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RESEARCH PAPER

Development of solar dryer and its performance evaluation by drying of mushroom

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Abstract: Study on solar drying of mushrooms was carried under Indian climatological conditions. The study was conducted in geographical location of Sonepat, Haryana (28.87' N, 77.13' S) in month of June. The solar dryer for the drying of agricultural produce were fabricated using wooden plies. The dryer was evaluated for its efficiency with mushroom drying. 2.5 kg of mushroom were dried using fabricated dryer. Solar drying was compared with open sun drying for percent time reduction. It helped to reduce the drying time by 36 % than that required in open sun drying. Solar dryer took 21 hrs for drying of mushroom up to 5.9 % (wb) final moisture content, on the other hand 33 hrsrequired with open sun drying to reach same amount of final moisture from initial 91 % (wb). The efficiency was calculated accounting correction as collector heat removal factor (F_R). The rated efficiency was observed when dryer was receiving maximum amount of direct solar incident radiations. Thermal efficiency of solar drying was observed to be 60.26 %.

Keywords: Energy, Plate absorber, Solar drying, Thermal efficiency

Introduction

Drying process essentially involves supply of heat from external source to surface of product mainly by radiation or convection and further to inner core of the product by conduction; in exchange there occur transfer of mass followed by surface evaporation.Temperature is an important parameter during drying of thermosensitive food products through qualitypoint of view e.g. vitamins, color, flavor etc. to be maintained unchanged (Belessiotis and Delyannis, 2011).

Open sun drying was early day's preservation technique. It is simple, least cost involving method but involves number of pitfalls like uncontrolled drying, non-uniformity, insects, rodents and birds attacks, exposure to atmospheric conditions etc. which leads to deterioration of product. Solar drying on the contrary is carried out in enclosure; hence controlled and free from contamination. Drying parameters like temperature, mass flow rate of drying air, incident radiations and relative humidity of drying air are controlledachieving better quality of final product. The product is protected from being attacked by rodents, insects and other external factorswhich potentially would damage the drying commodity. Solar drying is faster process than sun drying. Mangaraj *et al.* (2001), has studied drying of chilly (Variety: *Jwala*) with the help of cabinet solar dryer compared with sun drying. They used unpunchedand punched chilly for drying. The drying required 36 hours and 54 hours respectively to dry it from 300 % (d.b.) to 8 % (d.b.). Joy *et al.*(2001)observed in solar drying of red chilly a reduced drying time up to 2 days against traditional drying which required 7-10 days for same amount of moisture removal. Desai *et al.* (2002)evaluated multi rack solar dryer for fig and observed reduction in drying time, 42 hrsfor open sun drying,where solar dryer took 28 hrs. Full load of 2.5 kg of fig was analyzed for both methods of dryingsolar and sun drying from 77.2 % (w.b.) to 15 % (w.b.) moisture content.

Reviewing some of earlier work done, study was carried out as development and evaluation of solar dryer for drying of mushroom. Mushroom is edible fungi having high nutritional value as well as high commercial value. It exhibits some vitamins in high amount, mineral in considerable quantity. Mushrooms are also greater source of some essential amino acids and edible fibers. In India, there are nearly 20 species grown for its commercial advantagesare reported by Arora *et al.* (2003). Alas; the mushrooms are highly perishable,their shelf life at ambient storage conditions is less than 24 hours. Thus drying can be a better alternative for storing it for extended period of time.

Bala *et al.*(2009) stated that appropriate method for drying of mushrooms is an important concern since mushrooms are thermos-sensitive commodity.Solar dryer designed and developed at Sonepat, India as per the specifications determined from rigorous review of earlier work done and evaluated for the drying of button mushroom. Experiments were conducted in month of March, 2017.

Material and methods

The developed solar dryer is fabricated using wooden plies and batons. The dryer has two main components of design *viz.* solar collector where actual heating of drying air occurs and the drying chamber where product under consideration is dried.

12 mm wooden plies were used for entire casing of the dryer.The top cover of the solar collector plate is made of 5 mm transparent glass with transmittance (ô) 0.86 for maximum incident radiations into collector. Aluminum(Al) sheet of 1 mm thickness is used as absorber plate and painted in matt black. Al wire mesh is used for fabrication of trays. Two such trays are placed in drying chamber for drying of material.Fresh button mushrooms were procured from nearby market.

Plate1 Picture of solar dryer

Optimum temperature range for drying of mushroom is reported to be 35 to 65 ^{O}C by Bala *et al.* (2009), Rahman *et al.* (2014), Alejandro *et al.* (2013), Basumatary *et al.* (2013). The design was made so as to achieve optimum temperature (nearly 65 ^{O}C) of air (T_I) at inlet of drying chamber, heating from its ambient conditions (T_i) *i.e.,* 28 ^{O}C. Thus mean temperature difference to be obtained was nearly 37 ^{O}C.Air vent of 10 cmis kept at the bottom front of the collectorto maintain required air flow rate at the inlet of drying chamber, as suggested by Gupta *et al.* (2017). 4 mm thick transparent glass is best suited but exhibits risk of breakage,for use in solar plate collector (Bakari *et al.,* 2014). Present dryer is fabricated using glass of thickness 5 mm with transmittance of 0.86.Absorber plate selection is done considering parameters like its durability and thermal conductivity of material, ease in handling and most importantly the cost.Als, Al sheet of 1.0mm thickness was used for fabrication of absorber plate. Sufficient interaction of air with absorber plate is ensured keeping collector dimension 200 cm × 100 cm × 25 cm. The gap between glass surface and absorber plate surface is kept 15 cm.

Drying air requirement for drying is calculated as per heat load for drying of 2.5 kg of any crop at a time. The sliced sample of mushroom is uniformly spread on tray in thin layer. Constant exchange between drying air and the drying material was ensured. Average dimension of chamber was kept 78 cm x 58.5 cm x 74 cm. Two trays of dimension 74 cm x 58 cm with wooden batons and Al wire mesh were fabricated, so as to occupy 1 kg of sliced mushroom per tray. An angle of inclination is kept to be exactly equal to the latitude of the location of drying as suggested by Ofi (1982), Alonge (1989).Angle of inclination in this study is kept 29^{o}since latitude of Sonipat (Harayana), India is 28.887^{o} N.Standard solar intensity meter i.e. Suryamapiwith accuracy of 1 mW/ cm^{2}was used for measurement of incident solar radiations. The relative humidity was measured using a sling psychrometric with an accuracy of 1 per cent. The ambient temperature measurementwas done withthe help of digital thermometer with an accuracy of ± 0.5 °C. Point temperatures of air at different points in collector plate and over trays inside the drying chamber in the dryer were measured with the help of with K-type thermocouples with an accuracy of ± 0.5 °C.

Collector thermal efficiency

Collector thermal efficiency can be calculated as given by Hematian *et al.* (2012), Kurtbashand Durmush (2004).

$$\eta t = \frac{Q_{UE}}{Q\alpha} = \frac{\rho VCp\Delta T}{AIc}$$

Where, Q_{UE}isuseful energy received by drying air and Qaisenergy received by absorber plate measured in W/m^{2}, ñ is density of drying air in kg/m^{3} (*i.e.* 1.225 kg/m^{3}). $I_c$isintensity of incident solar radiations on the collector, ÄT is temperature elevation^{O}C, C_p is specific heat capacity of drying air at constant pressure measured in J/kgK, V is volumetric flow rate in m^{3}/s, A is effective area of the collector facing the sun (m^{3}).

Correction in energy gain using of collector heat removal factor (F_R)

While calculating heat loss, overall heat transfer (loss) coefficient (U_L)is important consideration, since major loss of heat from collector occurs from the top surface. Hence, actual useful energy gain always varies from the calculated, as it is quite difficult to land about average temperature of whole collector surface at a time. Thus,actual heat transferred to drying air can be corrected by heat removal factor F_R given by Malvi *et al.* (2016) as following and is calculated as,

$$F_R = \frac{\rho VCp\Delta T}{A[\, I\alpha\tau\alpha - U_L(Ti - Ta)]}$$

Hence, theactual collector energy gain of the absorber platethat supplied to drying air can be calculated by the *Hottel-Whillier-Bliss* equation (Struckmann, 2008) as follows,

$$Que = F_R A[\, Ia\tau a - U_L(Ti - Ta)]$$

Where, ***Que*** is actual useful energy gain in (W), ***FR*** is collector heat removal factor, ***A*** is surface area of absorber (m^2), ***Ia*** is intensity of incident solar radiations (W/m^2), ***ô*** is coefficient of transmission of glass (0.86 for the glass used in this study), ***á*** is coefficient of absorption of glass (0.9 for the glass used in this study), U_L is collector overall heat loss coefficient measured in (W/m^2), ***Ti*** and ***Ta*** are inlet (drying chamber)and outside (ambient) temperaturesrespectively for air (°C).

Collector overall heat transfer (loss) coefficient (U_L) can be derived considering losses from plate, taking into account actual heat archived on surface of collector plate out of total incident heat energy on plate as given by Gupta *et al.* (2017). Hence, for whole operation actual thermal efficiency of collector becomes;

$$\eta = \frac{Q_{ue}}{AI_a}$$

Therefore,

$$\eta = F_R \tau a - F_R U_L \frac{Ti - Ta}{I_a}$$

Thus actual collector thermal efficiency can be approximated with the help of difference between temperatures of inlet air and the ambient air directly as other almost parameter stands unchanged for standard set of conditions.

The variables in above equation are only the parameters which efficiency of the collector depends most prominently on, *viz.* amount incident solar radiations (I_a), inlet temperature of drying air (*Ti*) and the ambient temperature of atmosphere (*Ta*). While other components of equation are constants values related to material used to fabricate the dryer (*F_R, U_L, ô, á etc.)* Reduction in timewith the help of solar dryer in comparison with open sun drying is given in percentage.

Results and discussion

Ambient temperature, relative humidity and solar incident radiations

Incident solar radiations were found varying within the range 70 to 105 mW/cm^2. Highest amount of incident solar radiations were observed at 13:30 hrs in noon, hence temperature at in let of drying chamber was also maximum (56.10 °C) at the same timing of the day. The relative humidity observed at this point of time was least among the humidity values during complete drying operation (41 %). Relative humidity varied within the range of 41 to 67 %. The properties of ambient air on very first day of drying operation are presented in Table 1.

Representative values of ambient temperature of air, relative humidity and incident solar radiations etc. on first day of experiment (Table 1).

The maximum ambient temperature reached was 35.71 °C during drying study. Corresponding value of *Ia* was 1040 W/m^2 and relative humidity observed was 41 %. Fig. 1. depicts the variations in these properties.

Measurement of moisture contents

Moisture contents were determined using hot air oven method on regular interval. Solar drying of mushroom required 21hrs to reach final moisture content of 5.98 % (wb) from 91.05 % (wb) of initial moisture content, while open sun drying required 33hrs to reach equilibrium moisture content of 5.92 % (wb). Open sun drying also exhibited contamination and blackening of drying samples of mushroom. Solar dried samples were continuously under drying in enclosure hence were safely and fast dried. Faster drying can also be justified by the natural air current built in drying chamber which helped in carrying moisture off the sample at faster rate. The safe and faster drying this way is also reported by Esper and Muhlbauer (1998).

The moisture variation in the mushroom as drying progresses along with the variations in solar incident radiations, efficiency of the dryer also varies directly. Maximum efficiency was observed during noon time nearly at 13:30 h on every day. It was observed to be nearly 50-55 % as shown in Fig. 3. Drying curves presented in Fig. 2. are moisture content compared till it reach constant moisture in solar dryer, was observed to be 5.9 % (wb). Drying took longer time in open sun drying, *i.e.,* around 33-34 hrs for reaching moisture content 5.9 % (wb). This trend was close with trend reported by Banout *et al.* (2011).

Table 1. Representative values of ambient temperature of air, relative humidity and incident solar radiations etc. on first day of experiment.

Time (hrs)	Drying time Intervals (hrs)	Ambient Drying Temp. (°C)	Relative Humidity (%)	Solar Insolations (mW/cm2)
8.30	0	29.1	67	70
9.30	1	29.9	58	78
10.30	2	30.6	49	85
11.30	3	31.8	45	95
12.30	4	33.6	43	102
13.30	5	35.1	48	103
14.30	6	34.2	54	94
15.30	7	33.15	60	85
16.30	8	32.56	61	70

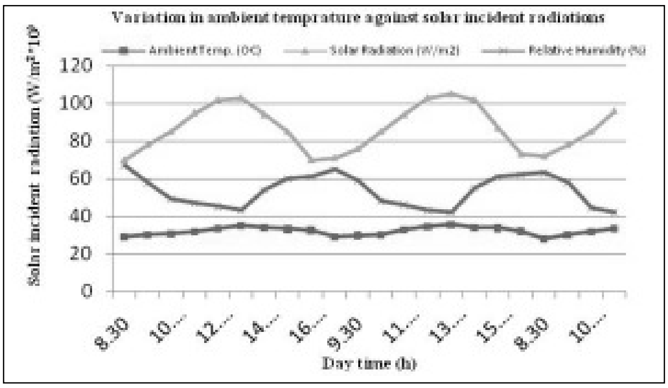

Fig.1. Variation in ambient temperature against solar incident radiations

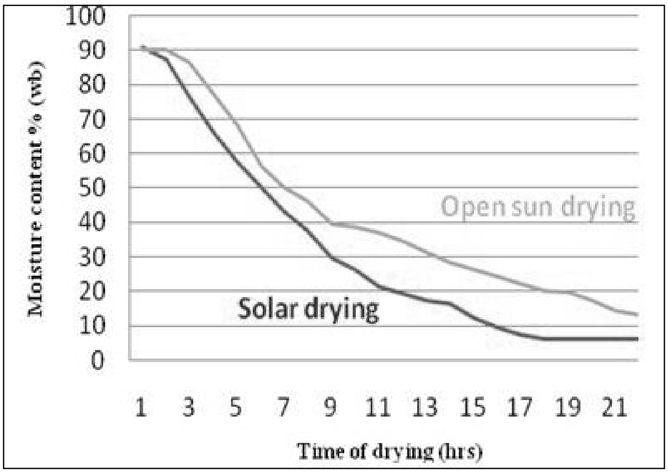

Fig. 2. Drying curves of solar drying and open sun drying

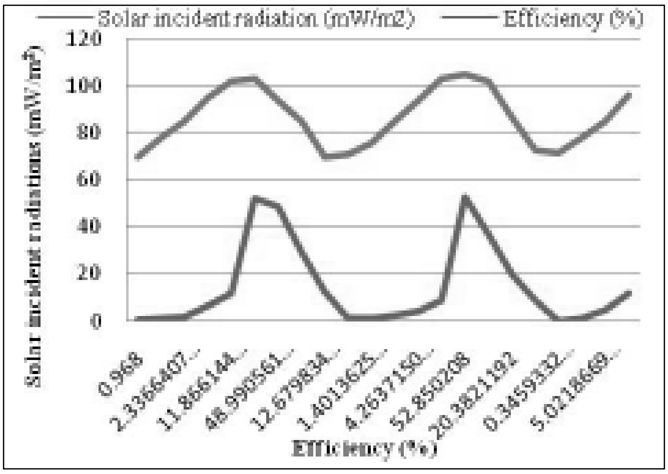

Fig. 4. Thermal efficiency of collector against solar incident

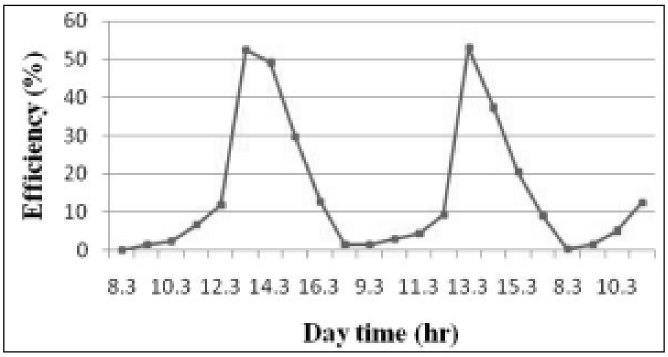

Fig. 3. Day time variations in efficiency

Percent reduction in drying time

Total time reduction with the help of solar drying while compared with open sun drying was observed to be 36.36 %. Reduction of drying time over open sun drying in this manner was also observed by Desai *et al*. (2002), Rajeshwari and Ramalingam (2012), Wade *et al*. (2014). Open sun drying required 33 hrs to dry mushroom to the final moisture of 5.9 % (wb), while solar drying took 21 hrs as said earlier.

Variations in efficiency against day time

Variations in efficiency after accounting collector heat removal factor (F_R), as day proceeds are presented in Fig. no.3. Maximum efficiency was observedbetween 12:30 pm to 1:30 pm. This was due to maximum reception of solar radiation during this period. Efficiency varies directly with solar radiation and temperature built up inside the collector. Jibhakate *et al.* (2015) have same relationship between efficiency and day time.

Variations in efficiency with solar radiation

Efficiency of the collector was found maximum, when radiation was observed highest on every day as shown in Fig. 4. Same pattern observed for each day. It may be due to maximum amount of moisture was removed in first falling period of drying as shown in Fig. 2. This can be supported with reason that maximum moisture gradient which bring about faster moisture depletion on first day of drying. It is also reported by Leon *et al.* (2002) that efficiency of dryer on first day could be considered as a fair measure for thermal performance of dryer.

Efficiency of the collector against overall heat loss from collector surface

Practically, heat loss also goes on increasing as temperature of collector increases above the ambient temperature. Temperature gradient between ambient air and surface of collector also found high when collector got heated, which may have increased heat losses. As reported by Struckmann (2008), efficiency always varies indirectly with the overall heat loss (U_L). From Fig. 5, it can be observed that efficiency decrease along with increases in heat loss once dryer heated to its highest.

Corrected efficiency was calculated accounting heat removal factor F_R. The efficiency increased as day proceeded. Up to the mid-day time, after which slight decrease was observed in efficiency. The overall heat loss coefficient of collector played a considerable role in performance of collector of solar dryer.

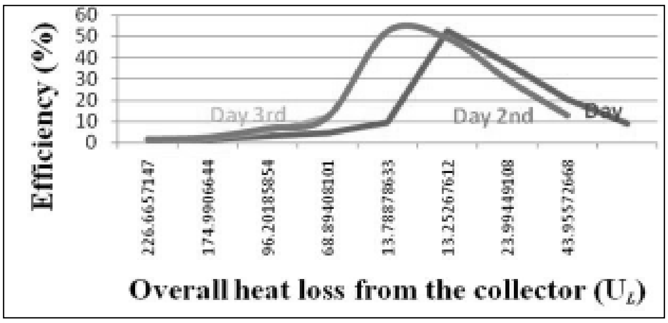

Fig. 5. Efficiency of the collector against overall heat loss from collector surface

Table 2. Variations in thermal efficiency of the solar collector based on the collector heat removal factor at 1 hr interval

Drying time (hrs)	$ç_t$	U_L	F_R	$Q_{UEact.}$	$ç_{act}$
0	0	-	-	-	-
1	0.075424	226.67	0.19	23.26	0.01412
2	0.098322	174.99	0.24	41.95	0.023366
3	0.171478	96.20	0.38	131.58	0.06558
4	0.238715	68.89	0.50	255.63	0.118661
5	0.6343	10.12	0.95	1310.96	0.602639
6	0.567815	12.46	0.89	984.80	0.506836
7	0.40712	23.99	0.73	531.33	0.295973
8	0.247877	43.96	0.51	187.46	0.126798

When U_L was at its minimal value (*i.e* 10.12), efficiency observed were at highest 60.26 % as shown in Table .2. The tabulated values are for first day of drying experiment. Similar pattern were observed for each day of drying process.

Conclusion

Solar energy as a renewable energy for drying of agricultural crops as reported by many researchers provides best alternative for farm level operation. Drying of mushroom in developed solar dryer was studied for evaluation of performance of dryer. Curve obtained plotting moisture depletion against time gave prominent first falling rate. The drying on first day of experiment was rapid than that on remaining days. Most of the drying is completed in first falling period. Drying efficiency obtained from useful energy gain was corrected using heat removal factor to obtained actual thermal efficiency.Solar dryer developed reduced moisture content from 91.5 % (wb) to a final moisture content of 5.9 % (wb) with 60.26 % efficiency. Percent drying time reduced with the help of solar drying than that by sun drying was 36.4 per cent.

References

Alejandro, R., Andrea, M., Francisco, C. and Pedro H., 2013, Mushroom dehydration in a hybrid-solar dryer. *Energy Conversion and Management,* 70:31–39.

Alonge, A., 1989, Design construction and evaluation of a solar dryer. *M.Sc. Thesis,* University of Ibadan, Ibadan (Nigeria).

Arora, S., Shivhare, U. S, Ahmed, J. and Raghavan, G., 2003, Drying kinetics of agaricusbisporus and pleurotusflorida mushrooms. *Transactions of the ASAE,* 46(3):721–724.

Bakari, R., Minja, R. and Njau, K., 2014, Effect of glass thickness on performance of flat plate solar collectors for fruits drying. *J. Energy,* 2014: 1-8.

Bala, B., Morshed, M. and Rahman, M., 2009, Solar drying of mushroom using solar tunnel dryer. Paper presented *In: International solar food processing conference,* Indore, India.

Banout, J., Ehl, P., Havlik, J., Lojka, B., Polesny, Z. and Verner, V., 2011, Design and performance evaluation of a Double-pass solar drier for drying of red chilli (*Capsicum annum* L.)*, Solar Energy,* 85:506–515.

Basumatary , B., Roy, M., Basumatary, D., Narzary, S., Deuri, U., Nayak, P. and Kumar N., 2013, Design, construction and calibration of low cost solar cabinet dryer. *Intl. J. Environmental Engg. and Mgmt.,* 4(4):351-358.

Belessiotis**,** V. and Delyannis**,** E.**,** 2011.Solar drying. *Solar Energy,* 85:1665–1691.

Desai, S. R., Vijaykumar and Guruswamy, T., 2002, Multi rack solar dryer for fig drying.Proc. All India Sem. Advances Agric. Mechanization, Institutions of Engineers (I) in association are KAEA, Bangalore, December 27-28, pp:161-168.

Esper, A. and Muhlbauer, W., 1988, Solar drying– an effective means of food preservation. *Renewable Energy,* 15(1-4):95-100.

Gupta, P., Das, A., Barai, R., Pusadkar, S. and Pawar, V., 2017, Design and construction of solar dryer for drying agricultural products.*Intl Res. J. Engineering and Technol.,* 4(03): 1946-1951.

Hematian, A., Ajabshirchi, Y., Behfar, H. and Ghahramani, H., 2012, Designing, construction and analysis of speed control system of the fan with PV feeding source in an air solar collector. *Modern Applied Sci.,* 6(1):136-144.

Jibhakate, Y. M., Waghmare, A.C. and Choudhary, S.K., 2015, Experimental Investigation of Solar Tunnel Dryer for Drying Red Chilli using Taguchi L9 Orthogonal Array. *International J. Scientific Research in Sci., Engineering and Technology,* (1)6:443-447.

Joy, C. M., George, P. P. and Jose, K. P., 2001, Solar tunnel drying of red chillies (*Capsicum annum* L.). *J. Food Sci. and Technol.*, 38:213-216.

Kurtbash, I. and Durmush, A., 2004, Efficiency and exergy analysis of a new solar air heater. *Renewable Energy,* 29(9):1489-1501.

Leon, M. A., Kumar, S. and Bhattacharya, S.C., 2002, A comprehensive procedure for performance evaluation of solar food driers. *Renewable and Sustainable Energy Reviews,* 6:367–393.

Malvi, C., Gupta, A., Gaur, M., Crook, R. and Dixon-Hardy, D., 2016, Experimental investigation of heat removal factor in solar flat plate collector for various flow configurations. *Intl. J. Green Energy,* 14(4):442-448.

Mangaraj, S., Singh, A., Samvel, D.V. K. and Singhal, O. P., 2001, Comparative performance evaluation of different drying methods for chillies. *J. Food Sci. and Technol.,* 38:296-299.

Ofi, O., 1982. Construction and evaluation of a solar dryer. *Nigerian J. Solar Energy,* 2:46-59.

Rahman, M. M., Saad, M., Billah, A.G.M.M. and Rahman, S., 2014, Energy consumption and quality aspect for solar drying of mushroom. Paper presented In*: AUN/SEED-Net Regional Conference on Electrical Engineering.* University of Malaya, KL, Malays, March 4-5, 2014.

Rajeshwari, N., Ramalingam, A., 2012, Low cost material used to construct effective box type solar dryer. *Archives of Applied Sci. Res.,* 4(3):1476-1482.

Struckmann, F., 2008, Analysis of a flat-plate solar collector, Project Report, 2008-MVK160, Heat and Mass Transport, Lund, Sweden. Available online (Last archived 20/06/2017)

http://www.lth.se/fileadmin/ht/Kurser/MVK160/Project_08/Fabio.pdff

Wade, N.C., Wane, S.S. and Kshirsagar, S. M., 2014, Comparative study of drying characteristics in Chillies. *Indian J. Scientific Res. and Technol.,* 2(3):105-111.