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Research Article

DRYING OF ASPARAGUS ROOTS IN SOLAR AND FLUIDISED BED DRYER

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Abstract- This study presents the drying kinetics of asparagus using solar dryer and fluidized bed dryer at four temperature levels of 40, 50, 60 and 70^{0}C. The drying rate was always higher in case of fluidized bed dryer as compare to solar dryer and it was increased with increase in temperature. The maximum drying rate 5.953% d.b./min was observed in fluidized bed dryer at 70^{o}C in the first 60 min. Three thin layer drying models were fitted to the experimental data of asparagus. The best model to predict the moisture content of asparagus in thin layer was found to be Page equation. Color of asparagus was slightly changed after drying. The power consumption was found lower for fluidized bed dryer as as compare to solar dryer. The rehydration ratio was maximum of 5.745 for fluidized bed dryer at 60^{0}C and dehydration ratio was maximum 7.092 for solar dryer at 70^{0}C.

Keywords- Drying, Asparagus Racemosus, Solar Dryer, Fluidized Bed Dryer, Colour

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Introduction

Asparagus is the one most commonly used traditional medicine [1]. It is used as anti-cancer herbal medicine and blood purifier. Several tonics like energetic tonics and medicines to relieve hypertension, anaemia and to improve digestion are prepared from asparagus roots. Asparagus has high respiratory activity even after harvesting so it deteriorates rapidly which results in very short shelf life at the room temperature [2,3]. The fresh tubers contain 85 to 90 % moisture.

Drying is the most common and simple preservation technique for preservation of medicinal plants and to provide a long shelf life and increase marketability of the product. The required amount of thermal energy for drying depends on factors, such as, initial moisture content, temperature and relative humidity of drying air, and air flow rate. Drying temperature must be as high as possible with minimum change in the quality of the medicinal plant to achieve increased dryer capacity [4]. Under- or over drying must be avoided for good quality purpose. Under drying with higher final moisture content than equilibrium moisture content results in a higher microbial count in food product [5]. Drying could result in an undesirable change in active ingredients contents. Although with the advent of high temperature short time processing methods it has become possible to reduce the destruction of pigment in processing steps [6]. Low temperature drying is much suitable to achieve the good quality product. Blanching of vegetables is carried out before drying to inactivate natural enzymes to improve colour, texture and ultimately the overall acceptability of the product [7].

The objective of this research is to evaluate effective drying temperature for solar dryer and fluidized bed dryer that might produce high-quality asparagus. Drying rate, rehydration ratio, dehydration ratio, color, and power consumption were used as indices for comparison.

Materials and Methods

Fresh wild asparagus (*Asparagus racemosus* L.) plants were obtained from the Medicinal plant Research and Development Centre, Pantnagar and stored at +4°C. After stabilization at the room temperature, the roots were blanched with hot water at 80°C for 5 min and immediately cooled, unwanted particle is removed from asparagus roots followed by cleaning in tab water to remove soil and dust particles attached to it. Then the selected asparagus samples were cut into 2-4mm long slices and were weighed in digital balance (METTLER, Capacity: 210g, least count: 0.001g) and placed in solar and fluidized bed dryer for drying at drying temperature 40, 50, 60 and 70°C and weight was recorded with an interval of 1 hour until two to three consecutive weights didn't vary more than 3 – 5mg and final weight was recorded. The dried asparagus roots were packed in polyethylene bags of 200 gauges, sealed air tight and stored at room temperature for further analysis. The initial moisture content of the asparagus was determined by oven method drying at 105°C for 24 hours [8].

Equilibrium moisture content

Equilibrium moisture content is the moisture content at which there is no loss and gain of moisture content. It is required for calculations of Moisture Ratio (MR). It was found by a method developed by Henderson and Perry (1961) [9]. The equilibrium moisture content (M_e) was determined by following equation:

$$M_e = \frac{M_1 \times M_3 - (M_2^2)}{M_1 + M_3 - 2M_2} \quad .....[1]$$

Overall drying rate

The overall rate of drying is the ratio of difference of initial (M_o)and final moisture content (M_F)and total drying time (t_F).

$$\frac{dM}{dt} = \frac{M_O - M_F}{t_F} \quad ... [2]$$

Average drying rate

The average drying rates at different timings during drying can be computed in all experimental conditions using following relationship:

$$\left(\frac{dM}{dt}\right)_{avg} = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad \text{... [3]}$$

Where, $\left(\frac{dM}{dt}\right)_{avg}$ is average drying rate (% d.b./min), t is time at any instant (min) and t+Δt is time after on interval of Δt (min).

Moisture ratio

The moisture ratio curve can better explain the drying behavior as compare to moisture content curve, as the initial was one in each of the experiment. Moisture Ratio (MR) can be calculated as follows:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \text{...[4]}$$

Where, M is moisture content at time t (min) during drying, % d.b.

Drying models

The moisture ratio values were used to predict the drying model for pre-treated samples of asparagus roots. Moisture ratio data were fitted into model to select the best predictive model for drying of asparagus. The models which were tried to describe the drying characteristics of asparagus roots are shown in [Table-1]. The equations were evaluated in terms of coefficients of determination (R^2) and standard errors of estimation (SEE) by using CURVE EXPERT 1.3. A model was considered to be the best when the residual plots indicated uniformly scattered points i.e. random; SEE is a minimum value and R^2 is a maximum value .i.e. close to 1.0.

Table-1 *Thin layer drying models.*

S. No.	Model expression	Name of model
1	$MR = e^{-kt}$	Exponential model
2	$MR = A\, e^{-kt}$	Generalized exponential model
3	$MR = e^{-kt^n}$	Page's model

Where t is time (h), k is drying constant (h^{-1}), A, B, n are drying parameters. These were fitted in the experimental data in their linearised form using regression technique.

Dehydration ratio

Dehydration ratio was calculated by taking the weights of sample before drying in gram (WB) and weights of sample after drying in gram (WD) [10,11].

$$\text{Dehydration ratio} = \frac{WB}{WD} \quad \text{...[5]}$$

Rehydration ratio

Rehydration capacity was used as a quality characteristic of the dried product [12]. 2 g of the dried sample (WD) is boiled in 150 ml distilled water in a 250 ml laboratory glass and then cooled. The cooled content was filtered through filter paper and weighed (WR). The rehydration ratio was calculated as:

$$\text{Rehydration Ratio (RR)} = \frac{WR}{WD} \quad \text{...[6]}$$

Colour measurement

The color of fresh and dehydrated samples was measured using Hunter lab color meter (Labscan XE). Three parameters, L* (lightness), a* (redness) and b* (yellowness) were used to study the changes in color. Three readings were taken for each and every root samples and then mean values of L*, a* and b* were used [13].

The hue angle:

$$h° \text{ (in degrees)} = \tan^{-1}(b^*/a^*) \quad \text{...[7]}$$

The total colour difference (ΔE) was calculated as follows:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{...[8]}$$

Where, $\Delta L^* = L^* - L_0^*$, $\Delta a^* = a^* - a_0^*$, $\Delta b^* = b^* - b_0^*$

L_0^*, a_0^*, b_0^* – colour parameters of fresh asparagus samples.

Chroma indicates color saturation and calculated as:

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad \text{...[9]}$$

Results and Discussions

Moisture content

The initial moisture content for all experiments for drying was observed as 637.71% (d.b.). There is a non linear decrease of moisture content with drying time [Fig-1]. Initially the moisture decreases rapidly and then slows down considerably. In drying of asparagus at temperature 40°C for solar dryer, there is 317.623% decrease in moisture for the first 120 minutes and for the last minutes; the decrease was only 15.762%. The drying time varies with drying temperature and dryer and generally it is lower for higher drying temperatures. The drying time was minimum of 300 min for fluidized bed dryer at temperature of 70°C and maximum of 540 min for solar dryer at temperature of 40°C. The final moisture content varied from 4% to 6% (d.b.).

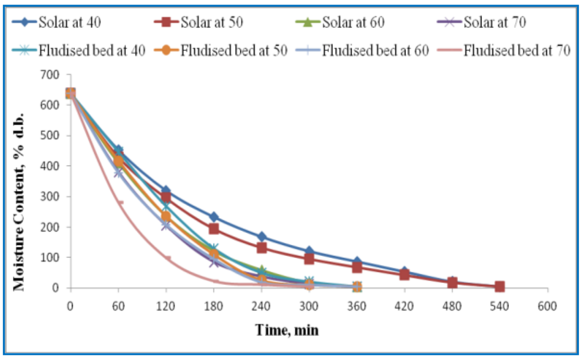

Fig-1 Variation of moisture content with drying time.

Average drying rate

The average rate of drying decreases continuously with the increase in time and the decrease in drying rate with the period of drying was non-linear. It was faster at higher temperatures [Fig-2]. The drying rate was always higher in case of fluidized bed dryer. At 40°C in solar dryer, the rate for the first 60 min was 3.075% d.b./min and which decreases to a value of 0.263% d.b./min at the end of drying. The fluidized bed dryer at 70°C in the first 60 min had maximum drying rate of 5.953% d.b./min. At few points there were unexpected interactions of curves because of experimental variations. Overall drying rate varied from 1.170 to 2.107 % d.b./min [Table-2].

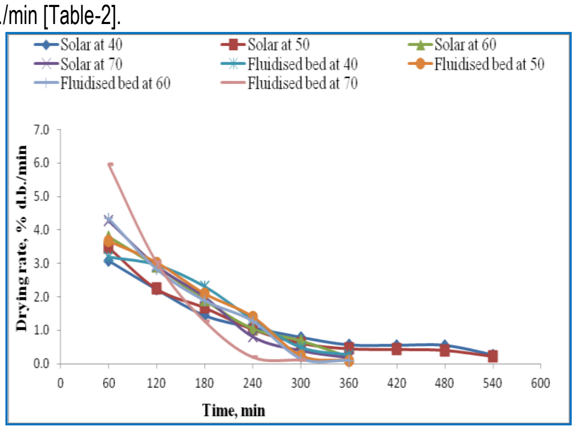

Fig-2 Variation of drying rate with drying time.

Table-2 *Overall drying rate at experimental drying air temperature*

Temp. (^{0}C)	Dryers	Drying Time	Overall Drying Rate (%d.b./min)
40	Solar	540	1.170
	Fluid	360	1.755
50	Solar	540	1.172
	Fluid	360	1.756
60	Solar	360	1.759
	Fluid	360	1.858
70	Solar	360	1.760
	Fluid	300	2.107

Moisture ratio

The moisture ratio used for calculation of best drying models because the initial value for all the experiment is one. There was rapid decrease in moisture ratio at initial stage of 60 to 120 min of drying in all cases, but in later stage of drying the decrease in moisture ratio was at slower rate [Fig-3]. Both moisture curve and moisture ratio curve almost have same trend. It was clear that the time required to reduce the moisture content was mainly affected by temperatures of drying air. The deepest curve was obtained for fluidized bed dryer at 70°C which was fastest drying condition.

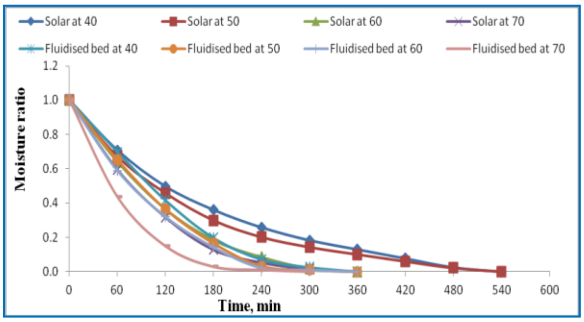

Fig-3 Variation in moisture ratio with drying time.

Validity of drying models

There was absence of constant rate period in experimental drying of asparagus roots, so only the models which describe the phenomenon of drying in falling rate period were attempted. It is observed that based on the highest average coefficient of determination and lowest standard errors of estimation, Page model posses first rank [Table-3]. The Generalized exponential model ranked second followed by the Exponential model. Residual plots of different models for single layer drying of asparagus for drying temperature of 50, 60, and 70 0C are shown in [Fig-4]. For Page model the residual plots indicated a scattered pattern and the residuals are very close to X-axis leading to suitability for predicting single layer drying of asparagus. For other models, the residual plots indicated a systematic pattern and/or the residuals are not close to X-axis.

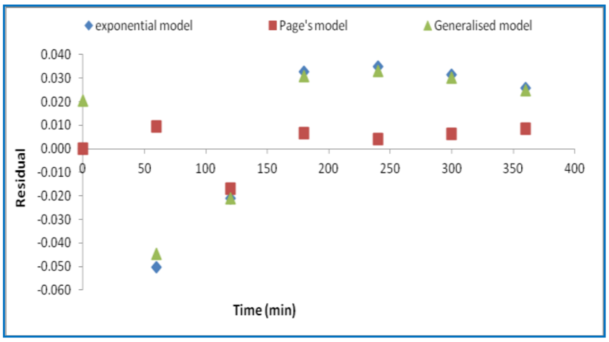

Fig-4 Residual plots of different models for single layer drying.

Effect of drying conditions on rehydration ratio

The rehydration ratio is quality index for all dried product and higher the rehydration ratio, better the quality of product. The rehydration ratio varies from 4.73 to 5.745. For all process condition the rehydration ratio was always higher for fluidized bed dryer as compare to solar dryer. The maximum rehydration ratio was obtained in fluidized bed dryer at 60°C. It was also observed that the rehydration ratio increased with increase in the drying air temperature from 40 to 60°C and decreased from 60 to 70°C [Fig-5]. It may be due to the fact that the rate of moisture removal at higher drying temperature is very fast and which causes less shrinkage of the samples or it may probably due to cellular breakdown of the asparagus roots during drying at 70 °C.

Table-3 *Model parameters, coefficient of determination (R^2) and standard estimation error (SEE) of thin layer drying models at different temperatures.*

Models	Temp. (^{0}C)	a		k		n		R^2		SEE		Rank
		Solar Dryer	Fluidized bed dryer	Solar Dryer	Fluidized bed Dryer	Solar Dryer	Fluidized bed Dryer	Solar Dryer	Fluidized bed Dryer	Solar Dryer	Fluidized bed Dryer	
Exponential	40			0.00584	0.00833			0.9981	0.9879	0.0199	0.0593	3
	50			0.00666	0.00927			0.9992	0.9899	0.0123	0.0543	
	60			0.00896	0.01022			0.9947	0.9946	0.0382	0.0391	
	70			0.01015	0.01517			0.9959	0.9981	0.0339	0.0244	
Generalized exponential	40	1.00531	1.04278	0.00586	0.00863			0.9981	0.9891	0.0210	0.0614	2
	50	1.00200	1.03479	0.00667	0.00953			0.9993	0.9907	0.0130	0.0571	
	60	1.02550	1.02063	0.00915	0.01039			0.9951	0.9949	0.0400	0.0418	
	70	1.02043	1.00821	0.01031	0.01526			0.9962	0.9981	0.0359	0.0269	
Page's model	40			0.00455	0.00095	1.0466	1.436	0.9984	0.9995	0.0196	0.0132	1
	50			0.00597	0.00131	1.0207	1.3985	0.9993	0.9989	0.0126	0.0189	
	60			0.00244	0.00283	1.2633	1.2654	0.9995	0.9988	0.0126	0.0205	
	70			0.00297	0.00504	1.2540	1.2448	0.9997	0.9999	0.0106	0.0065	

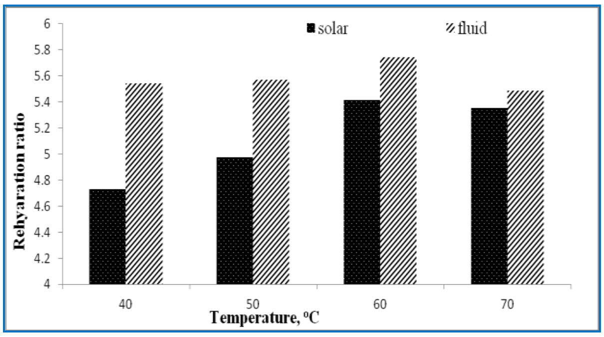

Fig-5 Rehydration ratio of dried asparagus roots.

Effect of drying condition on dehydration ratio

The dehydration ratio is important parameter to show the bulk reduction in the weight of asparagus roots. The high dehydration ratio gives better process of drying. The dehydration ratio varies from 6.972 to 7.092. For almost all process condition the dehydration ratio was always higher for solar dryer as compare to fluidized bed dryer. The dehydration ratio increases with increase in the drying air temperature from 40 to 70°C. The maximum value of dehydration ratio corresponds to the process condition of 70°C for solar dryer [Fig-6].

Effect of drying condition on power consumption

The power consumption for drying of asparagus roots at different temperatures for different dryers varied from 10 to 45 units [Fig-7]. The maximum power consumption was by the solar dryer at drying temperature of 40ºC and the minimum power consumption was corresponding to fluidized bed dryer at drying temperature of 70ºC. The low power consumption by fluidized bed dryer was may be due to the less time required for dying.

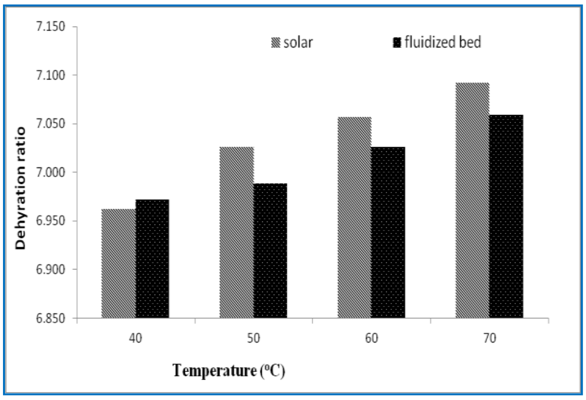

Fig-6 Dehydration ratio of dried asparagus roots

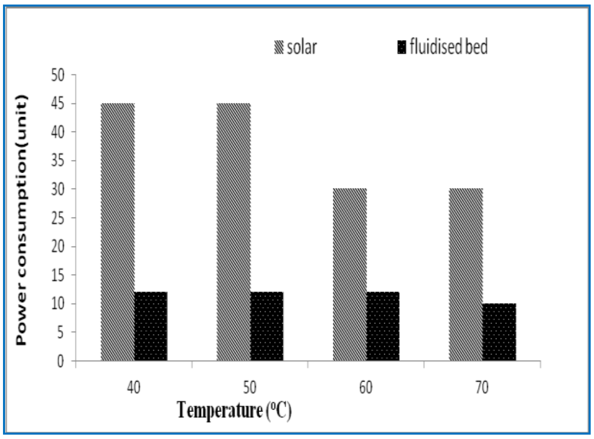

Fig-7 Power consumption for different dryers.

Effect of drying condition on color

ΔE values of the dried samples varied from 11.10 to 18.82. The sample dried at 60°C in solar dryer revealed the highest hue angle value of 76.12°. The hue angle decreases with increase in temperature but there was no significant difference between hue for 40 and 70ºC. Fresh asparagus samples were used as the reference for all while a higher ΔE represents a greater colour change from the reference material. The ΔE was less in solar dryer as compare to fluidized bed dryer. The cream color of asparagus roots in combination remained almost unchanged after drying but brightness increases [Fig-8 and 9].

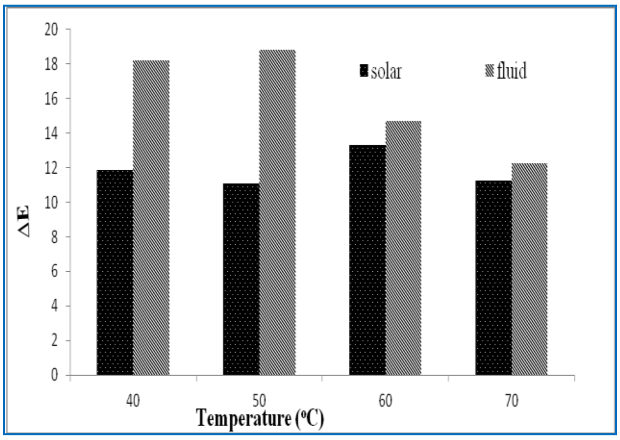

Fig-8 Color difference (ΔE) of dried asparagus samples

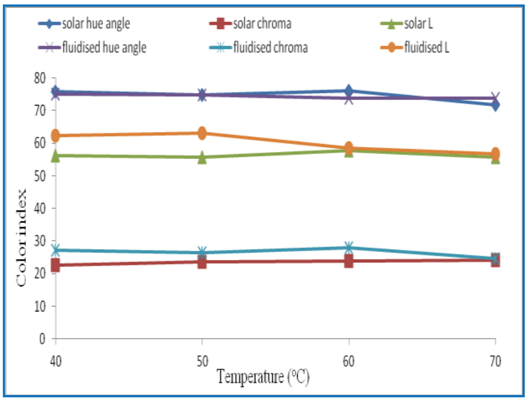

Fig-9 Influence of drying on lightness L*, hue angle (h) and chroma

Conclusion

Drying characteristic of asparagus roots in solar and fluidized bed dryer at temperatures level of 40, 50, 60 and 70ºC were investigated. It is clearly indicated that drying temperature and dryer affects the rehydration ratio, dehydration ratio and color change. The drying rate increased with the drying air temperature. The drying time decreases with increase in drying temperature. The decrease in moisture was non linear. The power consumption is also dependent on the drying temperature and dryer. Fluidized bed dryer shows the fastest drying and consume less power. The colour change was minimum in case of solar dryer as compare to fluidized bed dryer. The rehydration ratio was always higher in fluidized bed dryer as compare to solar dryer but dehydration ratio was greater for solar dryer as compare to fluidized bed dryer. The best model to predict the moisture content of asparagus in thin layer was Page equation

Abbreviation

M_1,M_2 & M_3 = Moisture content (%d.b.) at time t_1 ,t_2 & t_3 respectively
M_e = Equilibrium moisture content
M_o = Initial moisture content
M_F = Final moisture content
A, B, n = Drying parameters
d.b. = dry basis
MR = Moisture ratio
k = drying constant

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Author contributions

Deepika Kohli participated in the experiments and data analysis, and also contributed to the writing of the manuscript**.** N.C. Shahi designed the research plan, organized the study, participated in experiments and coordinated the data analysis. J.P. Pandey participated in the experimental design and coordinated the data analysis

Conflict of Interest: None declared

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