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Experimental and Comparison Studies on Drying Characteristics of Sliced Cut Tomatoes and Cube Cut Tomatoes

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Abstract: A natural convection solar greenhouse tunnel dryer was designed and developed for studying and comparing the drying characteristics of sliced cut tomatoes and cube cut tomatoes. Three experimental runs with 30 kgs of tomatoes were carried out in the dryer during the month of June 2014. The performance of the dryer was studied (drying time and product quality) in comparison with open sun drying method. The absolute geometry of cut for the products to be dried was also revealed. It was found that the solar tunnel greenhouse dryer took only 29 hours for reducing the moisture content of sliced cut tomatoes from 90% (w.b.) to 9% (w.b.) and 56 hours for reducing the moisture content of cube cut tomatoes from 90% (w.b.) to 9% (w.b.) whereas the open sun drying took 74 hours and 123 hours for the same. The sliced cut tomatoes were dried at an earlier time than the cube cut tomatoes in both solar tunnel dryer and open sun drying due to the larger area of exposure to surrounding hot air which allowed higher rate of moisture removal from the tomatoes. Thus, the optimum geometry of cut for ensuring quicker drying of tomatoes is the sliced cut of the tomatoes. Also, the quality of dried tomatoes produced from solar tunnel dryer is much superior compared to that of open sun drying.

***Index Terms**: Cube cut tomatoes, moisture content, open sun drying, quality, sliced cut tomatoes, solar tunnel dryer.*

I. INTRODUCTION

Tomato is the world's most commercially produced vegetable [1]. Tomato is considered among seven major vegetables in the world, (onion, garlic, cauliflower, green peas, cabbage, tomato and green beans [2]. It is a rich source of minerals, vitamins, organic acid, and dietary fiber [3]. Global tomato production reached 146 million tons in 2011, according to FAOSTAT, and therefore considered the most important vegetable grown in the world. Tomatoes are rich in photochemical lycopene, which is a powerful antioxidant. The most abundant carotenoid in tomatoes has been promoting several research activities on fresh tomato and tomato products. Tomatoes help in the prevention of cardio-vascular disease and enhance cancer–fighting abilities. The most abundant carotenoid in tomatoes has been promoting several research activities on fresh tomato and tomato products [4] & [5]. Reference [6] reveals that dehydration of tomatoes is a process commonly used to preserve the product and extend shelf-life. Tomato is one of the most profitable cash crops grown among Indian small scale farmers. The average consumption pattern of tomatoes in Indian diet is very high as they form an integral ingredient of ethnic cultural cuisine. Since tomato is highly perishable in the fresh state, it will leads to wastage and losses during the harvesting period. Tomatoes produced in the peak seasons are either consumed fresh, sold at relatively cheap prices, or are allowed to go waste [7]. The prevention of the losses and wastage is of major interest especially when there is a subsequent imbalance in supply and demand at the harvesting off-season. Among the processing methods for tomato preservation, drying is one of the most convenient since product water content is greatly lowered thus preventing microbial spoilage [8]. In addition, final product weight and volume are considerably reduced after dehydration, which may account for important savings in transport and storage costs [3]. Many experiments were done to process tomatoes by the foam-mat technique or by spray drying. Trials to dry whole tomatoes were also undertaken [9]. The demand for a wide range of processed tomato products has increased remarkably both in the retail and the food ingredient markets [10]. In agricultural countries like India, drying of agricultural products has always been of much importance for its preservation. Most of the agricultural products contain the highest moisture content of 25-80% which is undesirable for long preservation. Because of this high moisture content, bacterial and fungal growth is rapid in crops. It is noted that moisture content of crops to a certain level lowers the effects of bacteria, enzymes and yeasts. So, it is essential to reduce the moisture content in food if a longer preservation is required. In India, drying is achieved in the natural method by spreading out the material on the ground. In this way, there are many disadvantages like low quality and hygienic problems. In the open sun drying, the problem of being products unprotected from windborne dirt and dust, rain will leads to troubles such as infestation by insects, rodents and other animals which in turn degrade the quality of food to a greater extent. The resulting loss of food quality in the dried products may have negative effect on trade potential and economical worth. A solar tunnel dryer was designed and constructed that basically operates on the principle of green house effect which overcomes the practical difficulties of open sun drying.

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A greenhouse is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favourable micro-climate for higher productivity. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area. This heat is recovered at night to satisfy the heating needs of the green. The solar tunnel dryer, thus, absorbs all the radiation falling into the dryer and it will not emit the radiations back, acting as a solar trap. This trapping of radiation increases the temperature inside the dryer constantly and enhances a quick drying when compared with open sun drying. Many researches have been conducted on the mathematical modeling and experimental studies on thin layer solar drying processes of various vegetables and fruits, such as green bean [11], pistachio [12], red pepper [13], mint leaves [14], tarragon [15], potato [16], chilli pepper [17], carrot [18] and citrus aurantium leaves [19]. The drying process can be conducted by using several solar drying methods [20]. Solar dryers can cost effectively because relatively unskilled village artisans can construct, operate and maintain the dryers at minimum cost and locally available materials can be used for the construction [21]. Reference [22] studied drying of organic tomato by solar tunnel drying to obtain the final moisture content of 11.5% from 93% wet basis .The drying time was between 82 to 96 h and 106 to120 h for open sun drying. Crops of tomatoes have socioeconomic importance to families, gardeners, farmers, laborers, marketers, retailers, chefs and other workers and services in the food and restaurant industries. Various investigators have studied the greenhouse for crop drying [23], [24] & [25]. Reference [26] studied a solar dryer with a greenhouse as a collector for drying grapes. Reference [27] studied solar energy collection characteristics of a fibre reinforced plastic drying house for paddy drying.

This study was carried out to experimentally investigate the drying characteristics of sliced cut tomatoes and cube cut tomatoes in solar tunnel greenhouse dryer and open sun drying and also to compare the quality of tomatoes being dried in solar tunnel dryer and under open sun. The optimum geometry of cut for quicker drying of tomatoes was also studied. Various parameters such as relative humidity, temperature, velocity of air, solar intensity, moisture content & air flow rate of the samples (tomatoes) were calculated and compared accordingly for solar tunnel dried tomatoes and open sun dried tomatoes.

II. EXPERIMENTAL SECTION

Experiments were carried out under meteorological conditions of Pollachi (latitude, 10.39°N; longitude, 77.03°E) in India during the summer months of 2014. On the basis of measurement, sunshine duration at this location was measured to be about 11 h per day. However, potential sunshine duration is only 8 h per day (9.00 am- 5.00 pm) based on higher solar intensity.

III. SOLAR TUNNEL DRYER

An STD (Fig.1) as a community model solar tunnel greenhouse drier [4 m (W) x 10 m (L) x 3 m (H) at centre] was designed and constructed at Negamam village using locally available materials. Semicircular portion of drier was covered with UV (200µ) stabilized polyethylene film. No post was used inside the greenhouse, allowing a better use of inside space. Two exhaust fans (diam., 30cm) one at front and another at rear end, were fixed. Three exhaust vents with adjustable butterfly valves were provided at roof top. Inside drier, cement flooring was coated with black paint to improve its performance.

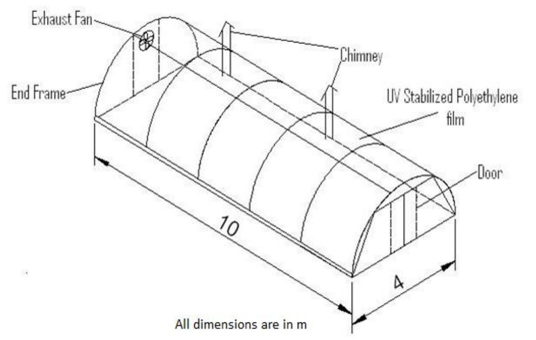

Fig.1 Solar tunnel greenhouse dryer

STD is provided with metallic racks for keeping the products in layers for drying. To investigate the influence of parameters affecting the performance of solar tunnel drier, various measuring devices were installed. A pyranometer was used to measure the incident solar radiation on the top of the roof of the green house. Thermocouples were used to measure air temperature at four different points inside the dryer and ambient air. To measure the relative humidity of the air, a hygrometer was employed. The electric signals from the thermocouples and the pyranometer were recorded with an 8- channel data logger. A sling psychrometer was also used to measure the dry bulb temperature and wet bulb temperature of the air.

IV. INSTRUMENTATION

Figures calibrated thermocouples (8 numbers, PT 100, uncertainty ±1%) were fixed at different locations inside drier to measure air temperature. Humidity sensors (4 numbers, uncertainty ±1%) were placed at different locations inside drier for measuring air humidity. Ambient humidity was calculated based on measured values of wet and dry bulb temperatures, using two calibrated thermometers, one covered with wet cloth. A solar intensity meter (Delta Ohm, Italy; uncertainty, ±10%) was used to measure instantaneous solar radiation. All temperature sensors, humidity sensors and solar intensity meter were connected to a computer through a data logger (Simex, Italy). Air velocity at drier exit was measured by using a vane type thermo-anemometer (Equinox, Germany; uncertainty ± 0.1%) was used for weighing samples.

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V. PRINCIPLE OF SOLAR TUNNEL GREENHOUSE DRYER

The solar radiation is transmitted into the drying chamber by the UV stabilized polyethylene film which provides the greenhouse effect. This film allows all the outside solar radiations to pass into the drying chamber and prevent the re radiation from the drying chamber to the outside and there by helps to accumulating the heat inside the drying chamber. Therefore, the temperature inside the drier is always more than the ambient temperature. This will helps to remove the moisture content of the product placed inside the dryer and therefore it gets dried.

VI. EXPERIMENTAL PROCEDURE

Experiments were conducted during 3-5th of June 2014 under meteorological conditions of Pollachi, India. Matured and good quality tomatoes were taken for the experiment and were cut into two specific geometries namely sliced cut (1.0 cm thick) and into quarters/cube cut (approximately 2.5cm radius). Initial moisture content was calculated by taking 10 different samples from different locations. Sliced cut tomatoes and cube cut tomatoes were loaded over the trays (porosity 90%) of drier unit. Then, exhaust fan was switched on to exhaust initial high humid air. Solar intensity, ambient wet and dry bulb temperatures were measured every 1 h interval till end of drying.

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VII. DATA ANALYSIS

A. Determination of Moisture Content

Samples (10g) were chopped from randomly selected 5 tomatoes and kept in a convective electrical oven, maintained at 105± 1°C for 5 h. Initial (m_i) and final mass (m_f) at time t of samples were recorded using electronic balance and repeated every 1 h interval till end of drying. Moisture content on wet basis (M_{wb}) is defined as

$$M_{wb} = (m_i - m_f) / m_i$$

where, m_i and m_f are initial and final weight of samples respectively.

VIII. RESULTS AND DISCUSSIONS

B. Variation of solar intensity and temperature with time

The fig.2 shows the variation of solar intensity, ambient temperature and dryer temperature during the experimental period (3-5th June, 2014). During the first day, the solar intensity varied between 313 W/m^2 and 717 W/m^2, the ambient temperature varied between 31°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 39°C and 61°C with a peak value of 61°C at around 1.00p.m. During the second day, the solar intensity varied between 305 W/m^2 and 737 W/m^2, the ambient temperature varied between 30°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 34°C and 63°C with a peak value of 63°C at around 1.00p.m. During the third day, the solar intensity varied between 320 W/m^2 and 720 W/m^2, the ambient temperature varied between 32°C and 39°C with a peak value of 39°C at around 1.00 p.m. and the dryer temperature varied between 41°C and 67°C with a peak value of 67°C at around 1.00p.m.It is clear from the figure that the dryer temperature was 22°C to 26°C more than the ambient temperature in all the three days of experiment which suggests that the products kept inside the drier are dried very effectively. Also, the drier temperature varied according to the solar intensity during this experimental period. The maximum solar radiation observed was about 737 W/m^2.

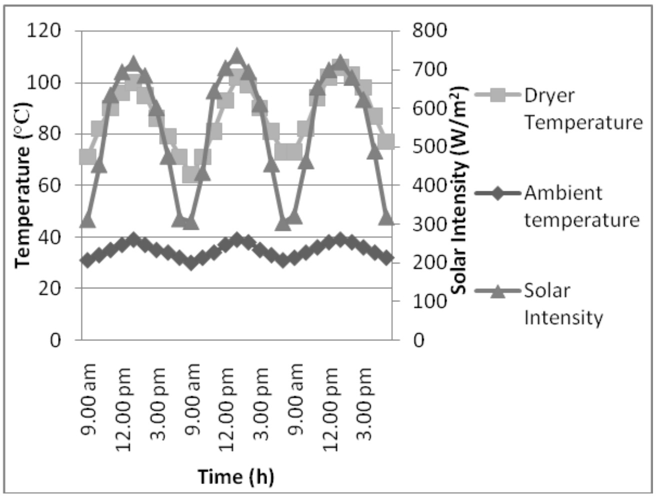

Fig.2. Variation of solar intensity and temperature with time

C. Variation of relative humidity with time

The fig.3 shows the variation of dryer relative humidity and ambient relative humidity during the experimental period. During the first day, the relative humidity of the dryer varied between 28% and 50% whereas the ambient relative humidity varies between 50 % and 75%.

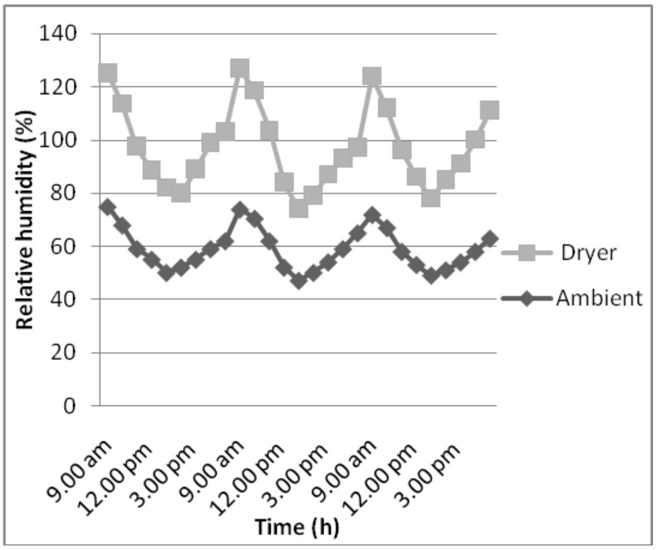

Fig.3 Variation of relative humidity with time

During the second day, the relative humidity of the dryer varied between 27% and 53% whereas the ambient relative humidity varied between 47% and 74%. During the third day, the relative humidity of

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the dryer varied between 29% and 52% whereas the ambient relative humidity varied between 49% and 72%. Because of the decreased relative humidity inside the dryer, all the time (due to the green house effect), the temperature inside the dryer was high which is sufficient enough to dry the tomatoes at an early time.

D. Variation of air velocity with time

The fig.4 shows the variation of ambient air velocity and Dryer air velocity during the two days of experimental period. During the first day, the ambient air velocity varied between 1.7 m/s and 3.5 m/s whereas the dryer air velocity varied between 1.3 m/s and 2.7 m/s.

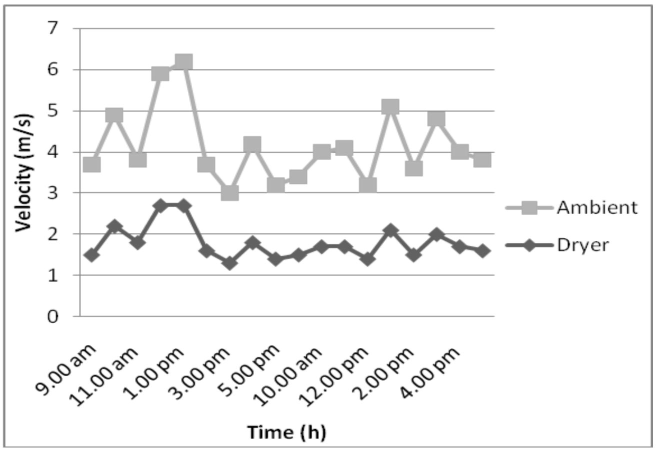

Fig.4 Variation of air velocity with time

During the second day, the ambient air velocity varied between 1.8 m/s and 3 m/s whereas the dryer air velocity varied between 1.4 m/s and 2.1 m/s which are quite lesser than the variation in first day. It was evident that the dryer air velocity is lesser than the ambient air velocity due to the buoyancy effect where there is no natural convection. This is the reason for the lower air velocity and increased drying rate inside the dryer.

E. Variation of air flow rate with time

The fig.5 shows the variation of air flow rate with time during the experimental period. During the first day, the air flow rate varied between 0.52 m^3/s and 1.08 m^3/s. During the second day, the air flow rate varied between 0.56 m^3/s and 0.88 m^3/s with a peak of m^3/s at p.m. The air flow rate variation in second day is lesser than that of first day and it varies accordingly with time.

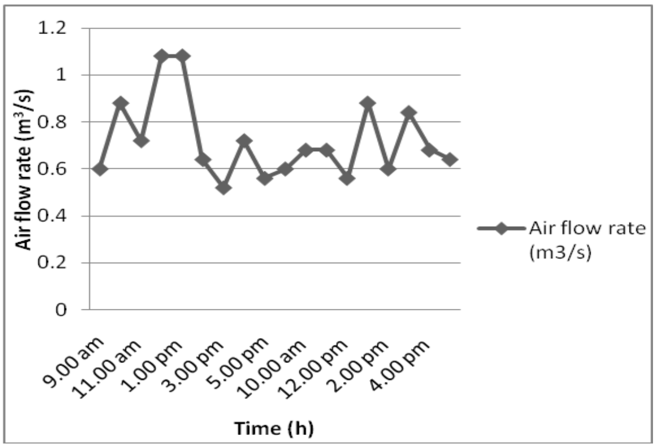

Fig.5 Variation of air flow rate with time

F. Variation of moisture content of sliced cut tomatoes with time

The fig.6 shows the variation of moisture content of sliced cut tomatoes dried inside the dryer and in the open sun during the experimental period. During the first day, the moisture content of these tomatoes inside the dryer reduced from 90% to 40% whereas for the open sun dried tomatoes, it is reduced to 56% from 90%. During the second day, the moisture content of the tomatoes inside the dryer reduced from 40% to 9% whereas for the open sun dried tomatoes, the moisture content is reduced from 56% to 30.5%. By the mid of second day, the moisture content of the tomatoes inside the dryer was reduced to 9% which was the maximum level of moisture removal from tomatoes.

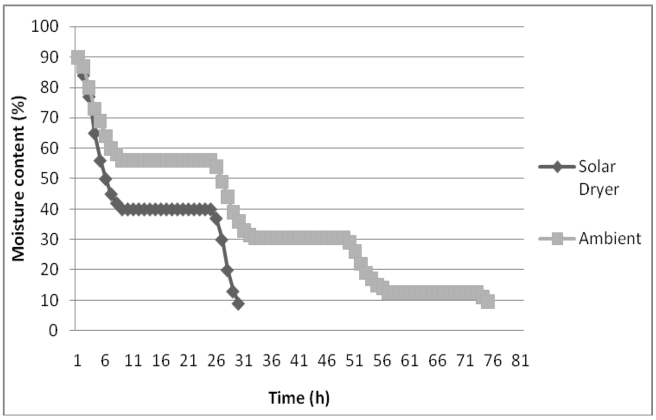

Fig.6 Variation of moisture content with time

During the third day and fourth day, the moisture content of open sun dried tomatoes reduced from 30.5% to 12.5% and from 12.5% to 9.5% respectively. In the open sun drying, the products has an initial moisture content of 90%, is reduced to 9.5% for time period of 74 hours, while in the solar tunnel dryer, the products which has an initial moisture content of 90%, is reduced to 9% for time period of only 29 hours. Thus, the solar dryer appears to be the effective and quicker method of drying of tomatoes (products) since the drying time is very less compared with open sun drying. This is due to the green house effect inside the solar tunnel dryer where the temperature inside the dyer keeps on increasing with decrease in relative humidity inside the dryer. Also, in both solar tunnel drying and open sun drying, the drying time of sliced cut tomatoes were less when compared with the cube cut tomatoes due to the larger surface area of exposure of the sliced cut tomatoes to the surrounding hot air. When the surface area of exposure is high, ultimately, the drying time will be less and the moisture removal rate will be high.

G. Variation of moisture content of cube cut tomatoes with time

The fig.7 shows the variation of moisture content of cube cut tomatoes dried inside the dryer and in the open sun during the experimental period. During the first day, the moisture content of the cube cut tomatoes inside the dryer reduced from 90% to 53.5% whereas for the open sun dried tomatoes, it is reduced from 90% to 65.5%.

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During the second day, the moisture content of these tomatoes inside the dryer reduced from 53.5% to 27.5% whereas for the open sun dried tomatoes, it is reduced from 65.5% to 46%. By the third day, the moisture content of the tomatoes inside the dryer was reduced to 9.5% which was the maximum level of moisture removal from tomatoes.

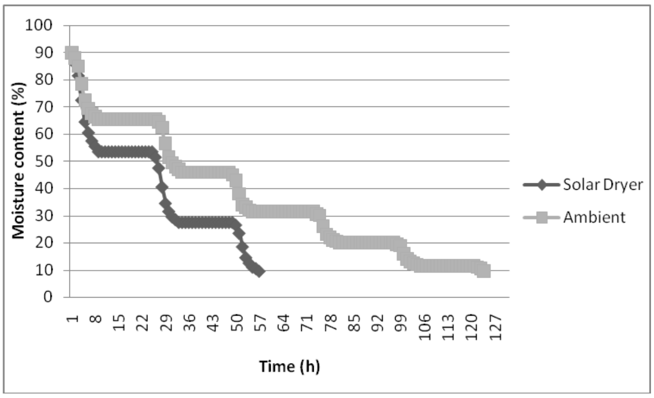

Fig.7 Variation of moisture content with time

During the third day, fourth day and fifth day of the experiment, the moisture content of open sun dried tomatoes reduced from 46% to 31.5%, from 31.5% to 20% and from 20% to 11.5% respectively. By the mid of the sixth day, the moisture content of the open sun dried tomatoes were reduced to 9.5% which is the maximum rate of moisture removal from tomatoes. In the open sun drying, the products has an initial moisture content of 90%, is reduced to 9.5% for time period of 123 hours, while in the solar tunnel dryer, the products which has an initial moisture content of 90%, is reduced to 9% for time period of 56 hours. Here, in both solar tunnel dyer and in open sun drying, the surface area of exposure of cube cut tomatoes to the surrounding hot air is very much less than that of sliced cut tomatoes which leads to an extended drying time and a slower rate of moisture removal which all in turn, paved the way for longer drying period.

IX. CONCLUSION

Experiments were conducted in a natural circulation solar tunnel greenhouse dryer in order to experimentally study the drying characteristics of sliced cut tomatoes and cube cut tomatoes in comparison with open sun drying during the month of June 2014. Three full scale trails were conducted with 30 kgs of tomato. It was found that the solar tunnel greenhouse dryer reduced the moisture content of sliced cut tomatoes and cube cut tomatoes from 90% (w.b.) to 9% (w.b.) in 29 hours and 56 hours whereas open sun drying method took 74 hours and 123 hours for reducing the moisture content of sliced cut tomatoes and cube cut tomatoes to the same level. It was clear that in both solar tunnel dryer and open sun drying method, the sliced cut tomatoes were dried at quicker rate than the cube cut tomatoes due to the lager area of exposure of sliced cut tomatoes to surrounding hot air which ensures higher rate of moisture removal and lesser drying time. Due to smaller surface area of exposure of cube cut tomatoes, the drying time is more and lesser rate of moisture removal from the tomatoes. The quality of dried tomato produced from solar tunnel greenhouse dryer was superior when compared to open sun dried tomato. Therefore, solar tunnel greenhouse dryers are more suitable for producing high quality dried agricultural products like tomatoes, chillies, grapes, coconuts etc. Also, it was found out that the tomatoes are to be cut into slices rather than any other geometries of cut in order to attain higher rate of moisture removal from the tomatoes and quicker drying of tomatoes.

Fig.8 Sliced cut tomatoes dried inside the solar tunnel dryer

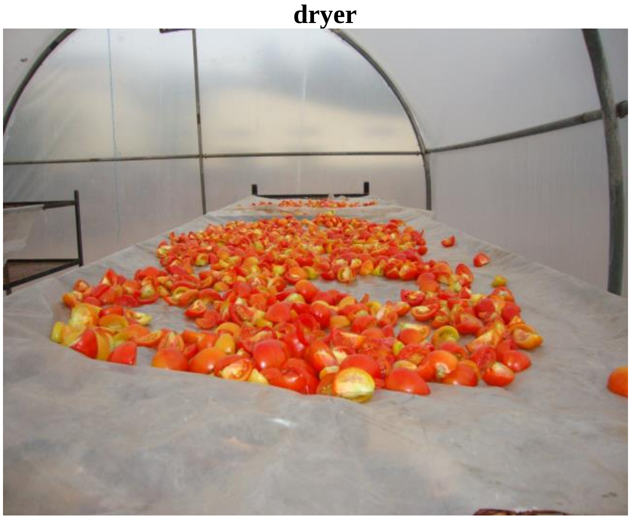

Fig.9 Cube cut tomatoes dried inside the solar tunnel dryer

The fig.8 & 9 shows the drying of sliced cut and cube cut tomatoes inside the solar tunnel dryer during the month of June, 2014

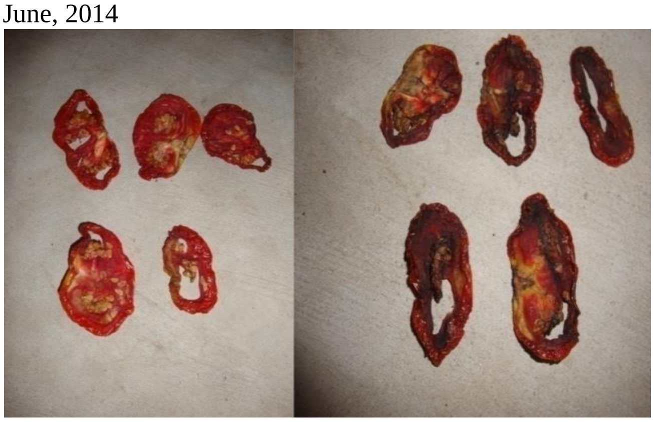

Fig.10 Quality comparison between open sun dried and solar tunnel dried tomatoes (sliced cut tomatoes)

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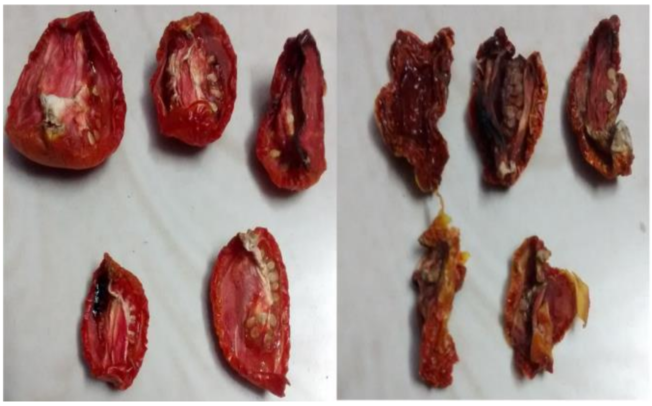

Fig.11 Quality comparison between open sun dried and solar tunnel dried tomatoes (cube cut tomatoes)

The fig.10 & 11 shows the comparison between solar tunnel dried and open sun dried tomatoes for both the sliced cut tomatoes and cube cut tomatoes. It was found that, in both the cases, the solar tunnel dried tomatoes were found to be superior to that of open sun dried tomatoes and also, the sliced cut tomatoes were found to be dried effectively without the spoilage of colour, texture etc. than the cube cut tomatoes.

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- Popularization of Solar Tunnel Dryers for Copra Production in Pollachi Region(Tamil Nadu) funded by Department of Science & Technology (Govt. of India, New Delhi.), 2011-13.
- Development of Vacuum Frying Technology for selected Fruits and Vegetables funded by Tamil Nadu State Council for Science and Technology (TNSCST), Chennai, 2009-2011.
- Improved Coconut post harvest technologies for empowering the women of Pollachi Region funded by Department of Science & Technology (Govt. of India, New Delhi.), 2007-2009.

Publications *(number only)*

Books	Research Papers/ Reports	General Articles	Patents	Others (Please specify)
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1	Indian Institute of Technology, Kharagpur, India	Ph.D. (Food Engg.)	1983
2	P.S.G.College of Technology, Madras University, India	M.Sc.(Engg.) (Production Engg.)	1975
3	N.S.S.College of Engineering, Kerala University, India	B.Sc.(Engg.) (Mech.Engg.)	1968

Research Experience in various institutions: (As a Principal Investigator)

- Popularization of Solar Tunnel Dryers for Copra Production in Pollachi Region(Tamil Nadu) funded by Department of Science & Technology (Govt. of India, New Delhi.), 2011-13.
- Improved Coconut post harvest technologies for empowering the women of Pollachi Region funded by Department of Science & Technology (Govt. of India, New Delhi.), 2007-2009.
- Consolidation of food security in south India.(Addressing out-reach activities in improved postharvest technologies) funded by CIDA in Collaboration with McGill University, Canada, 2002-2004.

Publications *(number only)*

Chapters in Books	Research Papers/ Reports	General Articles	Patents	Others (Please specify)
04	36	163	----------	------------