Using a forced convection solar drier for bamboo shoots

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Abstract

Three different drying methods, a new designed forced convection solar drier, typical cabinet type natural convection solar drier and traditional open-sun drying were used for draying of bamboo shoots in central Vietnam. During drying the operational parameters such as drying temperature, relative humidity, air velocity, insolation and water evaporation have been recorded hourly. The mean drying temperatures and relative humidity in the drying chamber were 55.2°C, 23.7%; 47.5°C, 37,6%; 36.2°C, 47.8% in forced, natural convection solar driers and open-sun drying, respectively. The mean global radiation during all experimental runs was 670 W/m^2. The result also shows that fastest drying process was occurred in forced convection solar drier where the falling-rate period was achieved after 7 hours, in change to open-sun drying where it took 16 hours. The dryer efficiencies were 22%, 15.8% and 9.7%, for forced, natural convection solar driers and open-sun drying, respectively. It may be concluded that a new designed forced convection solar dryer is suitable for drying crops such as bamboo shoots and in all cases, the use of this drier led to considerable reduction in drying time in comparison to traditional open-sun drying.

Key Words

Solar drying, drying efficiency, bamboo shoots, central Vietnam

1. Introduction

Preservation of human food such as meat, vegetable, fruit, spices and herbs by open-air drying on the sun was presumably one of the first systematic technological activities undertaken by human being [1]. Due to lack of adequate preservation methods, among other because of absence of electricity grid and other sources of conventional energies, open-air drying is still a widely used practice of food preservation technique in most regions of the developing world. This traditional method has many disadvantages such as: damage of the crop by animals and rodents, contamination by dirt and dust, Insect infestation and grow of microorganisms and degradation of the product through direct exposure to unfavorable climatic conditions [2]. An alternative to traditional open-sun drying is the use of solar driers especially because of lower investments comparing to sophisticated drying techniques using fossil fuels and because of most developing countries are situated in climatic zones where the insolation is considerably higher than the world average of 3.82 kWh.m^{-2} a day [3]. Advantages of solar driers that enable them to compete with

traditional open-air sun drying techniques and/or artificial driers powered by energy from fossil fuels have been previously reported in the literature by many researchers [4 - 6].
Thus the main objective of this research was the design and experimental run of a new model of forced convection indirect type solar drier called Double-pass solar drier under the specific conditions in central Vietnam. As the reference product to investigate the drier performance a bamboo shoot was chosen. Spring bamboo shoots (*Phyllostachys pubescens*) are a popular and highly priced vegetable grown widely in most Southeast Asian countries such as China, Philippines, Thailand and Vietnam. They contain amino acids, carbohydrates and vitamins essential for human nutrition [7]. Fresh bamboo shoots are not easily stored as they rapidly turn brown during storage. Therefore, drying can prolong the shelf-life of fresh bamboo shoots and helps to provide the consumer with the product throughout the year.

2. Description of Double-pass solar drier

A Double-pass solar drier (DPSD) was designed at the Institute of Tropics and Subtropics, Czech University of Life Sciences Prague, Czech Republic in 2007. The drier is classified as a forced convection indirect type and is based on the known construction of the suspended plate air heating solar collector called "Double-pass". The dimensions of the drier are as follows: length 5 m, width 2 m and height 0.35 m as shown in Fig. 1. The drier consists of five equal modules that are connected together. The supporting structure of each module is made from square steel rods. The sides are equipped with doors enabling access on each side into the drying chamber. The casing is done from a custom-made sandwich material consisting of four layers. Moving from inside out: aluminum sheet metal (corrosion resistance and odor absorbing free), 2 mm layer of cork (insulation barrier from high heat that could harm the insulation), 20 mm styrofoam (insulation) and galvanized metal sheet (protection from outside influences). The absorber is made by galvanized metal sheet painted black matt to ensure good absorption of sun radiation. The absorber is supplied by axial metal fins that increase the absorber surface. Polycarbonate panel sheet represent the glazing of the collector part of the drier. It is a UV light stable material with good shatter resistance and transmissivity. At the beginning of the drier there are five DC fans which provide the necessary air flow through the absorber and drying chamber. The fans are connected directly to a photovoltaic panel by a parallel connection. No regulatory systems are required as the system regulates the air flow itself due to the position of the sun during the day. The drying chamber is fitted with ten trays 1×1 m, made from a steel frame and a HDPE (High Density Polyethylene). This form of plastic is temperature resistant and does not represent intoxication danger for the product.

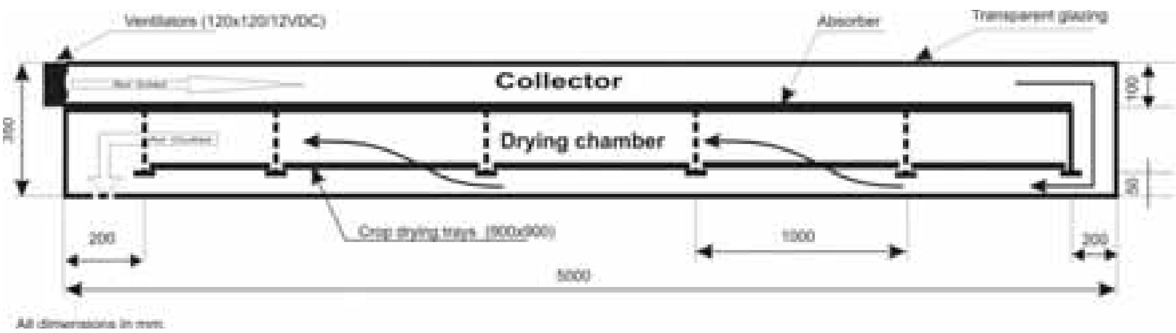

Fig. 1. Double-pass solar dryer

3. Materials and Methods

3.1 Sample preparation

Fresh bamboo shoots (*Phyllostachys pubescens*) were purchased at the local vegetable market in Hue City, Vietnam. For each experimental run (drying in DPSD, cabinet drier and open-air sun drying) a 50 kg of fresh bamboo shoots were used. Fresh bamboo shoots were stored before each experimental run at 5°C and used within 1 to 2 days of purchase. Before drying the bamboo shoots were washed by potable water and placed on plastic trays to drain out excess water. Then the bamboo shoots were cut to 0.3 cm thick and 5 cm x 4 cm (width x length) slices. The drying was occurred without any pretreatments.

3.2 Experimental procedure

Two different types of solar driers together with open-air sun drying were used for the present investigation: (i) a Double-pass solar drier (DPSD), (ii) a typical cabinet-type natural convection solar drier (CD) [8] with floor area 0.65 m × 1.5 m and 0.6 m one side height and 0.3 m second side height, (iii) a black plastic sheet 2 m × 2 m (width × length) was used as traditional open-air sun drying method (OSD). All drying facilities were established at Hue University of Agriculture and forestry, Hue city, central Vietnam. A total of three full scale experimental sets of bamboo shoots drying were conducted from June 2007 to September 2007 in each drying facility. Drying was started after completion of the loading, usually at 8 a.m. and discontinued at 4 p.m. Following operational parameters were measured every hour during solar drying experiments: ambient air temperature (°C); ambient air relative humidity (%); inlet and outlet drying air temperature (°C); inlet and outlet drying air relative humidity (%); drying airflow rate (m^3/h); drying air velocity (m/s); and global solar radiation (W/m^2). To compare the performance of DPSD with CD and OSD three control samples of bamboo shoots were weighed and placed on well-marked areas on the trays in each drying unit. Weight loss of control samples (g) in the DPSD, CD and OSD were measured during the drying period at one hour intervals as well. At the end of each drying test all control samples were collected and placed to the laboratory electric oven for 24 h at 105°C to estimate dry matter content.

3.3 Performance and data analyses

The drying rate was found by the decrease of the water concentration during the time interval between two subsequent measurements divided by this time interval. The drying rate (DR) was therefore expressed by following Eq. (1):

$$DR = Mw / Mds.t \qquad (1)$$

Were *Mw* is a mass of evaporated water from the product in (kg), *Mds* is a mass of dry solids in (kg) and *t* is a time of drying in (s).

To evaluate the performance of each drying method an overall drying efficiency ηd was calculated using following equitation (2 and 3).

$$\eta d = W \Delta Hl \,/\, I.A.t \qquad (2)$$

$$\eta d = W \Delta Hl \,/\, I.A.t + Pf \qquad (3)$$

Were *W* is a mass of evaporated water from the product (kg) in time *t*, ΔHl is a latent heat of evaporation of water (kJ/kg), *A* is aperture area of the drier (m^2), *I* is a solar radiation on the aperture surface (W/m^2) and *Pf* is energy consumption of fan (kWh).

Effect of drying method on the relationship between drying rate and the moisture content was statistically evaluated using Statistica software version 8.0 (StatSoft Inc.Oklahoma, USA).

4. Results

A mean values of drying air temperature, drying air relative humidity and solar radiation in DPSD, CD and OSD as recorded during a typical experimental run are presented in Fig. 2. It is evident that in case of DPSD, it is possible to achieve higher drying temperatures succeeded by lower drying air relative humidity with similar solar radiation in comparison with CD and traditional OSD.

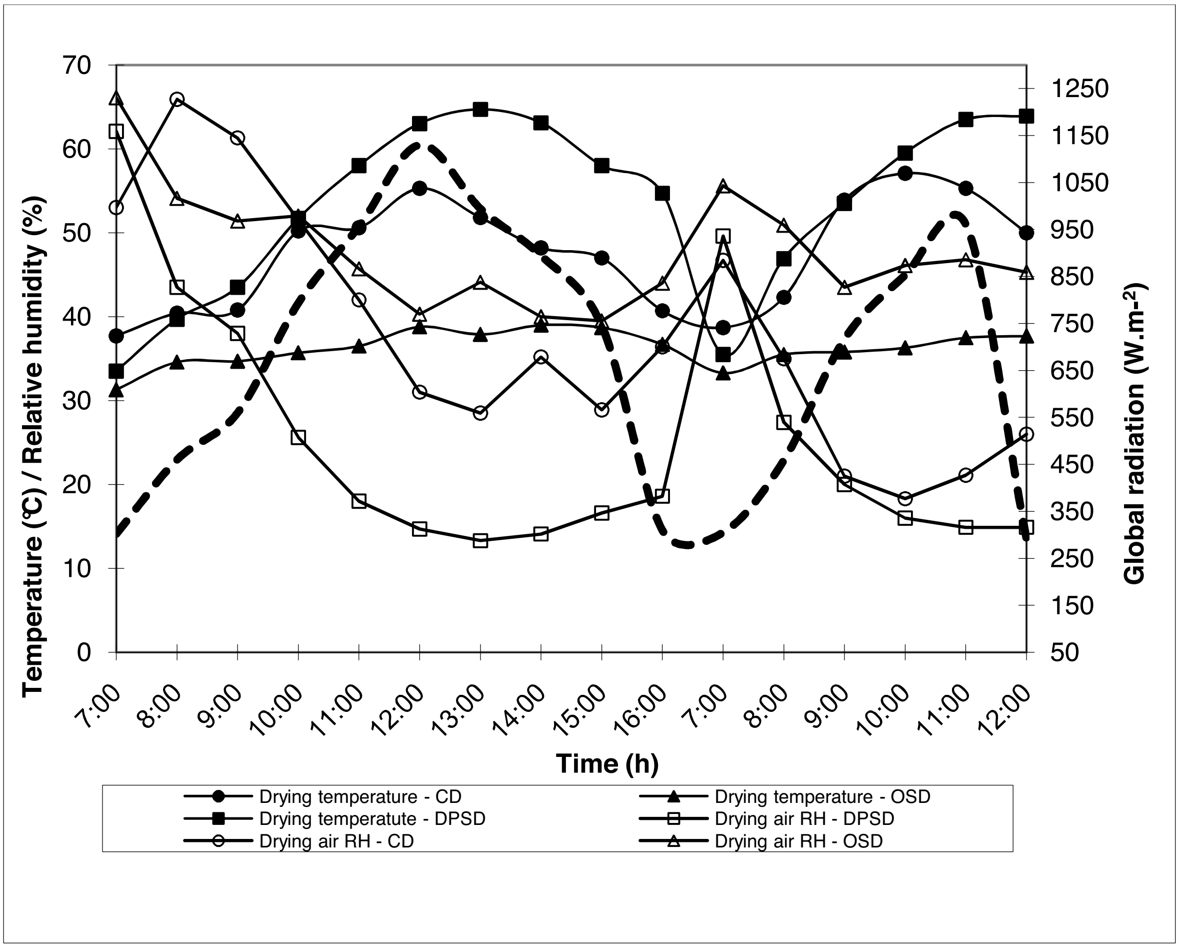

Fig. 2. Variations of drying air temperatures, drying air relative humidity and global solar radiation for typical drying test.

The peak drying air temperatures with corresponding air relative humidity were 64.7 ±1.2 °C, 13.3 ±0.9 %; 57.1 ±2.2 °C, 17.3 ±1.9 %; and 38.8 ±4.5 °C, 39.3 ±3.9 % for DPSD, CD and traditional OSD, respectively. Changes of moisture content with drying time for a typical experimental run for DPSD, CD and OSD for bamboo shoots drying is shown in Fig.3.

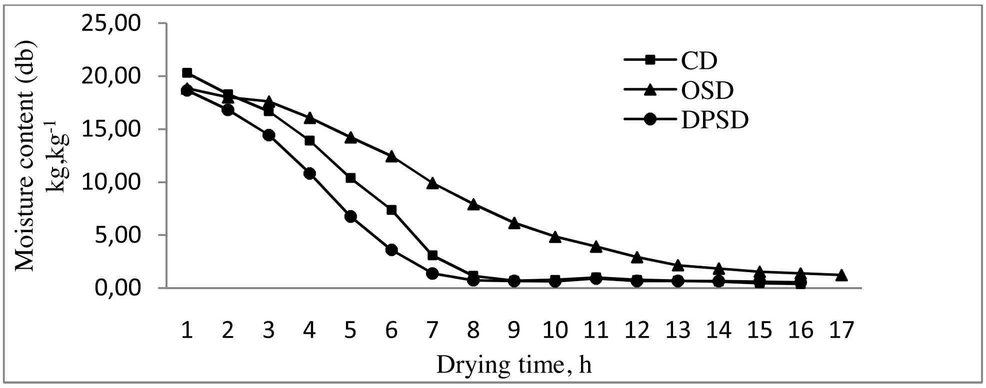

Fig.3. Variation of moisture content of bamboo shoots in DPSD, CD and OSD.

From the drying curves in Fig. 2 is evident, that the fastest drying process was occurred in DPSD where the falling-rate period was achieved after 7 hours, followed by CD where the falling-rate period was achieved after 8 hours and OSD where it took 16 hours.

Drying rate versus moisture content during DPSD drying, CD drying and traditional OSD are presented in Fig.4. All figures shows higher drying rate at the initial stages of drying which corresponding to higher initial moisture content of the product.

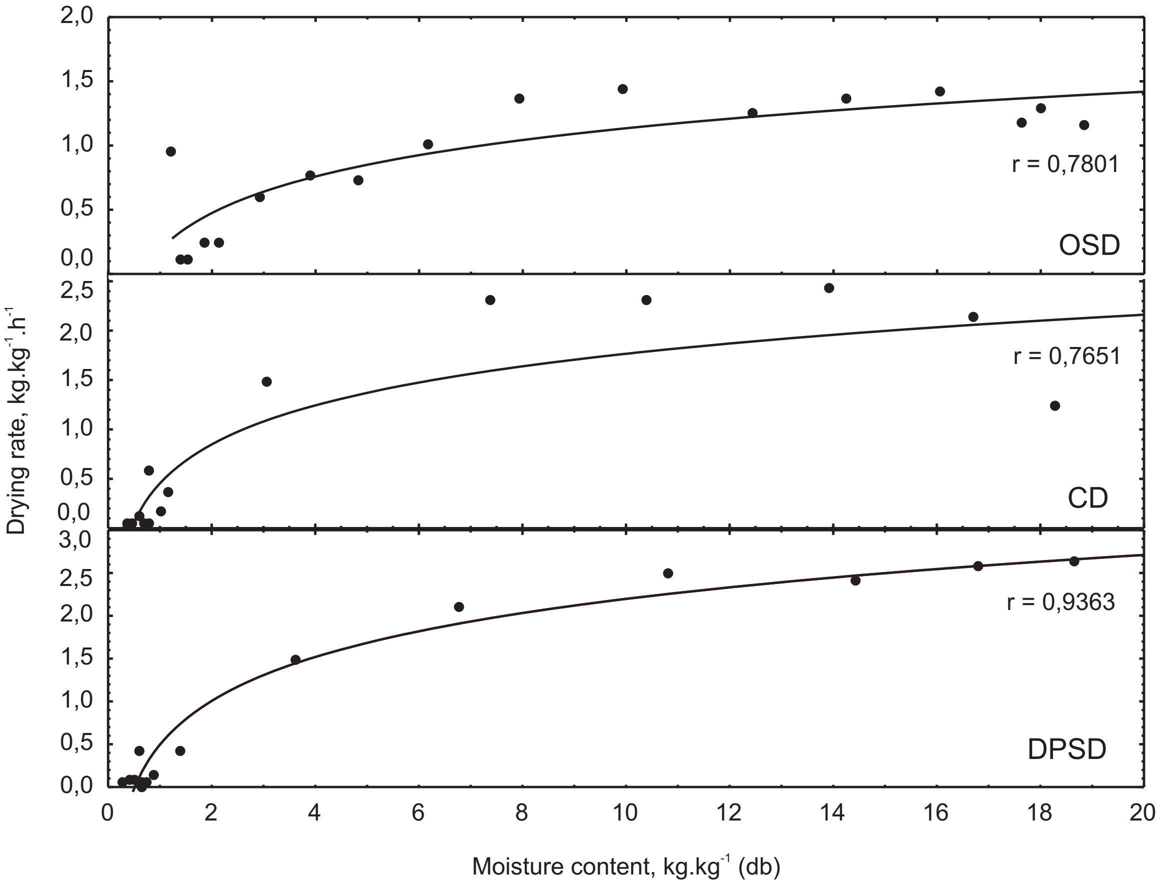

Fig.4. Drying rates of bamboo shoots as a function of moisture content during drying in DPSD, CD and traditional OSD. (db), dry basis.

The drying rates decreased logarithmically as moisture content reduced during the drying process. Further, no constant rate period has been observed during bamboo shoots draying while drying took place only in the falling rate period. The following regression equations were created for drying rate with moisture content of bamboo shoots.

For drying in DPSD:

$$DR = 0.4931+1.705 \, Ln\,(M) \qquad (4)$$

For drying in CD:

$$DR = 0.453+1.313 \, Ln\,(M) \qquad (5)$$

For traditional OSD:

$$DR = 0.1909+0.9441 \, Ln\,(M) \qquad (6)$$

According to the regression equations is obvious that highest drying rate was observed in DPSD followed by drying in CD and traditional OSD. These results corresponding to the fact, that in DPSD powered fans are used to ensure adequate airflow rate. Similar results have been observed in case of overall dryer efficiency. Here the best dryer efficiency was obtained in DPSD, followed by CD and OSD with 22%, 15.8% and 9.7%, respectively. Reached drier efficiency in case of DPSD is in the optimal range 20 – 30% typical for forced convection solar dryers reported in the literature [9].

5. Conclusion

According to our results it may be concluded that a new designed Double-pass solar drier (DPSD) is suitable for drying crops such as bamboo shoots under specific conditions of central Vietnam. In all cases, the use of this drier led to considerable reduction in drying time and substantial increase of drying rate in comparison to traditional open-sun drying and drying in natural convection solar drier.

Acknowledgement

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References

[1] L. Imre, (1997). Solar driers, in: L. Baker, (Ed.), Industrial drying of food. Blackie academic and professional, London, pp. 210–238.

[2] A, G. Ferreira, C. B. Maia, M. F.B. Cortez, R. M. Valle, Solar Energy, 82 (2008) 198–205.

[3] L. Imre, (2007). Solar drying, in: A.S. Mujumdar, (Ed.), Handbook of industrial drying, CRC Press, Taylor & Francis Group, Florida, pp. 307–361.

[4] M.A. Hossain, B.K. Bala, Solar Energy, 81 (2007) 85–92.

[5] B.K. Bala, M.R.A. Mondol, B.K. Biswas, B.L. Das Chowdury, S. Janjai, Renewable Energy, 28 (2003) 183–190.

[6] V.T. Karathanos, V.G. Belessiotis, Journal of Food Engineering, 31 (1997) 35–46.

[7] Y. Xu, M. Zhang, D. Tu, J. Sun, L. Zhou, A. S. Mujumdar, International Journal of Food Science and Technology, 40 (2005) 589–595.

[8] O.V. Ekechukwu, B. Norton, Energy Conversion & Management, 40 (1999) 615–655.
[9] P. Purohit, A. Kumar, T. Ch. Kandpal, Solar Energy, 80 (2006) 1568–1579.