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Quality Enhancement of Dehydrated Products through the Modification of Solar Tunnel Dryer for Continuous Operation in Rural Communities

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Abstract Solar dehydration of food crops is an important area for the economic development of rural communities in Sri Lanka. However, the economic gain is marginal because of inadequate product quality and quantities achievable with present drying methods. Present solar dryers need a few days of drying to reduce the moisture content of perishables to safe levels causing unfavourable product qualities. In this study a solar tunnel dryer was modified by the attachment of a supplementary biomass heating source for day and night operation to shorten the drying duration and to preserve the product quality. The dryer was tested in five different locations in Sri Lanka using local perishables and spices with the participation of local communities. The dryer was well received by the rural sector as an alternative to traditional sun drying. The dehydrated products produced were of acceptable quality in terms of sensory parameters and market acceptability.

Keywords Solar Dryer, Dehydration Technologies, Innovations, Rural Community, Technology Transfer

1. Introduction

Innovation and technological progress in energy sector is an integral part of economic development in any country. In the long term the ability to develop technology and to manage technological changes effectively is decisive in determining a country's international competitiveness and capacity to grow[1]. The technological growth and the diffusion of economic activities to the rural areas is the key to alleviate poverty and establish a knowledge based economy[2].

Sri Lanka is both a producer and a consumer of perishables. Today, agricultural crop production has been stimulated by increased demand for raw materials for dehydration and processing. Country will have a promising future in many competitive world food markets, provided a proper technology is introduced to enhance the food product quality and variety. Locally, food dehydration serves as a preventive measure for food scarcity as well as a means of generating high income through value added production. The cost and the quality are prime important factors in food dehydration as it is purely an energy process. In contrast to this situation, however, in the rural sector of Sri Lanka, at farmer level, open air sun drying of perishables is practiced which causes many problems. Open sun drying is a time consuming, with a likelihood of contamination, infestation and microbial attack. Compared to sun drying, solar dryers can generate higher air temperatures and lower relative humidity, which is both conducive to improved drying rates and lower final moisture contents of the dried product. As a result, the risk of spoilage is reduced, both during the drying process and in the storage. Even though required quality standards can be achieved by using electrical dryers, it is not economically feasible due to high cost and non-availability of national grid connection in the rural sector[3]. In Sri Lanka the consumption of petroleum and electricity in rural sector agriculture based industries has increased[4], but the use of these energy sources for dehydration industry at community level is not viable at present.

Under these circumstances, food dehydration industry has shown a little progress in spite of its great potential for rural development. The only viable option to rectify this situation is to develop dehydration technologies with the use of renewable energy sources[5, 6], especially the solar[7–11] as it has the potential of fulfilling the energy needs in the rural sector without much efforts[12, 13]. In Sri Lanka, except in the mountain regions and particularly in the dry zone a great potential exists to utilize solar energy[14,15] for dehydration of fruits and vegetables. In spite of this, a penetration of solar dehydration technology into these areas is very minimal. Hence, the problems associated with solar dried fruits and vegetables remain unsolved due to lack of efforts in problem identification and proper technology transfer.

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Many solar dryers, in the absence of a proper mechanism to control extended drying periods due to the absence of heat during night time, produce dehydrated products with poor organoleptic qualities[16,17]. The solution to operate the solar dryer during non-available periods of solar radiation is to use a supplementary heat source, and obviously it should be biomass or fuel wood as it is abundant with a little cost in the rural areas of Sri Lanka. The main focus in the present study was to investigate the prototype solar tunnel dryer developed by the University of Hohenheim[18], and to modify it to suit for local requirements.

In Sri Lanka fuel wood is used extensively in many industrial heat energy requirements including food processing. From the total energy needs of the industrial sector[3], 72% are met from fuel wood. In a study by carried out by the Swedish International Development Cooperation with the Asian Institute of Technology, on Energy, Environment and Climate Change in Sri Lanka, the non-plantation bio energy potential was estimated at 123PJ increasing up to 133PJ by the year 2010. The petroleum consumption for the period was estimated at only 106PJ. The annual energy potential of plantation biomass is estimated to vary from 30 to 150PJ in 2010. It is projected that the total energy consumption in Sri Lanka in 2010 will be 425PJ; thus the plantation biomass could supply about 7% to 32 % total energy consumption in 2010[19]. Therefore, fuel wood was favourably considered in this study as a supplementary heat source in the development of continuous solar dryer.

In the commercialization process of solar dehydration, business development has a crucial role to play. It manages the risk of new technology based enterprise by creating a business environment for development as well as assisting in the speedy commercialization of research out puts. In some instances a direct transfer method emanating from technology is little used in practice because of weak or nonexistent links between technology developing institutions and potential users. It is difficult to predict whether a particular technology would be successful in commercial level due to market forces that play a major role in determining success[1], of solar dehydration of foods. Governments have shown an effective progress as a major role player in facilitating these transformations, and clustering of business and net working. However, a proper coordination is required among the relevant government authorities to ensure that development strategies in rural sector producers are in line with the government policy. Therefore, recognized expertise and experience is needed to surmount these obstacles.

The objective of this study was to develop a commercial solar dryer based on tunnel dryer initially developed by the University of Hohenheim to meet drying requirements of the rural communities of Sri Lanka, with the possibility of day and night operation. Further, this study specifically addresses transferring of proposed solar dehydration technology, testing the performance in the rural sector and commercialization of the process to change from present open sun drying practice to solar dehydration. Thus, to identify the field problems that stands as obstacles for the speedy adoption of the technology for commercialization of the dehydration technology.

2. Materials and Methods

A prototype of the Hohenheim solar tunnel dryer (Figure 1) was assembled at Industrial Technology Institute (ITI) in Colombo at East-West direction. A photovoltaic solar panel (model BP 255) was used to power two axial fans of 12V each to generate an air flow of $0.25m^3s^{-1}$ through the drying bed. The temperature, humidity and air velocity along the drying length and across the tunnel were measured under no load conditions. The temperature and humidity sensor locations in the dryer are given in Figure 2. The temperature and relative humidity of the ambient air was measured by the sensor No. 1. The experiment was repeated three times to confirm the results.

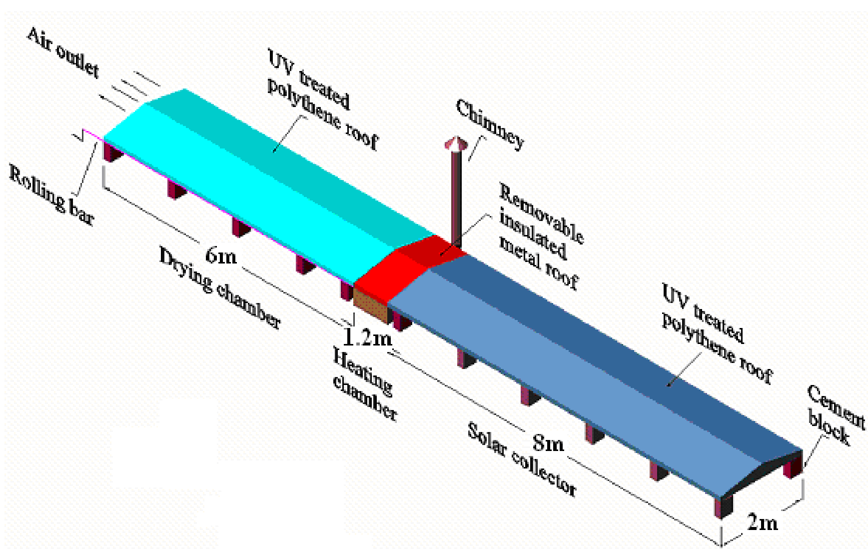

Figure 1. Schematic diagram of the modified solar tunnel dryer (Prototype solar tunnel dryer had no heating chamber)

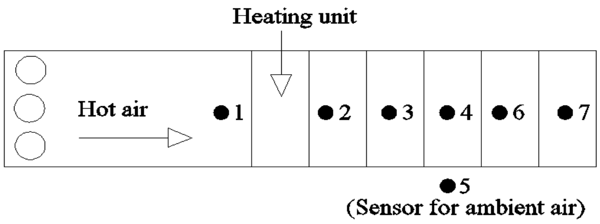

Figure 2. Locations of temperature and humidity sensors

The prototype solar tunnel dryer was modified by the attachment of a supplementary heating unit as shown in Figure1 to facilitate the continuous operation. The heating unit was fabricated consisting of a combustion chamber, heat exchanging bottom plate, removable roof and a chimney. This unit was installed between the collector and the drying section of the proto-type solar tunnel dryer. In this design, the width of the bottom plate equals the width of the dryer. The thickness of the bottom plate was taken as 4mm. Design calculation was carried out to select the optimum length of the bottom plate in order to transfer required thermal heat to evaporate the moisture of the product in the drying chamber per unit time. Trials were carried out with conventional barrel type saw dust stove with different capacities (40cm diameter and 60 cm in height to 60 cm diameter and 70cm in height) to test the drying air temperature and humidity development.

A batch trial was carried out using pineapple (*Ananas cosmos*) fruits. Fruits were peeled and cut into angular slices with 7 - 8 mm in thickness. Slices were dipped in 0.1% sodium meta-bisulphite and 0.3% citric acid solutions respectively for 10 minutes.

Drained slices were placed on the drying bed at 12.00 noon. The temperature and the humidity developments in the dryer were measured using the EnviroMon Data Logger with temperature/humidity sensors positioned at different locations similar to that of no-load test (Figure 2). The moisture content of the drying product was determined at two-hour intervals overing the entire length (5.5m) of the drying chamber with samples drawn at 1m intervals. Dried pineapples were removed from the dryer at 12.00 noon on the second day. Dried products were subjected to a semi trained taste panel. The drying trial was repeated using same quantity of pineapple. Batch trials with papaya (*Carica papaya)*, mango (*Mangifera indica*), and jak-fruit (*Artocarpus heterophyllus*) were also conducted to assess the applicability of the operation of the modified dryer for a variety of fruits. Thus, characteristics of the different dried fruits were compared with the standards developed for dehydrated products with respect to physico-chemical, microbiological and organoleptic parameters of the products.

After initial tests, the modified solar tunnel dryer was installed for field demonstration and training the target groups at two different ecological zones of the country, namely *Rajanganaya* and *Monaragala*. In addition, the dryer was introduced to three other areas, namely *Marawila*, *Giriulla*, and *Buddama,* after completing the field test runs (Figure 3). The target groups consisted of small holder individual farmers and cooperative producers linked to the VIDATHA resource centers, a government sponsored community centers for technology transfer in rural areas of Sri Lanka. Raw materials for drying purposes were purchased from small scale producers in the respective areas.

In the field construction, further modifications were made to the dryer in order to reduce the material and fabrication cost to suit for local construction materials and technical know-how. The supportive structures of the drying and the collector beds of the dryer was made of angle iron bars on which black polythene layer followed by aluminium insulation foil and corrugated thin galvanized sheets were laid. Length-wise support was made of galvanized sheets. Rest of the construction was the same as that in the prototype dryer.

Figure 3. Locations of dryer installation in Sri Lanka

Principles of dehydration, operating system of the modified dryer, processing of raw materials including pre-treatments and recommended slice thickness, storage, packaging, management of hygienic conditions and maintenance of optimum quality were the areas covered under technology transfer programme. The maturity stages of pineapple, papaya and mango for the dehydration were 10% to 20%, 60% and 40% of yellowing of the skin color respectively.

The participants were educated on quality standards of final products, cost minimizing practices, utilization of crop potential, alternate uses, value addition and innovative areas for product development, together with linkages to large companies and competitiveness as key issues of enterprise and marketing development. Whole-lime dehydration was carried out to test the dryer as these areas are well-known for growing lime. Full matured green color lime was used.

3. Results and Discussion

3.1. No-load Tests

Test trials of the prototype dryer and the modified dryer were carried out at the ITI premises in Colombo prior to the field testing in remote rural areas. The solar radiation intensity and temperature/humidity build up inside the drying chamber of the modified dryer in relation to sensor number 5 under no-load in a normal hot sunny day is presented in Figure 4.

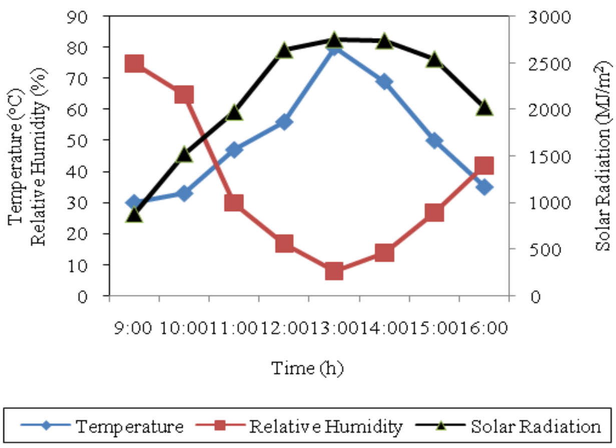

Figure 4. Solar radiation, temperature and relative humidity variation with time under no-load condition of the modified tunnel dryer

The temperature of the drying bed gradually increased from morning and reached its peak value at around 1.00pm and then gradually decreased in phase with solar radiation intensity.

3.2. Field Tests on Modified Dryer

During the solar hours of the trial period of the first day, products were exposed to high temperature (Figures 5 and 6). The initial airflow rate was in the range 0.30 - 0.33 m^3s^{-1} (0.8 - 0.9 ms^{-1} air velocity) and gradually it was lowered to 0.08 - 0.09m^3s^{-1} (0.2-0.24ms^{-1} air velocity) towards evening. Thereafter, this airflow rate was maintained throughout the night. In the morning of the second day, the airflow rate was gradually increased from 0.09m^3s^{-1} to 0.22m^3s^{-1} (0.24ms^{-1} to 0.6ms^{-1} air velocity) and it was maintained until the end of the trial.

Because of this gradual increment of airflow rate and the increasing solar intensity during the morning to noon of the second day, the temperature inside the drying bed was increased (Figure 6). During the night time, the temperature build up in the drying chamber was from 40℃ to 48℃. An important factor is that despite the absence of an optimum temperature level for drying i.e. 55℃, the supplementary heat source has been able to maintain the 22-23 ℃ temperature difference between the ambient and drying air during the night. Because of this heat, the relative humidity of the drying chamber lowered to 35-40% in the night (Figure 6). This drying potential was adequate to avoid the moisture re-absorption by the semidried products during the night and to reduce the moisture content to 30 to 20% on average.

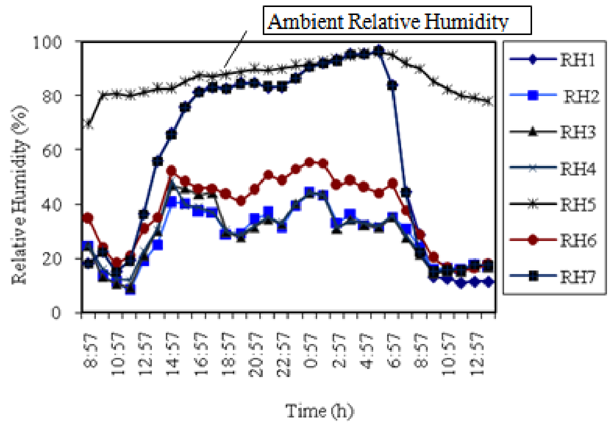

Figure 5. Variation of relative humidity with time

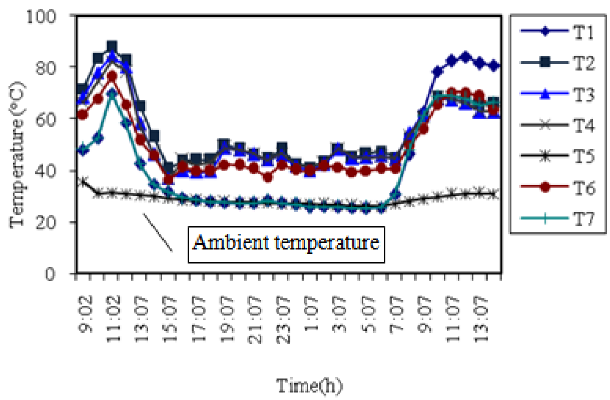

Figure 6. Variation of temperature with time

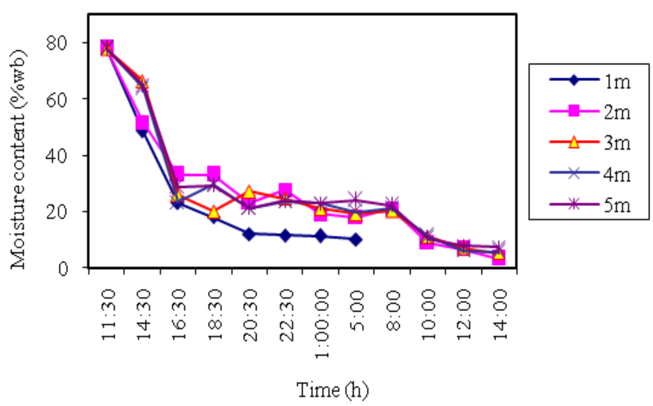

Figure 7. Variation moisture content of pineapple with time along the drying bed

3.3. Sensory Analysis

The results of sensory evaluation for different fruits are presented in Table 1.

Table 1. Results of Sensory Evaluation

Fruit	Sensory character	Score	
		Mean	SD (±)
Pineapple	Color	7.1	1.4
	flavor	7.5	1.3
	taste	8.2	1.0
	texture	6.7	2.3
	overall	7.6	1.1
Mango *Betti*	color	7.5	1.6
	flavor	6.5	1.7
	taste	6.3	1.6
	texture	5.8	2.0
	overall	6.3	1.7
Mango *Karthakolomban*	color	6.7	1.5
	flavor	6.3	2.2
	taste	6.7	1.9
	texture	6.6	1.6
	overall	6.8	1.6
Papaya	color	7.6	1.5
	flavor	6.5	2.2
	taste	7.0	1.8
	texture	6.5	2.1
	overall	7.0	1.8
Jak fruit - Uncooked	color	7.8	1.3
	flavor	7.2	0.8
	taste	7.1	0.9
	texture	7.2	0.8
	overall	7.6	1.0
Jak fruit Cooked	color	7.4	1.9
	flavor	7.3	1.2
	taste	7.5	1.3
	texture	8.1	0.6
	overall	7.7	0.6

According to the results of sensory evaluation carried out for dehydrated jak fruit, pineapple, mango and papaya based on 9- point hedonic scale (Table 1), results indicated that the modified solar tunnel dryer was capable of producing dehydrated fruits without off flavours and odour. Results indicated that the supplementary heating chamber promote the continuous drying during the night by the combined effect of preventing the moisture re-absorption and effecting further drying. In addition, the modified solar dryer prevented the product from direct contact with the smoke, and thereby it was possible to produce dehydrated pineapple similar to the quality of dehydrated pineapple, papaya, mango and jak fruit produced by commercial electric dryers.

At initial stages, the viability of this venture enterprise depends on intensive assistance and protection to start ups, so as to nurture and compete in the market[1, 2]. Technical change depends upon the action and decisions of a population of individuals each of whom has a personal propensity for risk taking. Deliberate efforts should be made to persuade recognized design heroes to adopt and promote energy efficient technology in the hope that it will inspire others to follow the suit[20]. A specific system or role model, that must be an important instrument in accelerating the transfer of technology incubation and commercialization, should be introduced in order to address the challenges. Such a system should be intended to brighten the survival prospects of start-ups by providing the right ambience, the needed infrastructure and professional services at the time when they are most vulnerable. Strategies are essential to develop entrepreneurship as well as to promote efficiencies.

The reports on information of drying trials carried out independently by users for a period of six months sent by relevant officers of *Monaragala* and *Rajanganaya* VIDATHA Resource Centers are given in Tables 2 and 3. Reports showed that other than the dehydration of pineapple, mango, papaya and jak fruit, the dryer has been used to dehydration a variety of commodities. Figure 8 shows one of the dryers installed for field trials.

Figure 8. Solar dryer installed for field trials

However, the results showed that the dryer took longer drying durations for pineapple and papaya in *Monaragala* and for mango and papaya in *Rajanganaya*. Compared to other commodities fewer quantities of pineapple, papaya and mango were dried in *Rajanganaya*.

The dryer was also found to be capable of producing brown lime, which is an incomplete form of dehydrated lime for the export market[21], which demands dehydrated black lime.

In the field trials the complete process of technology transfer was established. This was done through three progressive steps, namely the identification and screening of small entrepreneurs in case study areas, the initiation of enterprise development and the initiation of marketing. The screening of small entrepreneurs was based on the enthusiasm to start up, training received, ground level experience of agricultural enterprise and willingness to invest initial capital.

Table 2. Report on the Usage of Tunnel Dryer at *Monaragala* VIDATHA Center

Item	No. of trials	Quantity per trial (kg)	Participants	Quality of products
Lime	04 04 02	10 100 250	120 farmers and VIDATHA staff	Acceptable. 03 days per batch.. Need improvements to produce black lime
Jak fruit	03 02	05 15	30 farmers and VIDATHA staff	Discoloration appeared in the final product
Jak fruit seed	01	4	01 farmer with VIDATHA staff	Acceptable
Pineapple and papaya	01	5	01 businessmen and VIDATHA staff	Drying speed reduced due to rain Bad in quality
Raw mango	01	2	01 farmer and VIDATHA staff	Acceptable
Bilimbi	01	2	01 farmer and VIDATHA staff	Acceptable
Scraped coconut	04	4	02 farmer and VIDATHA staff	Acceptable

Table 3. Report on the Usage of Tunnel Dryer at *Rajanganaya* VIDATHA Center

Item	No. of trials	Quantity per trial (kg)	Participants	Quality of products
Breadfruit	02	10	VIDATHA staff and farmers	Acceptable
Jak fruit	15	40		
Brinjal	05	05		
Bitter gourd	03	07		
Banana	03	10		
Manioc	03	10		
Lime	05	250	VIDATHA staff	Acceptable
Mango	02	05		Acceptable. Took very long time
Papaya	03	15		Acceptable
Pineapple	02	10		Acceptable. Took very long time
Fish	02	50		Acceptable

Under the two case studies related to private sector entrepreneurs, enterprise development and market facilities were not provided as they did have their own systems and were well experienced. Two case studies with rural sector small producers in *Rajanganaya* and *Monaragala* were carried out with VIDATHA centers of these areas which come under the Ministry of Science and Technology and collaboratively supervised by regional secretariats in order to link government agencies for effectiveness of the study. Agro-climatic zones and intensity of agricultural enterprises were the selection criteria for demonstration sites.

In the field trials longer drying duration of pineapple and papaya was due to the dryer installed in a wet area of the *Monaragala* district. Discoloration of dehydrated jak fruit was shown in the field trials at *Monaragala* which *was* due to bleaching of original color by the direct exposure to solar radiation for longer hours and lack of recommended pre-treatments. Longer drying time taken for dehydration of mango and pineapple at *Rajanganaya,* and pineapple and papaya in *Monaragala* indicated that close supervision is essential in the initial stage to ensure that the recommended procedures are strictly followed in the start up.

Drying of fish takes a longer time because of the problem of case hardening and use of whole fish instead of slices. Results of the fish drying trials in *Rajanganaya* indicated that climatic conditions of *Rajanganaya* were far more suitable for drying operations than the location of *Monaragala*. Drying trials carried out in *Monaragala* and *Rajanganaya* showed that the temperature development by the dryer (70-80℃) was not sufficient in order to produce black lime but for dehydrated brown lime.

In the wet zone the use of solar energy is limited due to cloud cover and also high humidity retards the drying process. Numbers of possible drying cycles also decrease because of the narrow gap between two rain seasons[22]. Results reported here with regard to *Monaragala* indicated that the cloud cover and rainy weather increased the drying time of most of the sugar containing fruits such as pineapple, mango and papaya.

During the period of technology transfer and field surveys, it was possible to identify several operational problems that threaten to accelerate start up of this enterprise. In one way, manageable quantity of raw materials and manageable dryer capacity can cater to the problem of maintaining of the quality of final product. In this regard, it was noticed that construction of half sized drying chamber is recommended when the income of the farmers and available manpower to process raw materials are considered. Therefore, in the beginning, 3m length of the drying bed is sufficient. Material cost of the supportive structure, level of insulation of the collector and the fan box can be reduced to some extent.

Report received from the trial areas indicated that use of solar drying system can be popularized gradually to replace the conventional sun drying, reflecting technological changes in drying industry in the rural areas. Reduction of initial size of the drying bed area of the modified dryer, reduction of size of slices of pineapple, mango and papaya will increase the productivity of the system thus removing the technological barrier for a viable dehydration system.

If the price of natural gas or other fuels increases markedly, and the price of solar collectors becomes less expensive, the use of solar collectors and solar dryers could readily become cost effective. However, solar energy is available on an intermittent basis and therefore provides energy for drying foods, at present for small – scale operations. With regard to the economics of dehydration, solar drying of agricultural products appears to be financially attractive for cash crops such as tea, and spices and it may even be possible to justify the use of a high cost solar drying system in these cases. The problem is that the economic feasibility of using solar energy for drying highly perishables products such as vegetables and fruits is critical[6]. With a great effort, the present study challenges this research question successfully.

However, solar dehydration is, into some extent, an uncontrolled drying process; hence, it may significantly affect the structural properties of the products. Therefore, solar-dehydrated fruits showed low storage stability than other dehydrated fruits and vegetables[23].

However, in order to accelerate this technological change and enterprise development it is necessary to introduce market facilities for solar dehydrated products[23, 24]. System of innovation are networks of institutions, public or private, whose activities and interactions should be initiation, importation, modifications and diffusion of new technologies. Designing and implementing a significant long-term change may require joint action by many different actors-grass roots level groups, nongovernmental organizations, and private corporations. The capacity to affect large numbers of people is an important aspect for effectiveness, and scaling up to reach thousands of people is no small achievement[4, 25].

4. Conclusions

A modification to the prototype of the Hohenheim solar tunnel dryer was made by the attachment of a supplementary heat source provided by biomass stoves and successfully tested. The supplementary heating unit proved to be easy to construct, and enabled easy handling during operation. All components can be made in a simple workshop. The heating unit was successfully operated using barrel stoves with saw dust as the most suitable biomass fuel available in the rural environment.

Modification of the prototype dryer significantly reduced the drying duration by 1-1.5 days compared to prototype dryer. Physicochemical, microbiological and organoleptic parameters of dehydrated pineapple, papaya, mango and jak fruit from the modified dryer showed that the dryer was able to produce dehydrated products to match market standards.

Field trials carried out by end users in remote rural areas showed that the quality of dehydrated products obtained from the modified dryer was acceptable quality. Hence the modified dryer is recommended for commercial drying requirements of perishables and spices in rural areas of dry zone of Sri Lanka.

The use of powdered form of dehydrated fruits, vegetables, medicinal herbs and spices in the production of a variety of food items can be considered as supportive areas to boost the development of the dehydration industry. Supply of raw material inputs at affordable prices, market standards and facilitating links between these rural producers and the established private sector distributors with institutional mechanisms in place are vital for the establishment of solar food drying as a rural industry.

The introduction of the modified tunnel dryer in a large scale, but with a proper training on the construction and the art of use certainly provides the rural community to successfully practice food dehydration using renewable energies in comparable with those produced with hot air dehydration systems.

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