POST HARVEST PROCESSING OF SELECTED TROPICAL CROPS USING A NATURAL CIRCULATION SOLAR DRYER

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Abstract

Agriculture products are practically the only financial resource for the people near Pucallpa city in the Peruvian Amazon. Large quantities of tropical fruits (e.g. bananas, pineapples and papaya) are produced, but there is lack of suitable processing method to improve the income for the farmers. The goal of the study was to design a direct natural-circulation solar dryer, and compare its performance with the traditional open-to-sun drying. The design of the dryer was made to suit the local farmer needs, as a small-scale home drying unit with a capacity from 3 kg to 8 kg in relations to the product being dried. The dryer was built from materials available on the local market, therefore making it possible to construct more units by the farmers themselves. A series of seven tests were completed. The use of the dryer led to considerable drying time reduction and final product quality compared to the open-to-sun method. From the results obtained from the research it is possible to state that the use of a direct natural-circulation solar dryer is an appropriate technology for the preservation of some agricultural products in Pucallpa.

Key words*:* solar dryer; solar radiation; tropical crops; Pucallpa

INTRODUCTION

Agriculture products are one of most important financial resources for people near Pucallpa city in the Ucayali region of Peru. Tropical crops such as banana, pineapple and papaya are produced in large quantities, but the income for farmers is inadequate due to lack of any suitable processing method and marketing structures. Yields are usually more than immediate consumption needs and this fact lead to wastage of food surpluses during the harvest periods because of very low market prices. Drying is a generally known suitable preservation technique for processing of agriculture products. In the most general case, after initial period of adjustment, the dry-basis moisture content, *X*, decreases linearly with time *t*, following the start of the evaporation. This is followed by non-linear decrease in *X* with t until, after a very long time, the solid reaches its equilibrium moisture content, *X'* and drying stops (Mujumdar, 1997).

$$Xf = (X - X') \quad (1)$$

The drying rate drop to zero at $Xf = 0$. However by convection, the drying rate, *DR*, is defined as:

$$DR = -\frac{Ms}{A}\frac{dX}{dt} \quad \text{or} \quad DR = -\frac{Ms}{A}\frac{dXf}{dt} \quad (2)$$

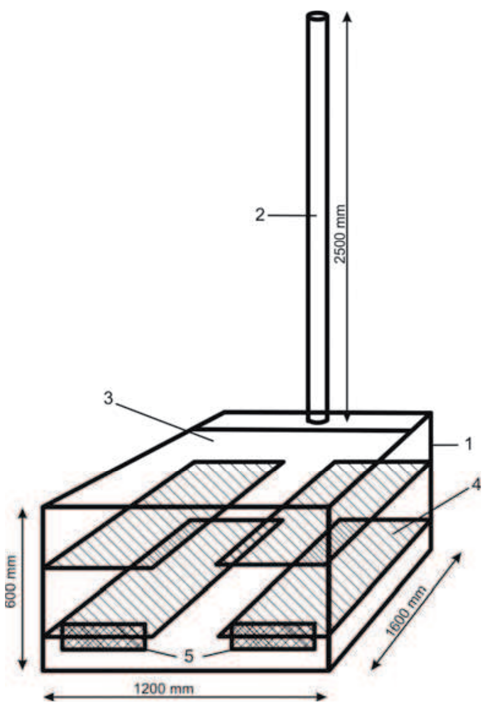
Under constant drying conditions. Were *DR* (kg/m$^{2/}$h) is the rate of evaporation of water, *A* is the evaporation area in (m^2) and Ms is the mass of dry solids.

The use of solar energy for drying agricultural products in the tropics is quite feasible, since at least 6 h of sunshine are received every day at 500–800 W/m^2 of radiation per hour, resulting in about 185 W/m^2 per day of insolation (Simpson and Tehernitz, 1980). Agricultural crops in Pucallpa are normally dried by open-to-sun drying. This method often results in inferior quality of dried product due to dependence on weather conditions and vulnerability to the attack of insect, pests, microorganisms and dust. In such conditions, natural-circulation solar-energy dryers appear to be as increasingly attractive commercial proposition. The advantages of solar-energy dryers that enable them to compete with traditional drying techniques and their use for processing wide range of agriculture products has been reported by many researchers (Sharma et al., 1995; Schirmer et al., 1996; Ekechukwu and Norton, 1997; Karathanos and Belessiotis, 1997; Bala et al., 2003). However, some of these solar-energy dryers have been constructed as dryers using a combination of solar and other conventional forms of energy, such as electricity or gas (McDoom et al., 1999; Condorí et al., 2001; Bennamoun and Belhamri, 2003). These techniques are inappropriate for most small farmers near Pucallpa either because grid-connected electricity is unavailable in these areas, the cost of conventional energy is too high or the final design of the solar dryer is rather complicated. The purpose of this research was to study the performance of an integral-type natural-circulation solar-energy dryer for the drying of different crops under tropical conditions in Pucallpa, Peru.

Design of experimental facility

The solar dryer which was built for drying local agriculture products in this study could be classified as an integral-type natural-circulation solar-energy dryer (Ekechukwu and Norton, 1997). The drying chamber is basically a wooden box with the dimensions 1 200 mm in wide, 1 600 mm in length and 600 mm height, improved by iron frame as shown in Figure 1. Depending on type of dried crops maximum capacity vary between 5 to 10 kg of fresh fruits or vegetable. The top lid is equipped with a glass window to enable the passage of solar rays and is also retractable for loading and unloading. The inside of the drying chamber is painted matt black for better heat absorption. Glass wool is used as insulation material to reduce the heat loss from the drier. Inlet openings are in the front part of drying chamber. Though these openings outside air enters the dryer, than is heated to a higher temperature and while it circulates around the crop trays secures the drying process. The warm air adsorbs the moisture from the products being dried and then leaves the dryer through an opening in the top part of the dryer. To ensure better buoyancy a chimney is used with a length of 2 500 mm. The materials available solely on the local market in Pucallpa were used for building of this solar dryer.

Figure 1: Integral natural-circulation solar energy dryer adapted for tropical crops drying in Pucallpa, Peru



1 = draying chamber; 2 = chimney for ensuring adequate air flow; 3 = transparent access door; 4 = plastic mesh trays; 5 = air inlet

MATERIALS AND METHODS

The integral natural-circulation solar dryer was installed at National University of Ucayali in Pucallpa, Peru. The dryer was oriented in north-east direction, placed on a raised platform and not shaded by trees or buildings between 8 a.m. and 5 p.m. seven drying tests with different agriculture crops were carried out from August to September 2004.

One local variety of plantain (*Musa* × *paradisiaca* L.) identified as "Inguiri" (AAB group) and four local varieties of dessert bananas (*Musa* sp.) identified as "Moquicho" (AA group), "Seda" (AAA group), "Manzano" (AAB group) and "Isla" (ABB group) were used in this study. Additional tests used pineapple [*Ananas comosus* (L.) Merr.], papaya (*Carica papaya* L.), cassava (*Manihot esculenta* Crantz) and one variety of pepper identified as "Aji Amarillo" [*Capsicum baccatum* var. *pendulum* (Willd.) Eshb.]. Immature fruits of plantain, mature fruits of dessert bananas, pineapple, papaya, pepper and tuberous roots of cassava were purchased from the local market Bellavista in Pucallpa. First they were washed by potable water, then peeled (except the pepper) and cut in to 5 mm thick slices (except the pepper, which was straightly cut in to two halves). Thus prepared material was then spread on wire-mesh trays of the drying chamber forming one layer. Whole crops were dried without any chemical pretreatement except for the slices of papaya which were dipped in 70°C hot syrup (one part of sugar, two parts of water) for 30 minutes.

Equipment for measuring important parameters affecting the drying process was installed to determine the performance of the solar dryer. A K-type thermo-couple complete with digital relative humidity meter (Lutron HT-3006) was used to measure the drying air temperature and drying air relative humidity inside the dryer. A pyranometer (LI-COR, LI-250A light meter along with LI-200SA sensor) was applied to measure the global solar radiation in the place of drying chamber of the dryer. The velocity of drying air was measured by an anemometer (Testo 425) at the outlet of the dryer. The relative humidity and temperature of ambient air were measured by a hair hygrometer complete with mercury thermometer (NOVI). Weight losses of the crops during the drying period were taken from 4 different samples seats in the drying chamber and were measured with electronic scales. The open-to-sun dried control samples were weighed as well. All these data were recorded at 2 hour intervals. The moisture contents of dried crops were measured at the starting and the end of each run of experiments by the oven method. To calculate the initial and final moisture contents the following equations (3 and 4) as proposed by Eke-chukwu (1999) were used:

$$m_i = (m_0 - m_d / m_0) \times 100 \quad (3)$$

$$m_f = (m_s - m_d / m_s) \times 100 \quad (4)$$

where m_i and m_f are the initial and final moisture contents (%), respectively. Further m_0, m_d, and m_s are the fresh weight of the product in (g), weight after solar drying in (g) and dry weight after 24 h drying at 105°C in (g), respectively.

To evaluate drying performance of the solar dryer, the system drying efficiency ηd was calculated using following equation (5) as expressed by Augustus Leon et al. (2002).

$$\eta d = \frac{W \times \Delta Hl}{Ic \times Ac \times t} \quad (5)$$

Where W (kg) is a mass of water evaporated in time t, ΔHl (kJ/kg) is latent heat of evaporation of water, Ic (W/m^2) is a solar radiation on collector surface and Ac (m^2) is a collector area.

A total of seven tests were carried out in this experimental study. Test number 1 was undertaken during banana draying namely Moquicho, Seda, Isla between 3 and 5 August 2004. Test number 2 was undertaken during Inguri banana drying on 2 August 2004. Test number 3 was undertaken during Manzano banana drying between 1 and 3 September 2004. Test number 4 was undertaken during papaya drying between 6 and 8 September 2004. Test number 5 was undertaken during pineapple drying between 9 and 10 August 2004. Test number 6 was undertaken during pepper drying between 6 and 8 August 2004. Finally test number 7 was undertaken during cassava drying between 14 and 15 September 2004. During all the tests, drying was started once loading was completed, usually at 8:00 a.m. and stopped at 5:00 p.m. Afterwards, the crops in the dryer were collected and placed in plastic vessels in order to reduce adsorption of air humidity by dried crops. These were again spread on the crop trays in the drying chamber the next morning and the experiment was continued. This process was repeated until a final moisture content less than 20% w.b. was achieved. For each of the experimental tests the dryer was loaded to full capacity between 3 kg to 8 kg depending on kind of crop being dried. To compare the performance of the integral natural circulation solar dryer with that used in Pucallpa traditional open-to-sun drying, control samples of fruits (except pineapple and papaya, test number 4 and 5) were spread in single layers on trays on a raised platform beside the solar drier. Both experimental and control samples were dried simultaneously under the same weather conditions.

RESULTS AND DISCUSSION

The variations of the applied conditions and performance parameters of the solar dryer during experimental run of all the tests are presented in Table 1. The mean solar radiation values over all the tests varied between 260 W per m^2 and 390 W/m^2 with peak values ranging between 590 W/m^2 and 720 W/m^2 de-pending on the climate conditions. The results show, that value of air flow corresponding with values of solar radiation and with ambient air temperatures. The maximum air flow 0.60 m/s was obtained at noon during test run number 3. Mean drying air temperatures recorded over the entire test series were between 42°C and 48°C. However, the maximum drying temperatures at noon during test number 1 and 3 (65.4°C and 66.2°C) exceed the recommended range of drying temperatures (50 to 60°C) for drying temperature-sensitive products like fruits and vegetables (Augustus Leon et al., 2002). To ensure better control of maximum drying temperatures a small fan operated by photovoltaic module can be installed in the chimney of solar dryer; however, adding the powered fan will make the construction of the dryer more complicated.

The typical drying air temperatures were approximately over 39–70% higher than ambient air temperatures. The corresponding distribution of drying air relative humidities were fairly below ambient relative humidities during runs of all tests. The mean drying air relative humidities were between 35% and 42% (with minimum values of 13–22%) and they were approximately over 27–37% lower than ambient air relative humidities. In all the tests, the drying air temperature decreased from the drying chamber to the outlet (chimney) of solar dryer with a corresponding increase in relative humidity. This behaviour occurs because, the air absorbs the evaporated moisture from the crops with simultaneous loss of heat to the crops, as it progress through the dryer from the inlet to outlet. The solar dryer efficiency for average daily insolation of 17.5 MJ/m^2/day varied between 15% and 30%. The highest dryer efficiency (30%) was obtained during run a test number 1 and the lowest (15%) during run a test number 4.

The values of initial and final moisture contents with related drying times for solar drying of different crops are presented in Table 2. The drying time required to reach 15% product moisture content in the integral natural-circulation solar dryer varied between 7 and 24 hours, depending on the weather conditions and type of product dried. To achieve the same 15% product moisture by the traditional open-to-sun drying, from 25% to 85% longer drying time is required, depending on the weather conditions and type of product. The results from all tests show that the decrease of products moisture content varied, on average between 2.5% and 6.9% hourly using the solar dryer, in comparison to an average decrease of products moisture content between 1.6% and 3.8% hourly using the open-to-sun drying method. The results of test number 4 show that due to pretreatment of papaya by sugar syrup before drying, lower final moisture content at the

Tab 1: Overview of experimental tests

Performance parameters	Test number						
	1	2	3	4	5	6	7
Mean solar radiation (W/m^2)	338	355	356	337	393	264	349
Peak solar radiation (W/m^2)	637	640	691	720	708	589	593
Mean ambient air temperature (°C)	30	28	32	31	27	28	28
Peak ambient air temperature (°C)	34	30	35	36	31	33	34
Mean drying air temperature (°C)	46.7	48.0	45.8	43.1	46.5	44.3	42.2
Peak drying air temperature (°C)	65.4	60.0	66.2	57.9	58.9	59.2	57.0
Mean outlet air temperature (°C)	46.0	45.4	41.7	41.1	42.3	39.9	39.1
Peak outlet air temperature (°C)	60.0	52.2	51.8	52.4	52.9	50.2	49.4
Mean ambient air relative humidity (%)	55	59	56	65	56	64	58
Minimum ambient air relative humidity (%)	37	50	42	46	41	49	44
Mean drying air relative humidity (%)	39.5	36.5	41.0	40.6	34.7	42.1	42.2
Minimum drying air relative humidity (%)	15.4	18.6	12.6	17.6	12.9	17.5	22.0
Mean outlet air relative humidity (%)	40.5	37.1	47.2	45.7	36.6	44.3	46.7
Minimum outlet air relative humidity (%)	16.5	21.6	24.7	20.9	17.8	20.4	26.5
Mean drying air velocity (m/s)	0.30	0.40	0.35	0.30	0.30	0.30	0.35
Peak drying air velocity (m/s)	0.55	0.50	0.60	0.55	0.55	0.50	0.50
Total initial weight of crop (kg)	7.5	6.5	6.8	4.8	5.5	3.0	4.2

Tab. 2: Values of initial/final moisture contents and related drying times for solar drying of different crops in Pucallpa, Peru

Type of fruit	Initial moisture content (% w.b.)	Final moisture content of sample[a] (% w.b.)	Final moisture content of control[b] (% w.b.)	Drying time (hours[c])
Dessert bananas (*Musa* sp.)				
Variety: Moquicho	65.44	7.50	21.85	27
Seda	74.97	8.00	23.04	27
Isla	72.72	6.81	20.46	27
Manzano	69.40	13.98	29.43	19
Plantain (*Musa* × *paradisiaca* L.)				
Variety: Inguiry	64.10	8.54	33.25	8
Pineapple [*Ananas comosus* (L.) Merr.]	86.96	8.37	–	17
Papaya (*Carica papaya* L.) [1]	91.50	18.02	–	22
Papaya (*Carica papaya* L.) [2]	85.71	13.86	–	22
Pepper [*Capsicum baccatum* var. *Pendulum* (Willd.) Eshb.]	91.35	16.84	68.05	15
Cassava (Manihot esculenta Crantz)	65.49	8.45	23.57	17

[a]samples dried by solar dryer; [b]control samples dried by traditional open-to-sun method; [c]cumulative sunshine hours (1day equal to 9 drying hours)
[1]without pretreatement; [2]dipped for 30 minutes in 70°C hot syrup

same drying time and better sensory properties could be achieved in comparison to not pretreated papaya. Finally, all tests indicate better sensory properties of the products dried in solar dryer in comparison with those dried by the traditional open-to-sun method. In accordance with results of this research it is possible to conclude that using the integral natural-circulation solar dryer is a more appropriate technology to preserve agricultural products in Pucallpa.

CONCLUSIONS

From the seven tests of the performance investigation of the integral natural-circulation solar dryer realized in this study, it was found that the drying air temperature varied between 40°C and 65°C, depending mainly on solar radiation and type of product dried. The results from all tests suggest that the above mentioned type of solar dryer could be used for drying a wide range of tropical crops grown near Pucallpa. Further, they indicate that it is a preferable technique in comparison to traditional open-to-sun drying mainly due to following: Drying time is considerably reduced and the final product is acceptable in appearance and quality, because the dried crops are completely protected from rain, insects and dust. The solar dryer reported in this study was designed as a small-scale home drying unit adaptable to local farmers needs with an estimated construction cost of 155 USD. This solar dryer was completely constructed from materials available on the local market in Pucallpa.

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REFERENCES

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

Bala B.K., Mondol M.R.A., Biswas B.K., Das Chowdury B.L., Janjai S. (2003): Solar drying of pineapple using solar tunnel drier. Renewable Energy, 28: 183–190.

Bennamoun L., Belhamri A. (2003): Design and simulation of a solar dryer for agriculture products. Journal of Food Engineering, 59: 259–266.

Condorí M., Echazú R., Saravia L. (2001): Solar drying of sweet pepper and garlic using the tunnel greenhouse drier. Renewable Energy, 22: 447–460.

Ekechukwu O.V. (1999): Review of solar-energy drying systems I: an overview of drying principles and theory. Energy Conversion and Management, 40: 593–613.

Ekechukwu O.V., Norton B. (1997): Experimental studies of integral-type of natural-circulation solar-energy tropical crop dryers. Energy Conversion and Management, 38: 1483–1500.

Karathanos V.T., Belessiotis V.G. (1997): Sun and artificial air drying kinetics of some agricultural products. Journal of Food Engineering, 31: 35–46.

McDoom I.A., Ramsaroop R., Sauderes R., Tang Kai A. (1999): Optimalization of solar crop drying. Renewable Energy, 16: 749–752.

Mujumdar A.S. (1997): Drying fundamentals. In: Baker L. (ed.): Industrial Drying of Food. Blackie Academic and Professional, London, pp. 210–238.

Schirmer P., Janjai S., Esper A., Smitabhindu R., Mühlbauer W. (1996): Experimental investigation of the performance of the solar drier for drying bananas. Renewable Energy, 7: 119–129.

Sharma V.K., Colangelo A., Spagna G. (1995): Experimental investigation of different solar driers suitable for fruits and vegetable drying. Renewable Energy, 6: 413–24.

Simpson W.T., Tehernitz J.L. (1980): Design and performance of a solar lumber for tropical latitudes. In: Proceeding on Wood Drying Party, IUFO Division V Conf., Oxford: UK, pp. 59–70.

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