RESEARCH ARTICLE

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Performance of Prototype Solar Tunnel Drier Developed by University of Hohenheim Under Local Environmental Conditions in Sri Lanka

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Abstract: The solar tunnel dryer developed by University of Hohenheim was studied under local environmental conditions in Sri Lanka to identify necessary improvements so that marketable dehydrated products could be produced. Batch trials were carried using *jak* fruit (*Artocarpus heterophyllus*) and brinjal (*Solanum melongena*). Temperature, relative humidity and air flow rate during the trial period were recorded. Drying duration, physico-chemical and orgonoleptic parameters of the dehydrated products were determined. The dryer was found to be technically feasible and products are hygienically good compared to the open sun drying. Depending on bad weather conditions drying duration varied between 2- 3 days causing to produce organoleptically unacceptable dehydrated products. The reasons identified for unacceptable quality were the long dying periods and keeping the materials inside the drying compartment overnight without drying. Therefore, there is a necessity to shorten the drying period together with maintenance of a correct temperature inside the drying compartment during non solar hours to preserve the quality of dried products.

Keywords: Solar Tunnel Dryer, drying duration, non-solar hours, quality of dried products.

Introduction

Post harvest losses of fresh fruits still amount to between 20-60% of the harvested crop in Sri Lanka [1]. An important factor contributing to this situation is that the majority of horticultural produce is grown on smallholdings. The farmers have limited financial resources and have inadequate technical knowledge for preventing such losses. Drying is one of the most feasible and still widespread preservation methods of perishables. Dehydration preserves the surplus produce and minimizes the fluctuation of market price [2]. Drying of crop produce requires thorough attention on the temperature of drying air. Energy consumed for drying of agro produce contributes substantially to the total cost of production. For drying to be economically viable and for market acceptability the cost of drying of the product must be significantly less than the cost of product itself. However, the low-cost drying methods should not degrade the quality of the final product. Hence, there is a necessity to introduce efficient and cost-effective drying methods utilizing renewable energy sources in order to benefit the remote rural communities [3]. Since the most of fruits are grown in hot sunny areas of Sri Lanka and they are harvested during the time of the year that solar radiation is abundant, solar drying is the most promising and cost-effective method for dehydration of fruits and vegetables for remote rural agro communities. There are many designs of solar dryers in the world for crop drying and most of these dryers show longer drying periods ending with quality loss in the final products. Therefore, performance and suitable capacity are important selection factors for viable micro dehydration enterprises.

A model solar tunnel dryer developed by University of Hohenheim [4] had a drying arm length of 10m and a solar radiation collection arm length of 8m. The arms were 2m in width providing 20 square meters of drying bed capacity. Dryer showed direct and indirect drying and least resistance to air flow. Because of these factors and the simple structure compared to the other solar dryers this model was selected for adaptation to the local environmental conditions for the establishment of solar dehydration industry in remote rural communities in Sri Lanka according to Amunugoda *et al* [5] and Prasantha and Amunogoda [6]. In solar tunnel dryers, heat emanated from conversion of solar radiation energy absorbed by the collector then flush off to the drying bed by airflow generated by the blower powered by a solar panel and direct heat absorb by the drying bed is responsible for the drying process. The airflow rate through the collector is one of the important factor that determines the outlet temperature and collector efficiency.

A model dryer was fabricated at the Industrial Technology Institute (ITI), Colombo Sri Lanka to test the performance and to identify the problems for adaptation. The findings of this research are connected to series of field work carried out to develop a viable dehydration system for remote rural communities. More suitable drying is examined through these activities paying special attention to the energy usage from solar energy in the rural sector.

2. Materials and method

Figure 1 shows the features of prototype solar tunnel dryer.

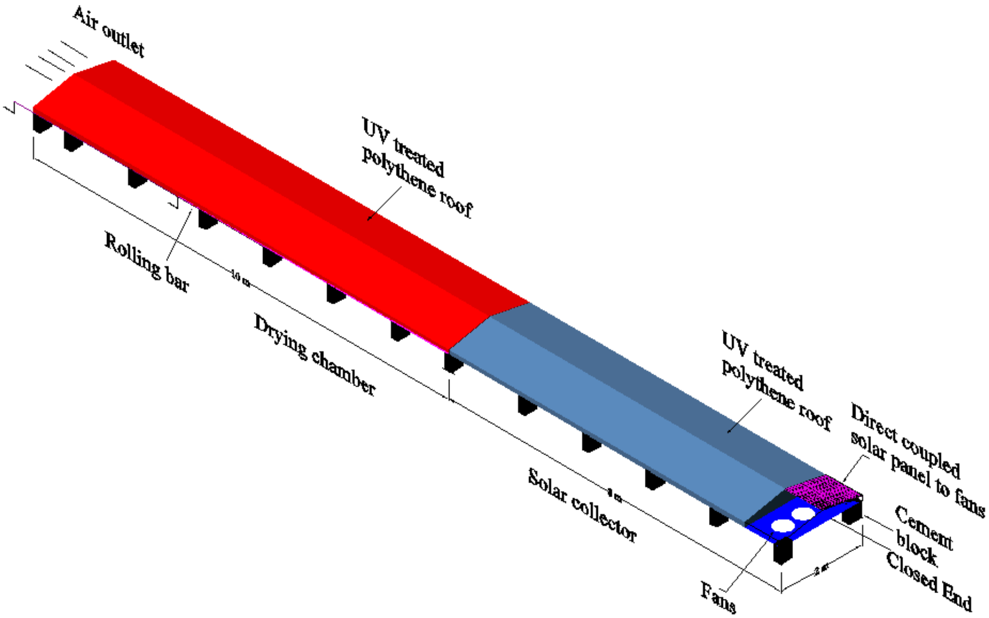

Figure 1. Prototype Hoenheim Solar Tunnel Drier.

Prototype model

The same version of prototype solar tunnel dryer was assembled in the Industrial Technology Institute premises, Sri Lanka. Testing of the drier was carried out by monitoring temperature, humidity and air velocity under no load conditions. Drying test runs were carried out using jak fruit and brinjal.

Control of airflow

Three motor engine radiator fans (12V DC) were used to control the air flow through the tunnel. Tests were carried out by coupling the fans directly to a solar panel located closed to the drier and by connecting the fans to an external DC supply (12V battery).

Full load batch trials in prototype solar tunnel dryer

Fresh slices of jak fruit of 30-40 x 10mm size were prepared. Slices were dipped for two minutes in boiled water at temperature close to 94 °C. Slices of brinjal of 40 x 6mm size were prepared and dipped for two minutes in boiled water at temperature close to 94 °C. Drained slices were kept in the dryer as a thin layer. The fans of the dryer were driven by coupling them to a solar panel. Temperature and humidity developments inside the dryer were recorded during the day and night time of the first day. After completion of drying, samples were analyzed for physic-chemical properties.

The temperature and humidity along the drying length and across the width inside the tunnel were measured using EL 008 Enviro Mon Data Logger with EL 026 temperature humidity converters and EL 030 temperature / humidity sensors. The air flow was measured using a turbo meter.

3. Results and Discussion

Flat plate solar collectors are usually constructed at an optimum slope angle depending on the relative position of the sun. The site of the present study is in the northern hemisphere therefore the dryer should face the south at an optimum slope angle. According to many authors, optimum slope angle for year-round operation is the latitude of the site, which is 6.9° for the present study. However, the dryer in the present study consisted of a longer collector and drying arm, causes severe problems during construction and handling. Therefore, the dryer did not conform to the slope design and developed for year-round operation. Because the site is close to the equator dryer receives sufficient solar radiation throughout the year. In a study of solar resource assessment for Sri Lanka [7] showed that that there is a slight difference between annual results of direct normal solar resources and calculated solar resources for a flat plate collector tilted to latitude. According to these authors the values were 4.2 to 5.6 kWh/m^2/ day and 4.5 to 6.0 kWh/m^2/day for annual results of direct normal solar resources and calculated solar resources respectively. Therefore, south facing of the dryer with 6.9° tilt to the horizontal was not considered as a necessary factor in this present study.

According to test the performance of the dryer under no load it was found that the temperature developments were below optimum temperature (55 – 60°C) for drying of perishables during early morning and late evening (Figures 2, and 3).

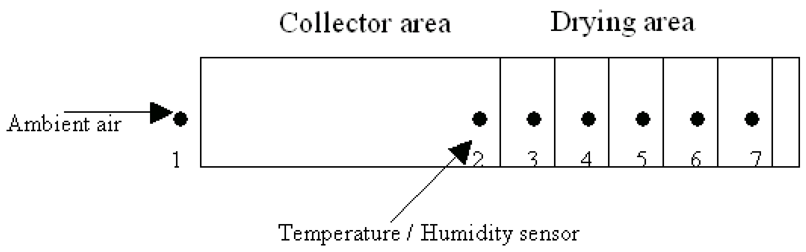

Figure 2. Tem/hum sensor locations

Between 11.30 a. m. to 2.00 p. m. the temperature of the drying bed recorded higher value than the optimum (55-60 °C) temperature (Figure 3) for the dehydration of most of perishables. It was observed that the temperature and the humidity variations were negligible (4-5 °C) along the 10 m length of the drying chamber (Figure2 and 4).

During cloudy days and days that had intermittent radiations the temperature development inside the drying chamber was below and above the optimum for the drying (Figure 2, 5, 6, and 8).

Air velocity was measured across and along the length of the drying bed showed that it was ranged from 0.2 ms^{-1} to 0.7 ms^{-1} from morning to evening of the day and are inadequate for optimum drying.

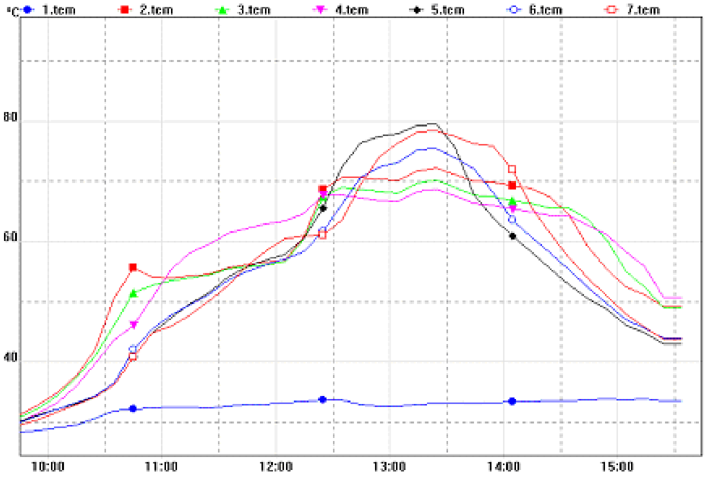

Figure 3. Temperature variation during daytime along the drying bed

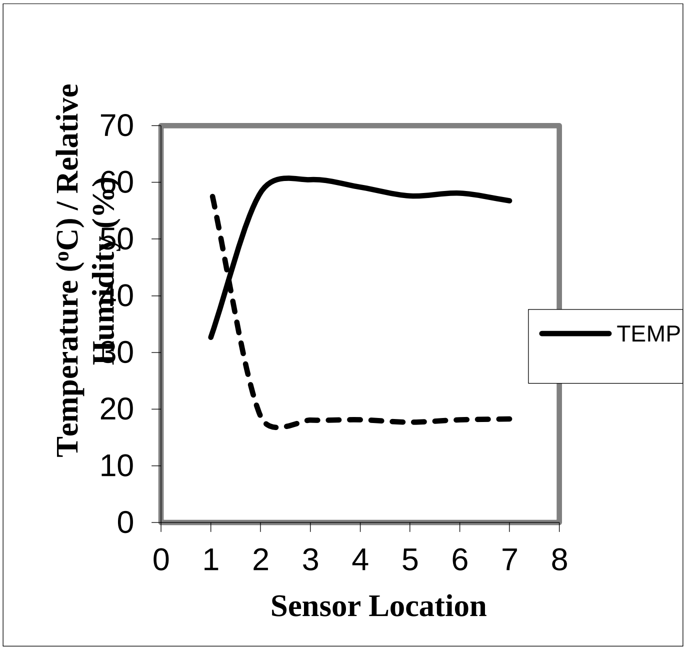

Figure 4. Temperature and Humidity variation along the drying bed at 11: 30 a.m.

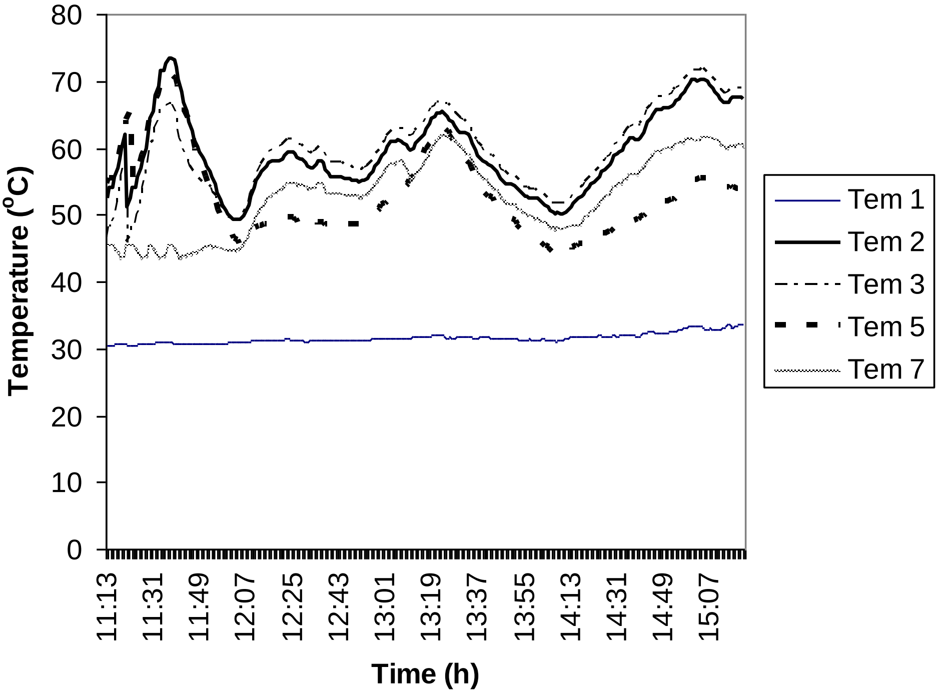

Figure 5. Intermittent radiation on temperature development along the drying chamber

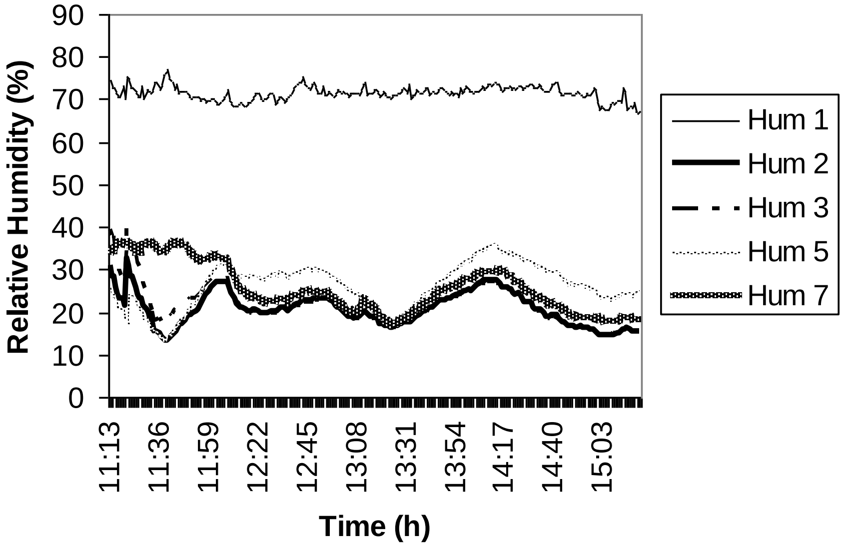

Figure 6. Intermittent radiation on humidity development along the drying chamber

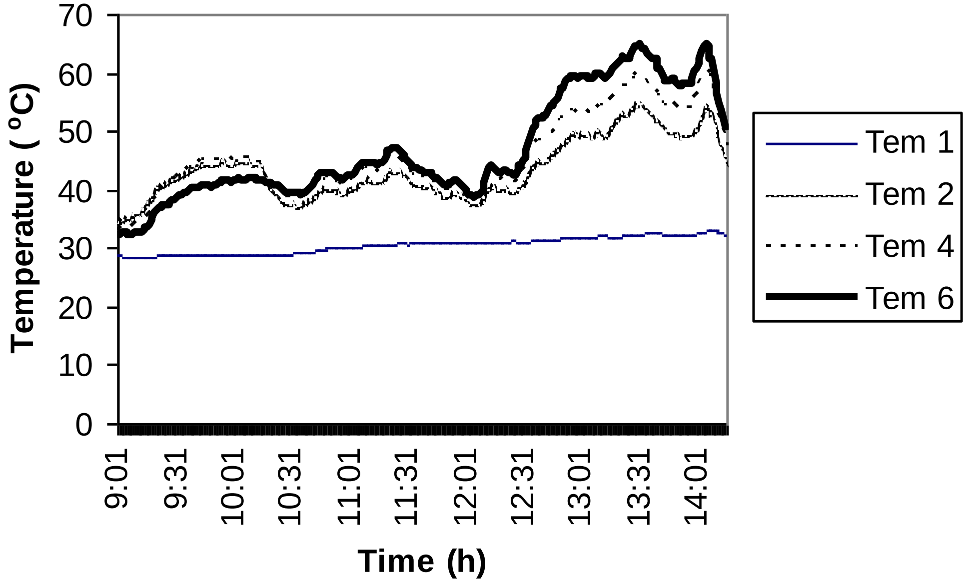

Figure 7 Influence on temperature development by low solar radiation in the morning

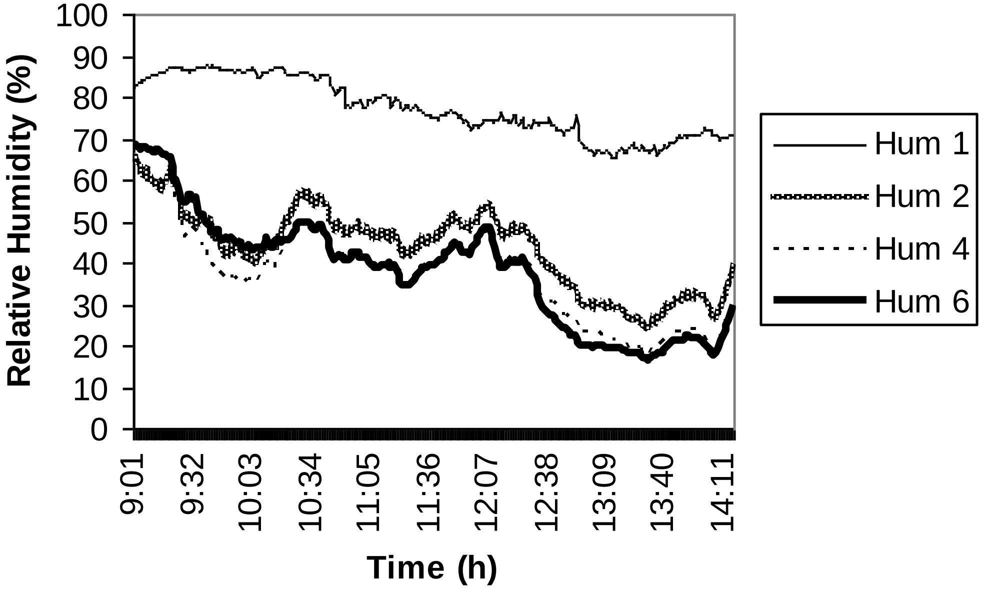

Figure 8. Relative humidity developments along the drying chamber with low levels of Radiation in the mornning

Drying characteristics and physico-chemical parameters of the dried jak fruit and brinjall are presented in Table 1.

Table 1. Drying and physic-chemical characteristics of dried products from solar tunnel dryer and electrical dehydrator

Parameter	**Jackfruit**	**Brinjall**
Fresh slice weight (kg)	24.0	43.0
Dried weight (kg)	4.8	3.0
Drying duration (hrs)	72.0	84.0
Solar duration (hrs)	20.0	24.0
Final moisture content (%wb)	7.0 ± 0.16	10 ± 0.13
Water activity	0.58 ± 0.04	0.62 ± 0.08
Colour (Lightness)	80.5 ± 0.3	68 ± 2
Overall sensory quality	4 ± 1.2	5 ± 1.8

Overall sensory attributes were 4 and 5 according to the 9- point hedonic scale in the case of jak fruit and brinjal, respectively. These low ratings can be attributed to browning, bleaching of the product inherent colour, poor texture and rehydration capacity caused by over drying and high shrinkage. The total drying duration of jak fruit was 72 hrs. Absence of heat during the nights, intermittent radiation during the daytimes, low temperature development during the morning and evening were the main reasons that caused the lengthening of the total drying period. Figures 2 and 10 shows the humidity inside the drier has increased up to 99% during mid night of the first day of the trial period.

The product remained in the drier for two nights without being dried fully. It is a common occurrence that high humid and cool conditions existing in the drying chamber during night the semi-dried products re-absorb moisture casing to extended the total drying period.

In most cases, drying process that employs high maximum permissible temperature for short time do less damage to food than drying processes employing lower temperatures for longer time. Quality changes and economics of dehydration throughout drying operation are most affected especially in the falling rate period [8], [9, [10]. Excess heat during drying results in case hardening, scorching and caramelization [11], [12], [13]. Accelerated browning by enzymatic and non-enzymatic chemical reactions, degree of shrinkage [8], [14] and high loss of volatile constituents are some critical phenomena that cause loss of product quality, while prolonged exposure of products to direct solar radiation causes bleaching and loss of inherent colour.

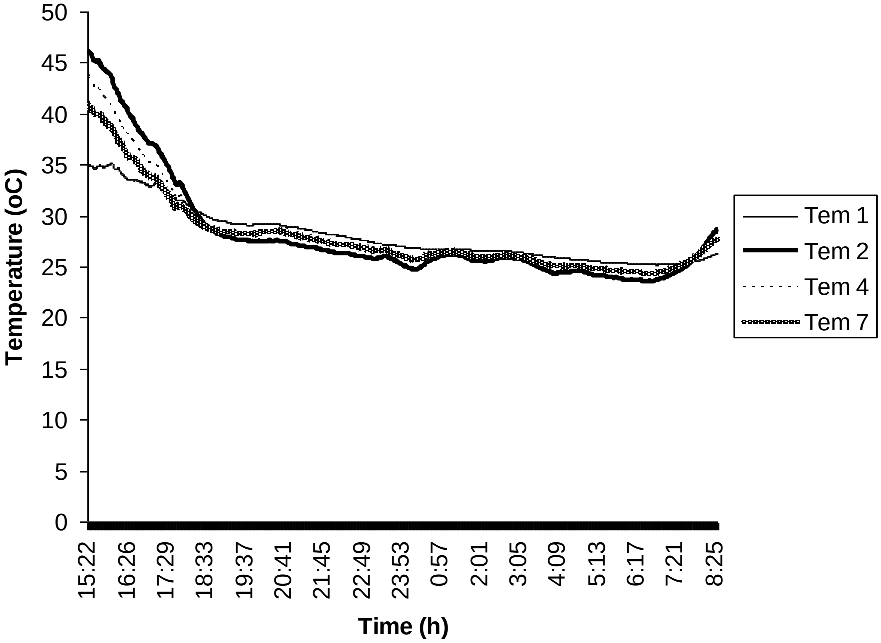

Figure 9. Temperature development vs time during the first day of the batch trial using brinjal

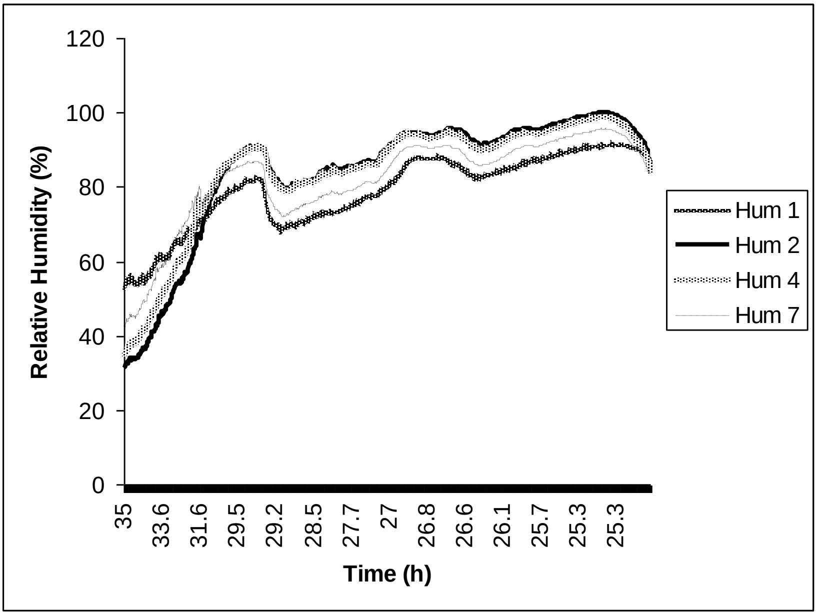

Figure 10. Humidity development vs time during the first day

These factors enhance the formation of unfavorable physicochemical changes within 72 -84 hours of jak fruit and brinjal drying trial perods in the present study. Poor colour development of the jak fuit may be due to prolonged exposure to the direct sun light. Research reported [15] has found, in his study, that photo protected solar drying resulted in better carotene retention and storage stability of the product than the light exposed drying. The rate of most browning reactions is greatly dependent upon the combined effect of time, temperature, and the medium -level moisture content of the food material thus the drying environment of the drier was more favourable for this to occur. High degree of shrinkage is a case of a slow rate of drying. Inability of the drier to control the excessive temperature development causes over-drying and caramelization [12], [13].

According to Lof [15], a large amount of air at reasonably low relative humidity must be used in hot drying process because of the low heat capacity of air and latent heat of vaporization of water. In case of solar dryers, the airflow rate through the collector is a prime factor, which regulates collector efficiency and drying bed temperature.

Because the solar panel was directly coupled to air blowers in this present study, air flow rate was directly proportional to the solar radiation intensity. With the increase of airflow rate, the outlet air temperature decreases, but the collector efficiency increases. By direct coupling of the solar panel to the fans showed relatively high temperature development during morning and evening even under low solar radiation intensities. Therefore, a system that direct couples solar panel with the fans is suitable to maintain temperature around optimum level during morning and evening. However, during noon the capacity and electrical power generation of the used solar panel was not sufficient enough to operate fans at high speed to flush of the excess heat development. Thermostat coupled with fans to a battery system and a solar panel coupled to a battery was tested to explore the possibility of controlling the excess temperature developed during the noon time. This kind of system is good to drying with intervals between two batches in order to re-charge the battery between intervals. Three car radiator fans (12 VDC) of 12 inches diameter were sufficient and attached to the drier with regulators in order to maintain the recommended air flow rate i.e. $1200 m^3/hr$ [4]. Further, testing indicated that by covering the first half-length of the collector, using a solar radiation reflector, excess temperature development inside the drying chamber could be controlled without changing the fan speed. By this way there is a possibility of developing automated temperature control system without changing the air flow rate.

The results of experimental tests carried out on the prototype dryer have shown that reduction of moisture content of crops to their safe storage level can be achieved compared to the sun drying and other advanced dehydration methods. Losses due to adverse environmental conditions (rain, dust, rodents) with sun drying were eliminated and drying time significantly reduced so that more crops could be dried in a given time. It is therefore safe to say that solar tunnel dryer prototype is technically feasible and effective alternatives to the Sri Lanka's environment than traditional sun drying method.

Test runs were carried out during the hottest and sunny periods of the Wet Zone of Sri Lanka, during February and March, where solar resources are most abundant. However, weather conditions mostly vary in other periods having mild to heavy rains followed by cloudy periods and these weather conditions may adversely affect to products quality. In case of dehydration of fruits and vegetables, organoleptic parameters determine the market acceptance, especially fruits to be consumed as snacks. Most of commercial hot air driers complete a batch of drying within a six-to-twelve-hour periods, giving acceptable quality. The solar tunnel drier must be able to complete a batch of product within twenty-four hours or less than that in order to have good products quality parameters complying with market standards requirements. For this, an alternative heat source and proper drying air controlling system need to be attached to the solar tunnel dryer.

Conclusion

The prototype solar tunnel dryer performed satisfactorily in temperature development to meet required temperature ranges for fruits and vegetable drying and hygienical conditions for products development and therefore, the dryer is technically feasible compared to open sun drying. Absence of heat during the nights, low temperature developments due to low sunshine duration are major factors for lengthening of total drying duration causing to poor organoleptic qualities of dehydrated products. A supplementary heating system is necessary to continue dehydration during night time and low sunshine hours in the day time with proper drying air controlling system to convert the dryer as a viable drying system.

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