac{\text{SS Total} - \text{SS Error}}{\text{SS Total}} \qquad [6]$$

$$SSE = \frac{1}{N}\sum_{i=1}^{N}(MR_o - MR_p)^2 \qquad [7]$$

Where,
MR_o = observed moisture ratio
MR_P = predicted moisture ratio
df = degrees of freedom
N = No. of data points
SS Total = Sum of squares total
SS Error = Sum of squares error

Results and Discussion

The present investigation was undertaken with the objectives of design and construction of solar tunnel dryer and to study dehydration kinetics of amla segments. The microclimate inside solar tunnel dryer and ambient conditions was recorded. The data collected from different drying methods with various pre-treatments were compared using two way analysis of variance (ANOVA) techniques for optimization of drying process. The results obtained during the present investigation are discussed hereunder.

Microclimate inside the solar tunnel dryer during drying of onion slices

The temperature and relative humidity inside solar tunnel dryer and ambient condition during the drying period of amla segments were recorded at an hourly interval. The Maximum temperature recorded inside the solar tunnel dryer was 47.7 °C and the minimum temperature was 25.4 °C during drying period of amla segments [Fig-4]. In open yard sun drying, maximum temperature was 31.4 °C and minimum temperature of 22.4 °C were recorded during drying period of amla segments. The patterns of temperature changes at two positions inside solar tunnel dryer were comparable with each other. Temperatures in these positions varied within a narrow band. In addition, temperature at each of the locations differed significantly from the ambient air temperature. Similar observations were made by **Serm Janjai (2012**) [7]. The drying air temperatures in the dryer varied from 35°C to 65°C in solar dryer.

The minimum relative humidity recorded inside the solar tunnel dryer was 9.1 per cent and maximum RH was 35.1 per cent whereas minimum RH recorded in OYSD was 16 per cent and maximum relative humidity was 66 per cent during drying period of amla segments [Fig-4]. Thus, the relative humidity of the hot air in STD was less than the relative humidity in the OYSD. Similar observations were made by **Kaleemullah and Kailappan (2006**) [4].The relative humidity decreased with time inside the dryer which was due to the temperature increase inside the dryer which in turn increased water holding capacity of dying air.

Drying characteristics of onion slices

The amla samples were dried under solar tunnel dryer and open yard sun drying and the drying characteristics were determined. The initial moisture content was not same for all the drying experiments due to dipping of amla samples in pre-treatment solution for a given period, hence the initial moisture of each treatment varied. The drying models were selected and fitted to the drying data. The drying constants and the statistical parameters *viz*., coefficient of determination (R^2), Root mean square error (*RMSE*), Sum of square error (*SSE*) were estimated by using MATLAB version 8.0 software packages. The results on drying characteristics of amla segments are presented here under.

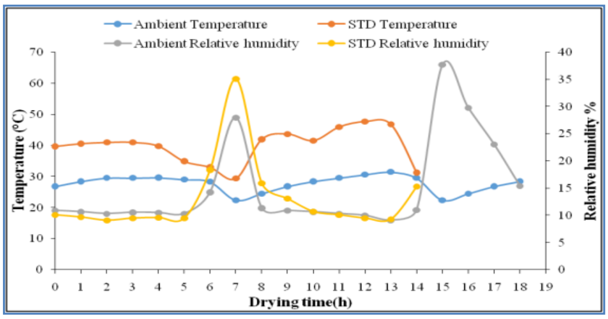

Fig-4 Temperature and relative humidity variation inside solar tunnel dryer and ambient condition during drying of amla segments

Effect of different pre-treatments and drying methods on moisture content of amla segments

[Fig-5] and [Fig-6] show the effects of different pre-treatments on moisture content of amla segments under different drying methods. The moisture content of amla segemnts got reduced exponentially. The drying required 15-18 h of drying in open sun drying to dry the different pre-treated amla samples from initial moisture content in the range of 430.13 to 520.14 % (d.b.) to safe final moisture content in the range of 17.09-17.83 % (d.b.) at different drying air temperatures and relative humidities. This variation might be due to less ambient air temperature and more relative humidity fluctuations in the atmosphere. In case of solar tunnel drying, the drying required 11-14 h to dry the different pre-treated amla samples from initial moisture content in the range of 422.32 to 521.46 % (d.b.) to safe final moisture content in the range of 17.01-17.39 % (d.b) at different drying air temperatures and relative humidities. This might be due to partial control of temperature and relative humidity in the solar tunnel dryer so that the drying required less time as compared to open yard sun drying. It was observed that the reduction of moisture content of amla segements followed an increasing trend in the beginning of the drying. As the drying proceeded the loss of moisture content decreased with the drying time till the samples reached the safe moisture content. The present results are in good agreement with Demir and Sacilik (2010) who recorded that the use of solar tunnel dryer led to considerable reduction in drying time in comparison to open sun drying apart from the protection of tomatoes from insects and dust. Sethi (1986) [8] reported that reduced drying period for blanched amla. He mentioned that blanched whole amla fruit required 7 days drying period as compared to 8 and 5 days in case of unblanched whole and raw amla pulp respectively. Bala *et al.* (2003) [1] also reported that the moisture content of sulfur treated pineapple (variety: Giant Kew) of a typical experimental run reached to 14.13% (w.b.) from 87.32% (w.b.) in 3 days of drying in the solar tunnel dryer while it took 3 days of drying to bring down the moisture content of similar sample to 21.52% (w.b.) in traditional method.

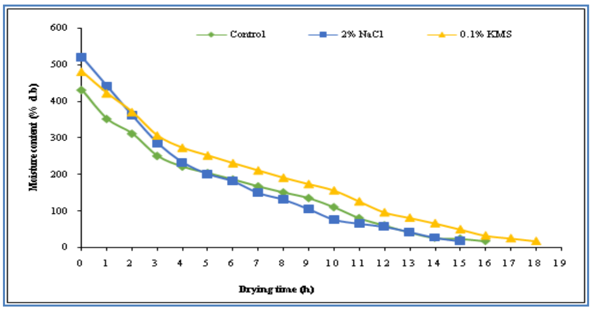

Fig-5 Effect of different pre-treatments on moisture content of amla segments dried under open yard sun drying

Effect of pre-treatments and drying methods on drying rate of amla segments

The per cent moisture loss and drying rate with drying time of amla segments dried under OYSD and STD with different pre-treatments are presented in [Fig-7] and [Fig-8]. The drying rate of amla segments dried under OYSD with untreated (control) samples and pre-treated with 2% NaCl and 0.1 % KMS samples varied from 78.82, 79.71 and 59.01% m.c. (d.b.).h^{-1} in the first hour to 6.26, 9.33 and 7.55 % m.c. (d.b.).h^{-1}, respectively during the final stage of drying within the experimental range. In OYSD, the drying rate mainly depends on varying drying temperature and relative humidity. The temperature and relative humidity varies with climatic condition. Whereas in STD the drying rate varied from 71.84, 116.07 and 79.36 % m.c. (d.b.).h^{-1} in the first hour to 13.88, 2.51, and 10.15 % m.c. (d.b.).h^{-1} during the final stage of drying within the experimental range.

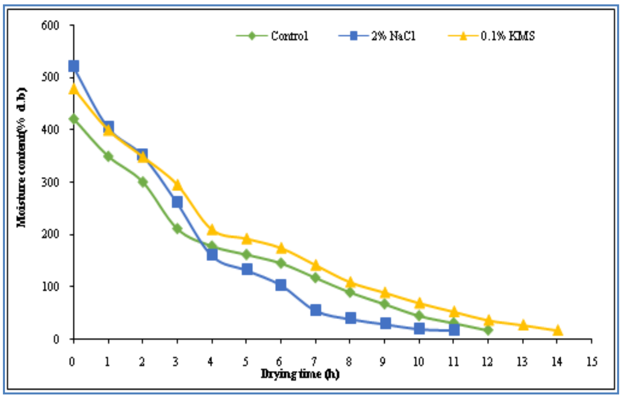

Fig-6 Effect of different pre-treatments on moisture content of amla segments dried under solar tunnel dryer

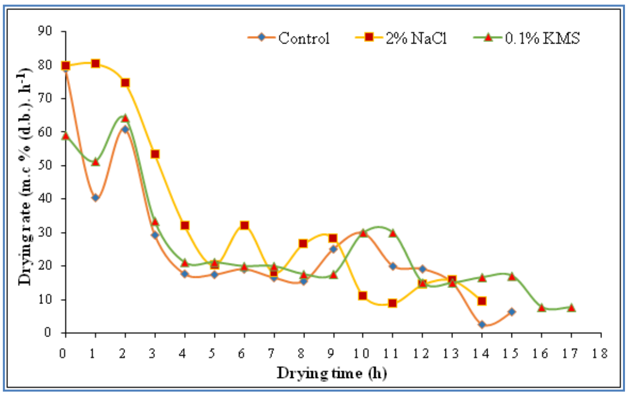

Fig-7 Effect of different pre-treatments on drying rate of amla segments dried under open yard sun drying

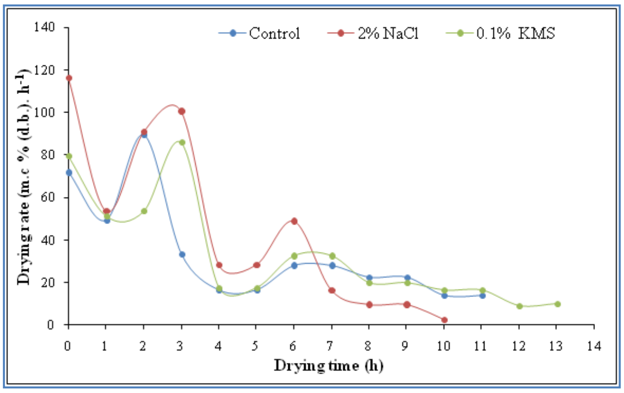

Fig-8 Effect of different pre-treatments on drying rate ofamla segments dried in solar tunnel dryer

This is due to fact that the moisture content of the material was very high during the initial phase of the drying which resulted in high drying rates due to the higher moisture diffusion. The entire drying process for the samples occurred in the range of falling rate period as reported by Derya and Mehmet (2010) [2]. A similar result was also reported by Edukondalu and Samuel (2009) [3] who reported that the initial drying rate for the chemically treated samples was fast, there was no significant difference in the drying time. All the treated samples and control took about 15 h to reach a final moisture content of 7.0±0.5 % (d.b.) and also this difference in drying rate can be due to the differences in some intrinsic properties of materials undergoing processing.

From the data obtained during investigation it was observed that the constant rate period of drying was absent during the entire period of drying and the drying took place under the falling rate period in both the drying methods. The constant rate drying period was absent due to quick removal of moisture from the pericarp of the samples. The drying rate was more up to an average drying time of 8 h in case of samples dried in solar tunnel dryer (STD) and the phenomenon changed opposite after that time. The reason was that in STD, more moisture was lost in less time and the free moisture available in samples was less at later stages. Less moisture content was lost during the initial periods of drying of samples in open yard sun drying compared to the solar tunnel dryer. Hence free moisture available in the samples dried in OYSD was more as compared to the samples dried in STD, which resulted in the higher drying rates at later stages.

Effect of pre-treatments and drying methods on moisture ratio of amla segments

The change in moisture profile with respect to time for different drying methods for both treated and untreated amla segments is presented in terms of moisture ratio (M/M_i) versus time graphs are shown in [Fig-9] and [Fig-10]. The moisture ratio for onion varied from 1 to 0.0140 for untreated (control) samples, 1 to 0.0053 for samples pre-treated with 2% NaCl and 1 to 0.0209 for samples pre-treated with 0.1 % KMS in 15-18 h of open yard sun drying. Whereas in solar tunnel dryer the moisture ratio varied from 1.0 to 0.0325 for untreated (control) samples, 1.0 to 0.0265 for samples pre-treated with 2% NaCl and 1.0 to 0.0244 for samples pre-treated with 0.1 % KMS in 11-14 h of drying. The variation might be due to different drying methods and pre-treatments. The moisture profile can be inferred that, the temperature had an inverse relation with drying time. This is quite obvious because as temperature increased, the vapour pressure inside the sample also increased and in turn the pressure gradient between the surface and inner side of the sample increased resulting in higher drying rate

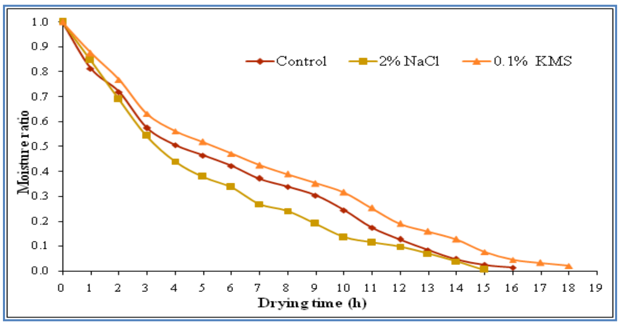

Fig-9 Effect of different pre-treatments on moisture ratio of amla segments dried under open yard sun drying

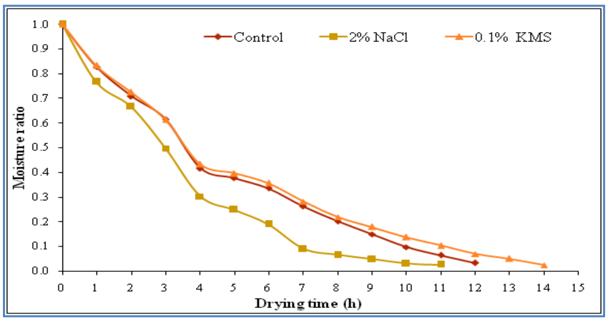

Fig-10 Effect of different pre-treatments on moisture ratio of amla segments dried under solar tunnel dryer

Fitting curves of dehydrated amla segments with different drying methods and pre-treatments

The experimental data of drying obtained during amla segments drying was fitted into two different drying models *viz*., Henderson-Pabis and Logarithmic models. The constants obtained in drying models are presented in [Table-1] and [Table-2]. The Henderson-Pabis and Logarithmic, equations adequately described the drying process of amla segments under different drying methods such as open yard sun drying, solar tunnel drying and different pre-treatments *viz*., untreated (control), 2% NaCl and 0.1 % KMS treatments. The values of moisture ratio were determined for all drying methods such as open yard sun drying and solar tunnel drying. The experimental and predicted drying curves of dehydrated untreated amla segments at different drying methods for Logarithmic model is shown in [Fig-11]. The Logarithmic model successfully described the relationship between moisture ratio and drying time but Henderson-Pabis model did not describe well.

The Logarithmic model gave the best fit to the experimental data with higher R^2 value of 0.9961 and lowest root mean square error (*RMSE*) and sum of square error (*SSE*) values of 0.02062 and 5.91×10^{-3}, respectively. The Henderson-Pabis model described a poor fit to the experimental data with lowest R^2 value of 0.9768, higher root mean square error (*RMSE*) and sum of square error (*SSE*) values of 0.04548 and 3.103×10^{-2}, respectively.

Table-1 *Estimated values of statistical parameters of Logarithmic used for different drying methods and pre-treatments*

Drying Method	Pre-Treatments	a	C	K	*SSE*	R^2	*RMSE*
OYSD	P_1	1.136	-0.1946	0.1041	1.75×10^{-2}	0.9869	0.03538
	P_2	1.041	-0.0378	0.1778	5.702×10^{-3}	0.9958	0.02094
	P_3	1.04	-0.0875	0.0875	1.345×10^{-2}	0.9912	0.02899
STD	P_1	1.147	-0.1495	0.1511	6.077×10^{-3}	0.9947	0.02465
	P_2	1.104	-0.0896	0.2318	1.06×10^{-2}	0.9911	0.03432
	P_3	1.091	-0.0912	0.1571	5.101×10^{-3}	0.9961	0.02062

Table-2 *Estimated values of statistical parameters of Henderson-Pabis model used for different drying methods and Pre-Treatments*

Drying Method	Pre-Treatments	a	K	*SSE*	R^2	*RMSE*
OYSD	P_1	0.9837	0.1561	3.103×10^{-2}	0.9768	0.04548
	P_2	1.016	0.1962	1.21×10^{-3}	0.9947	0.02269
	P_3	1.007	0.1359	3.10×10^{-2}	0.9797	0.04275
STD	P_1	1.028	0.205	1.42×10^{-2}	0.9876	0.03593
	P_2	1.037	0.2803	1.83×10^{-2}	0.9846	0.04288
	P_3	1.023	0.1937	1.06×10^{-2}	0.9918	0.02864

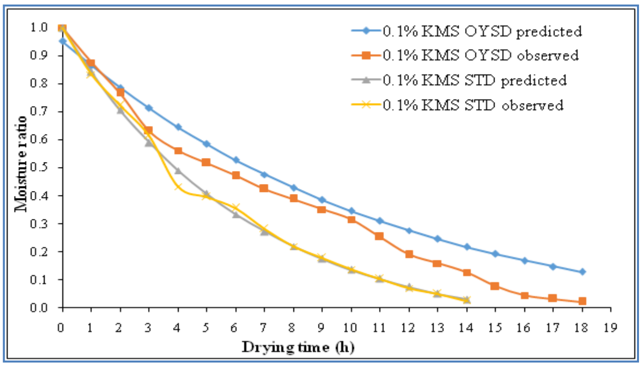

Fig-11 Comparison of experimental and predicted moisture ratios for Logarithmic model for different drying methods pre-treated with 0.1% KMS for amla segments

Conclusion

In this study of solar tunnel drying of amla segments is presented. Based on the experimental results reported herein, the following conclusions can be made:

1) In open yard sun drying, the drying required 15-18 h for various pre-treated amla segments to reduce from moisture content of 520.13 to

430.13 % (d.b.) to safe storage moisture content of 17.83 to 17.09 % (d.b.).

2) In solar tunnel dryer, the drying required 11-14 h of time for various pre-treated amla segments to reduce from moisture content of 521.46 to 422.32 % (d.b.) to attain a safe moisture content of 17.39 to 17.01 % (d.b).
3) The drying methods and pre-treatments had a major role on production of dehydrated amla segments.
4) The quality of the dehydrated amla segments mainly depends on the type of drying method and type of pre-treatment.
5) Among the two drying models for amla namely Logarithmic and Henderson-Pabis model, the Logarithmic model was found to be the best fit to describe the drying behavior of amla segments.
6) The temperature and relative humidity had a major role on drying of amla segments. As temperature increased the relative humidity decreased and thereby the drying rate of amla segments increased.
7) Solar drying of pre-treated amla segments in solar tunnel dryer resulted in 20-30 % reduction in drying time as compared to open-air sun drying.
8) The samples dried in the solar tunnel dryer were completely protected from insects and dust and of good quality dried product.

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Author Contributions:

1) U. Priyanka- Involved in conducting the research

2) Dr. A.Carolin rathinakumari, Dr. Senthil kumar and Dr. Tiwari- provided guidance for conducting the research and furnished the necessary inputs required.

Abbreviations: OYSD- open yard sun drying
STD – solar tunnel drying
w.b – wet basis
d.b – dry basis

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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