Design and Performance Evaluation of an Active Solar Dryer for Cinnamon Quills

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Abstract
Sri Lanka is the largest producer of true cinnamon in the world, accounting for about 60-70% of the global production. Cinnamon quills should be dried properly to contain less than 15% moisture to obtain a long shelf life. Air drying is one of the oldest methods of food preservation where the products such as cinnamon are dried without exposing directly to the solar radiation. But this method has many disadvantages such as spoilage of products due to rain, wind, dust, insect infestation, animal attack and fungi. Therefore it is essential to introduce solar dryer for the drying of cinnamon quills properly to supply high quality cinnamon to the market. The aim of the study was to design and to compare the performance of an active solar dryer for cinnamon and with the performance of existing shade drying technique. The dryer is composed of solar collector, drying chamber, plenum chamber. Ten kilograms of cinnamon quills were placed in the dryer and open shade drying system separately and, performance parameters were evaluated during one hour intervals. Initial average moisture content of the quills was 59 % and it was dropped to recommended safe moisture level (15%) with in 20hrs by solar dryer while open sun drying 36hrs to reach safe moisture level. Temperature inside the drier was higher than the ambient temperature and corresponding relative humidity in the drier was lower than ambient relative humidity Maximum drying efficiency of 52% was obtained during the peak sunshine hours and lowest efficiency of 31% was obtained during the initial stage of the experiment. As a result, drying rate of quills in a force convection drier was found to be higher than that of open shade drying.

Keywords: Drying, Solar energy, Cinnamon
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Introduction

Sri Lanka has been famous for spices from ancient times. The growing and processing of spices provide cash income to a wide range of rural Sri Lankans, particularly small holders. Cinnamon (*Cinnamon verum*) is an indigenous spice crop in Sri Lanka. It belongs to the family Lauracea. Sri Lanka is the fourth largest producer of cinnamon in the world, accounting for 80% of the global production (FAOSTAT, 2014).

Freshly peeled cinnamon chips contain water about more than half of its weight. Therefore it is important to reduce the moisture content of the final product. Air drying is one of the oldest methods where the products such as cinnamon are dried without exposing directly to the sun. This method has many disadvantages such as spoilage of products due to rain, wind, dust, insect infestation, animal attack and fungi. The speed of drying especially in open air drying is also very slow (Muhlbauer, 1986). Therefore it causes to retain more moisture inside the quills and thus negatively affect the quality of dried product due to improper drying. Open sun drying is a labor intensive process and crop handling particularly in periods of inclement weather incurs a high costs, damages crop and reduces quality. Therefore it is essential to introduce an efficient dryer for cinnamon quills to meet high quality standards in the global market.Mechanized dryers though faster and gives a better quality product, are expensive and require substantial quantities of fuel or electricity to operate, leading to high cost of drying (Ajay *et al.*, 2009). Therefore development of a solar dryer to dry the cinnamon quills is important. The term solar dryer is applied to a structure made for the deliberate use of solar energy to heat air and the products to achieve dehydration (Tarigan and Tekasakul, 2005).

The main objective of this research project is to design and evaluate the performances of active solar dryer by comparing the performance of the newly design dryer with existing shade drying technique.

Materials and Methods

Construction Details

The main parts of the dryer are solar collector system, plenum chamber and drying chamber. Main parts and critical dimensions are calculated according to the designing theories and schematic diagram of newly designed dryer are given in Figure 1.

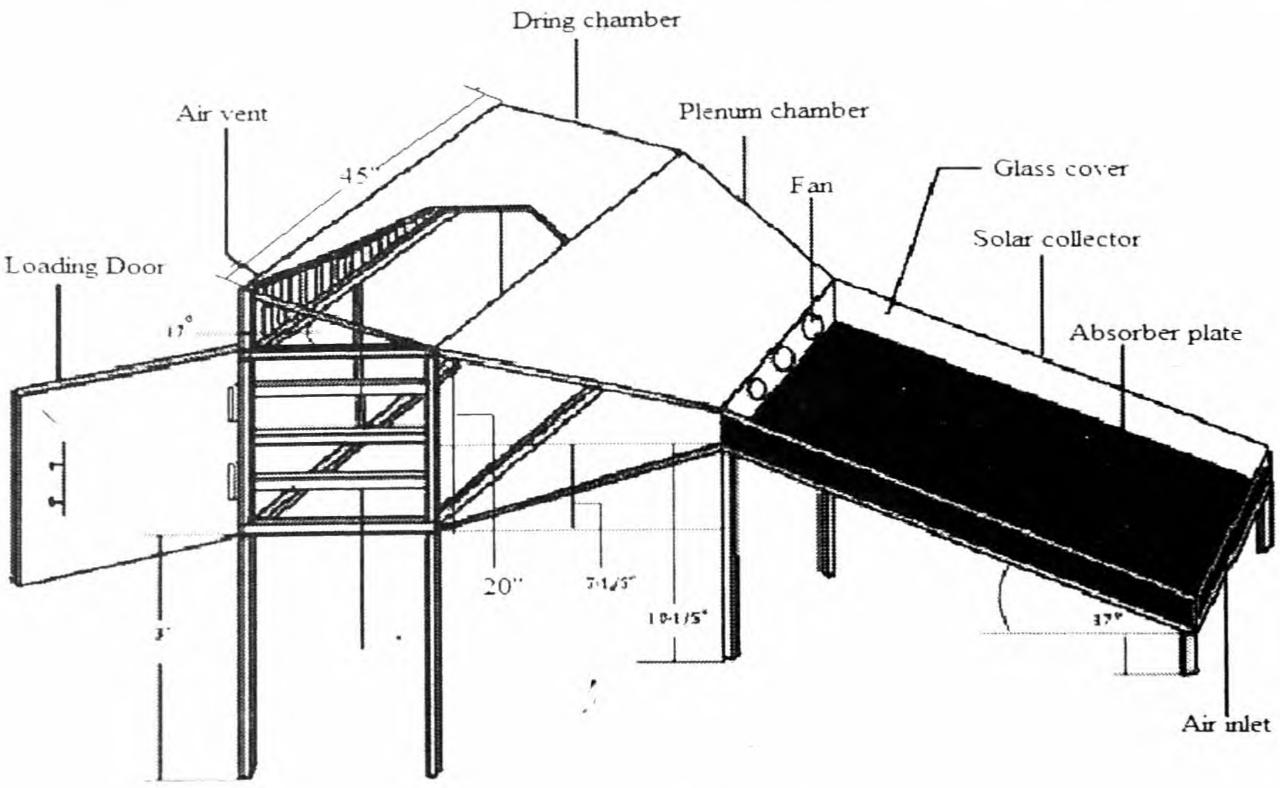

Figure 1: Schematic diagram of the solar cinnamon dryer

Outer insulation box of the solar collector (1.11m x 1.26m x 0.12m) was made of plywood and filled with foam material of about 12.5 mm thickness. V- Ribbed, black painted 0.45mm thickness steel sheet was mounted in the middle of the insulation box as an absorber. Glass of 5mm thickness is placed at the top of the collector. One end of the solar collector has an air inlet vent of area 0.1332 m^2, and other end is fitted with fan (12V/0.17A) to provide the forced convection to the drying chamber. The plenum chamber was constructed with plywood sheets and located between drying chamber and solar collector. The collector was supported and tilted at 17^0 with the help of a frame made up of wood and it was oriented toward south. Four drying trays were contained inside the drying chamber. An outlet vent was provided toward the upper end at the front of the chamber and access door was also provided at the front of the chamber. In addition, electronic temperature controller was designed and attached for precise control of airflow within 45 ^{0}C temperature in the solar dryer.

Procedure

Experimental study was performed in mid-December, in the Agriculture faculty (6.4°N latitude, 51°E longitude). The 20 kg of Cinnamon quills (C3, 106 cm) were purchased from a local market and each 10 kg was placed in solar dryer and shade dryed separately. Solar dryer was tested under no load and load condition. The trays were numbered as 1 to 4 from bottom to top. Weight losses were measured using 0.3kg of samples with 3 replicates in 4 different trays in the dryer and shade drying system separately at one hour interval. Moisture content of cinnamon quills was determined by distillation method. Thermocouple meter was used to measure temperature variation in the top and bottom of the drying chamber, collector inlet and outlet and ambient temperature. Air temperature, relative humidity, and solar radiation recorded and monitored continuously in every hour between 8:00 am and 15.00pm. Then drying performance of the dryer was studied using drying curves. Then drying efficiency was calculated using equation 1.

$$n_d = \frac{ML_v}{I_c A_c t}$$

η_d = dryer's efficiency (%)
M = Mass of moisture evaporated (Kg)
Lv = Latent heat of vaporization of water (KJ/Kg)
Ic= Solar insolation (W/m^2)
Ac= Area of solar collector (m^2)
t = Time of drying (hrs)

Results and Discussion

In the no load condition of solar drying, maximum temperature was observed at tray no 4 at 12 pm 45^{0}C while 44.3^{0}C, 42.3^{0}C, 44.1.3^{0}C for tray number 1, 2 and 3 respectively whereas maximum ambient temperature (36^{0}C) and solar irradiation (883.36 W/m^2) were observed at 12.00 pm. Minimum temperature was observed at 15:00 pm of all bottom trays. It implies in total four slots of trays inside the drying chamber, profile temperature was increasing from bottom

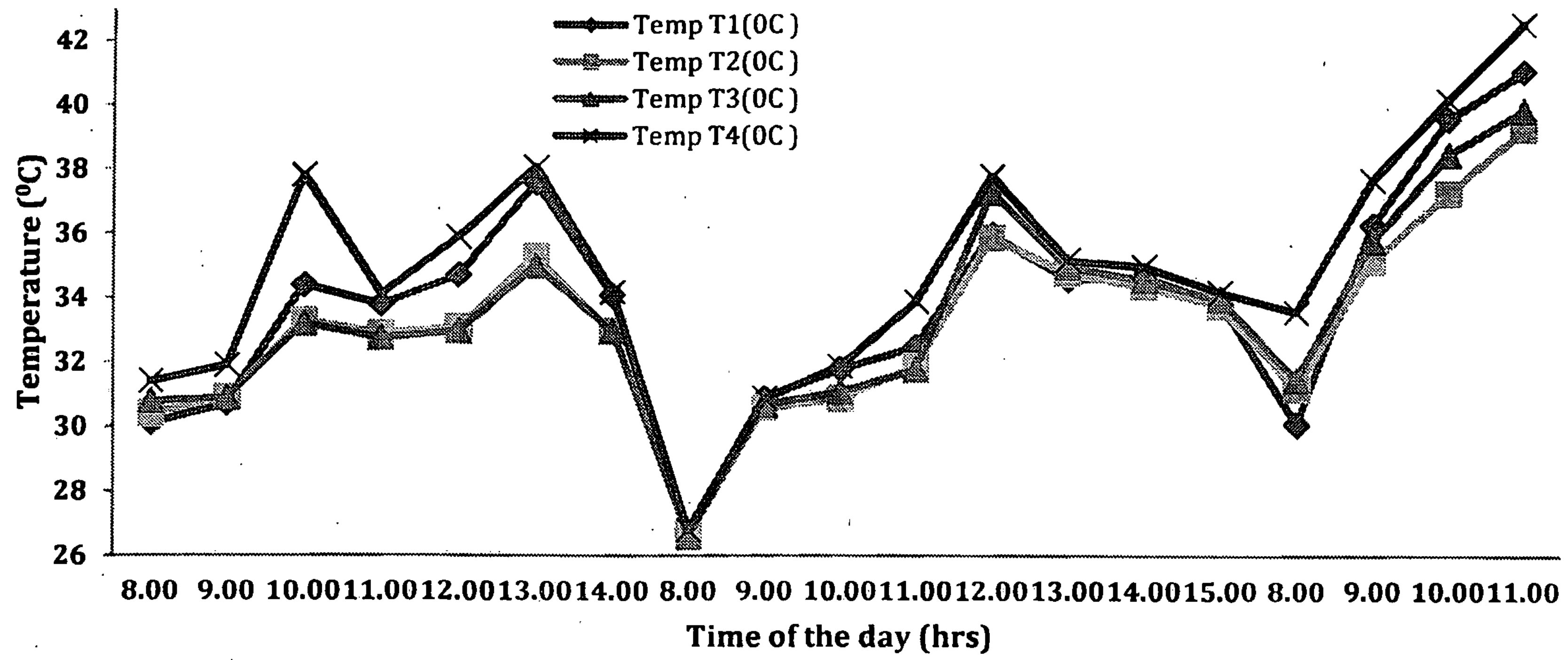

Figure 2: Temperature variation of different trays during loading test, T4 top tray (x), T_3 second tray (▲), T_2 third tray (■), T_1Bottom tray (♦)

tray to upper tray. Humidity varies from 41% to 22% inside the solar dryer whereas outside humidity varies from 81% to 56.5%

As shown in Figure 2, in loaded test, there were significant variations in the moisture lost at different tray levels during the day time where the crops on the top tray (tray 4) dried was the fastest while the quills on tray 2 was slowest drying trays. During the second day, the quills on tray 1 lost about 13.45% of the total moisture during 8 hrs drying period while, 11.36%, 11.48% and 13.39% moisture lost for those on tray 2, 3 and 4, respectively. The maximum temperature of the air measured just above the top tray was 42.6°C on the third day. This trend of drying continued in subsequent days but the difference in the moisture lost between the trays reduces as the moisture from the partially dried quills becomes harder to remove. Similar phenomenon was reported by Bena and Fuller, (2002) for a natural convection solar dryer. The maximum temperature of the air measured just above the tray 4 onuring the drying quills was about 42°C, which was about 1 and 3°C higher than other trays.

Initial average moisture content of the quills was 59% and it was dropped to recommended safe moisture level (15%) with in 20hrs by solar dryer while open sun drying needed 36hrs to reach safe moisture level (Figure 3)

The maximum drying efficiency of 52% was obtained during the peak sunshine hours and lowest efficiency of 31% was obtained during the initial stage of the experiment. The collector efficiency was found to increase with increasing

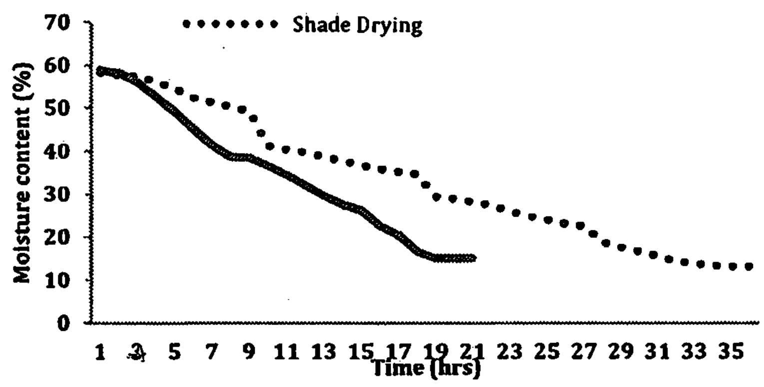

Figure 3: Drying curves of moisture content versus drying time for solar dryer and shade drying

mass flow rate and the differences in outlet and inlet air temperature.

Conclusions

Solar dryer increased air temperature and lowered relative humidity compared to shade drying condition. Cinnamon quills can be dried under controlled temperature of 45ºC with higher hygienic condition in shorter time using newly designed solar dryer compared to open shade drying. The reduction in cinnamon quills moisture content from 59% to 15% was achieved in solar dryer within 20 hrs duration. Average drying efficiency of the solar drier was estimated to be about 31.5%.

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