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# A Critical Review on Solar Dryers and It's Selection for Drying of Different Regional Food Products

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**ABSTRACT:** Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products; the major ones are canning, freezing, and dehydration. Among these, drying is especially suited for developing countries with poorly established low-temperature and thermal processing facilities. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, further processing and sanitation and is probably the oldest method of food preservation practiced by humankind. In this Paper, A comprehensive review of the drying principle with classification, Solar drying of different products using various solar dryers and other dryers and selection of solar dryers for drying of products is done. In addition to this, solar energy, Principles of Drying, classification of solar dryer is also studied.

**KEYWORDS:** Preservation, freezing, dehydration, sanitation.

## I. INTRODUCTION

In spite of being the first country to establish a ministry of non-conventional energy resources in 1980's, India is still backing huge energy issue. As a part of go-green campaign and global warming, it is our responsibility to investigate and understand the alternative sources of energy for the progress.

The country where agriculture holds the major economy, we pay less attention towards storage of the crop after harvest which is also a serious subject. Methods of preservation of food crops include canning, sugaring, salting, freezing, and dehydration, which might be an expensive affair to farmers in a country like India with a poor-framework for food storage.

If the production of renewable energy from the major renewable sources is not expensive, one can make best use out such abundant resources. So, one way of solving problem is to bring awareness among farmers in India and other Asian countries about the low-cost techniques and technologies that are beneficial in agriculture.

Solar energy is the abundant energy resource of the earth which can be used recurrently in such developing countries. Solar drying is one former technique used in drying the fruits, vegetables and agricultural food. Drying means moisture removal of the product. Drying preserves the food product for a long time and also it prevents the product from contamination. The different types of solar drying are direct solar drying, indirect solar drying & mixed mode solar drying. In the initial days direct sun drying technique is popularly used, but there are some disadvantages such as:

- The time required for drying is more as compared to other methods. Output product quality is poor.
- The product obtained is contaminated by dirt, dust as well as by bacteria. Drying rate is poor in sun or natural drying.

- To overcome this, indirect cabinet type of solar dryer is used for drying the different food products.

## II. REVIEW OF LITERATURE

Sudhir et al. [1] conducted experiment on a cabinet type solar dryer with the different collector geometries and also conducted several experiments on potatoes, chilies and tomatoes. He got the average collector & system drying efficiency, overall efficiency of tomatoes drying are found to be 39.06%, 6.89% respectively for flat plate, 42.97% & 8.95% for v shape, 42.76% & 8.88% of fin type collector. He has also illustrated that fin type collector has a highest average thermal efficiency of 46.15%, followed by v-groove type collector and flat plate type collector having average efficiencies 44.97%, 40.70% respectively. Solar dryer having a flat plate collector has a maximum average cabinet efficiency of 18.41% among other solar dryers with different collector plate.

While the cabinet efficiency of solar dryers having fin type collector plate and V grooved plate type collectors are found to be 17.38% and 16.49% respectively. Vaibhav et al. [2] Has designed & developed a solar cabinet dryer with thermal energy storage for drying chilies in June 2016. The capacity of the solar dryer is 15 kg. Vaibhav used paraffin wax as a phase change material (PCM). The drying experimented is tested with the chilies and drying process is completed within 17 hours in the solar dryer for open drying it took around 27 hours.

Hussain et al. [3] Has designed & fabricated a solar dryer at Bogra, Bangladesh for drying of chili in February 2014. He has used a DC fan of 10 watts, which was used for exhausting moisture with the help of solar panel of 15 W. 8.75 kg dried chili was obtained from 30 kg of red ripe chili. The drying levels of red chili were obtained after 41 hours at upper tray and 46 hours at lower tray, but took 91 hours in the open sun drying system having same weather conditions.

Basumatary et al. [4] Have worked for a low cost solar cabinet dryer as the main aim. Locally available materials are used in the experiment such as wooden plank, transparent glass or transparent thin plastic sheet, stainless steel net or bamboo net & GI sheet. The position of the tray was considered in such a way that the gap between each tray is  $\frac{1}{2}$  to  $\frac{1}{3}$  to that of the gap between lower most trays & bottom of the chamber.

Madhlopa et al. [5] Have designed and constructed a solar air heater with composite absorber systems for food dehydration during September 2001. The performance of the dryer was evaluated by drying fresh samples of mango. The Main components used are integrated flat plate collectors, collector absorber systems, several absorber plates, drying chamber & chimney. The main aim of the experiment is to reduce the moisture content and pH levels in fresh mangoes. The air heater achieved efficient drying of slices of fresh mangoes and a relatively high retention of ascorbic acid. The dehydrated fruits could therefore be preserved for consumption during the times of scarcity.

Mustafa Aktas et al. [6] Have done an analysis on drying of melon in a solar heat recovery assisted infrared dryer in August 2016. The infrared drying system is mainly popular for high heat & mass transfer. It is possible to catch fast heating and short drying time in comparison with other drying methods. The experiments were performed at 50–600C melons surface temperature. The material used are solar air collector, a heat recovery unit, drying cabinet, infrared lamps, K-type thermocouples (Range: 200 to 8500C) and thermo-hygrometers. Here the analysis was done by theoretical calculations, energy balance and CFD analysis.

Halil Ataly et al. [7] modeled and developed a solar air heater to determine the drying rate of an apple. In order to provide the drying process continuously a packed bed thermal energy system was designed and manufactured. The range of temperature maintained is 40–600C. The materials used are two air collectors, drying cabinet, fans and respiratory unit. Performance of packed bed thermal energy storage system has predicted with the help of mathematical models. Finite difference methods are also used.

Varun et al. [8] constructed an indirect solar dryer, integrated with solar air heater and evaluated the dryer performance under natural and forced convection modes of drying. The main parts of the solar collector are absorber plate, cover plate & insulator. The absorber plate used is GI sheet painted with matt black and glass wool was used as an insulator. Wood has been chosen for the drying chamber since it is a poor conductor of heat, it has a smooth surface finish

& heat loss by radiation is minimized. The performance study at no load and load are done. From his study of natural convection mode and forced convection mode, forced convection mode removes more moisture from the tomatoes as compared to natural convection. The overall efficiency of the drying chamber was found to be 17% and collector efficiency was found to be 30%.

Amer et al. [9] Designed and constructed a hybrid solar dryer using direct solar energy and a heat exchanger. Hybrid dryers were developed to control the drying air condition throughout the drying time independent of sunshine, especially at night when it is not possible to use solar energy. The components used in the experiment are solar collector, water tank, water pump, counter heat exchanger, drying chamber, blower (Axial type) and Auxiliary heater. Collector efficiency during day time, night time & solar dryer efficiency during night time was calculated. The

efficiency of solar collector could be raised by recycling about 65% the drying air again in the solar dryer. The best condition for collecting solar energy during the day by the solar dryer is using the solar reflectors with the holders to move it according to sun angles during a day & by turning the dryer also according to sun angles.

Spain generates a big amount of agro industrial products of high moisture that produce a high environmental impact. Hence, Montero et al. [10] Have designed, constructed & performance test analysis of drying kinetics of these agro industrial by products and their possible power valuation. The most efficient operation mode will be forced hybrid followed by passive and active modes. The materials used are flat plate collector, drying chamber, galvanized iron chimney and additional air heating system. The analysis of the drying kinematics of the olive pomace shows better performance of the hybrid and mixed modes obtaining reductions of drying time of a 50% in both cases.

Abhay Lingayat et al. [11] have designed and developed an indirect type solar dryer for banana drying. The main objectives of this experiment are to conduct the drying experiments with sample products of bananas, to find the initial moisture content using a hot air oven to estimate the transient moisture content distribution, to estimate collector efficiency and dryer efficiency and to develop drying co relations. The components used in this experiment are flat plate collector (with V-shaped corrugated absorption plates) insulated drying chamber and chimney for exhaust air. From this study, the authors concluded that the Indirect type of solar drying is more effective than open sun drying as it reduced the drying time & the dried product is free from dust, environmental pollution etc.

Nabnean et al. [12] have designed and performed analysis for drying osmotically dehydrated cherry tomato in the solar dryer at Thailand. The main components used in this experiment are a water type solar collector, drying cabinet, cross flow heat exchanger and heat storage unit. The drying time for drying 100 kg of cherry tomatoes was found to be for 4 days. Colour change and composition analysis are the qualities of dried osmotically dehydrated cherry tomatoes.

Dilip Jain et al. [13] developed a state of the art solar crop dryer with thermal energy storage to maintain continuity of drying of herbs for their color & flavor vulnerability. The thermal energy storage is used for continuous drying and is provided with air heater. The dryer is attached with a packed bed thermal storage having a capacity of 50 kg PCM. The drying in such a manner that (PCM) phase change material stores the thermal energy during sunshine hours and release the latent heat and sensible heat after sunset. Thus the dryer is effectively operated for next 5-6 hours. The developed solar crop dryer is an alternative to overcome the disadvantages of traditional open sun drying and utilization of maximum available solar radiations.

Kamble et al. [14] have evaluated a solar cabinet dryer with gravel bed heat storage systems for drying of green chili. The loading capacity of the dryer was 15 kg. Drying time due to the introduction of heat storage system was extended by 4 hours after sunset. Drying efficiency of the solar cabinet dryer was found to be 34%. The drying time of the solar cabinet type dryer for reducing moisture content from 88.5% to 7.3% (wb) was found to be 86% less than open sun drying.

Bhanu Prakash et al. [15] investigations were mainly concerned with the performance analysis of solar drying system for Guntur red chili. Chili was dried to final moisture content of 9% wb from 80% wb in 24 hours using this system. After thoroughly studying the available literature, an indirect solar cabinet, type dryer is designed. The main objectives of the project investigation are:

- To design and develop an experimental setup for indirect type cabinet solar dryer,
- To conduct the drying experiments with same food products such as grapes, red chilies etc
- To find the initial moisture content of red chilies & grapes
- To know the drying kinetics & dryer performance of the solar cabinet dryer.

### III. SOLAR ENERGY & DRYING PRINCIPLES

#### 3.1. Solar Energy

The sun is the primal energy producer of our solar system. Because of continuous nuclear fusion taking place in its core, a tremendous amount of energy is generated; a small fraction of the energy produced in the sun hits the earth and makes life possible on our planet. Solar radiation causes all natural cycles and activities such as rain, wind, ocean currents, photosynthesis and several other phenomena which are crucial for life. The entire world energy need has been based from the very beginning on solar energy. All fossil fuels (coal, gas, oil) are converted form of solar energy. The solar surface temperature of the sun is 6000°C which corresponds to 70,000 to 80,000 kW/m<sup>2</sup> radiation intensity. Earth receives only a very small portion of this energy. In spite of this, the incoming solar radiation energy in a year is some  $2 \times 10^{17}$  kWh; this is more than 10,000 times the yearly energy demand of the whole world. The solar radiation intensity outside the atmosphere is nearly 1,360 W/m<sup>2</sup> (solar constant). When the solar radiation penetrates through the atmosphere some of the radiation is lost so that on a clear sky sunny day in summer, 800 to 1000 W/m<sup>2</sup> (global radiation) can be obtained on the ground.

### 3.2. Drying Principles

Drying is basically a phenomenon of removal of liquid by evaporation from a solid. Mechanical methods for separating a liquid from a solid are not generally considered drying. In the following section an attempt is made to provide a concise overview of the fundamental principles of drying process for agricultural products. These principles are applied, in general, to mechanical conventional drying and here concerned mainly with solar drying. However in general, must be noted that conventional drying principles and phenomena are independent of the type of energy used. Ekechukwu and Norton (1999) and Mujumdar, 2007 gives a comprehensive review of fundamental principles and theories governing the drying process. A major part of energy consumption during drying is for the evaporation of liquid water in to its vapour (2258 kJ/kg at 101.3 kPa). The water may be contained in the solid in various forms like free moisture or bound form which directly affects the drying rate.

## IV. CLASSIFICATION OF SOLAR DRYERS

Drying equipment may be classified in several ways. The two most useful classifications are based on (1) the method of transferring heat to the wet solids or (2) the handling characteristics and physical properties of the wet material. The first method of classification reveals differences in dryer design and operation, while the second method is most useful in the selection of a group of dryers for preliminary consideration in a given drying problem. A classification chart of drying equipment on the basis of heat transfer is shown in Figure 2 (Ekechukwu,1999; Sharma et al., 2009). This chart classifies dryers as direct or indirect, with subclasses of continuous or batchwise operation. Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. In broad terms, they can be classified into two major groups, namely:

- Passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems) and,
- Active solar-energy drying systems (most types of which are often termed hybrid solar dryers).

Three distinct sub-classes of either the active or passive solar drying systems can be identified namely:

- Direct-type solar dryers;

It is a type of dryer in which solar radiation is directly absorbed by the product to be dried. It is also called as natural convection cabinet dryer since the solar radiation is directly fall on the product, the quality of product is reduced. This dryer comprises of a drying chamber that is covered by a transparent cover made of glass or plastic. The drying chamber is usually a shallow, insulated box with air-holes in it to allow air to enter and exit.

#### Advantages of Direct Solar Dryer:

- a. Contamination of product due to enclosure with transparent cover is less.
- b. Product quality obtained is higher than open to the sun drying.

#### Disadvantages of Direct Solar Dryer:

- a. Time required for product drying is same as sun or natural drying.

- Indirect-type solar dryers;

The solar radiation gained by the system is utilized to heat the air which flows through the product to be dried in this dryer. In this of dryer quality of product improved though drying rate increased. Heated air is blown through the drying chamber. At the top of drying chamber vents are provide through which moisture is removed. In indirect type of solar drying systems a better control over drying is achieved. Fig. describes another principle of indirect solar drying which is generally known as conventional dryer.

#### Advantages of In-direct Solar Dryer:

- a. This technique avoids contamination of final product.
- b. It is very efficient method than the direct type of solar drying.
- c. Maintain the quality of product by avoiding direct exposure in solar radiations.
- d. Time required for drying some product is less.
- e. Final conditions of product are avoided on the circumstances of natural phenomenon.

#### Disadvantages of In-direct Solar Dryer:

- a. Requires more initial cost.
- b. Need maintenance after particular period of time

- Mixed mode solar dryer.



As the name indicates it is combined action of the solar radiation incident directly on the material to be dried and the air pre-heated in the solar air heater furnishes the energy required for the drying process. For designing of this type of dryer various factors is to be considered are: 1] Thermal performance. 2] Cost. 3] Lifetime, durability, maintenance and ease of installation. Following are some advantages and disadvantages of mixed mode solar dryer:

**Advantages:**

- a. Rapid rate of drying with safe moisture level in product.
- b. Time required for drying is less than other drying techniques.

**Disadvantages:**

- a. Quality of dry grain obtained over a year is less than indirect type of dryer.
- b. Cost required for maintenance.
- c. Capital cost required is higher

The main features of typical designs of the various classes of solar-energy dryers are illustrated in Figure, showing three main groups for solar dryers on the basis of the energy sources used. The design of solar dryers is adjusted to the quantity, character, and designation of the material to be dried as well as to the energy sources used and accordingly, various types of solar dryers have been developed and are in use to date.

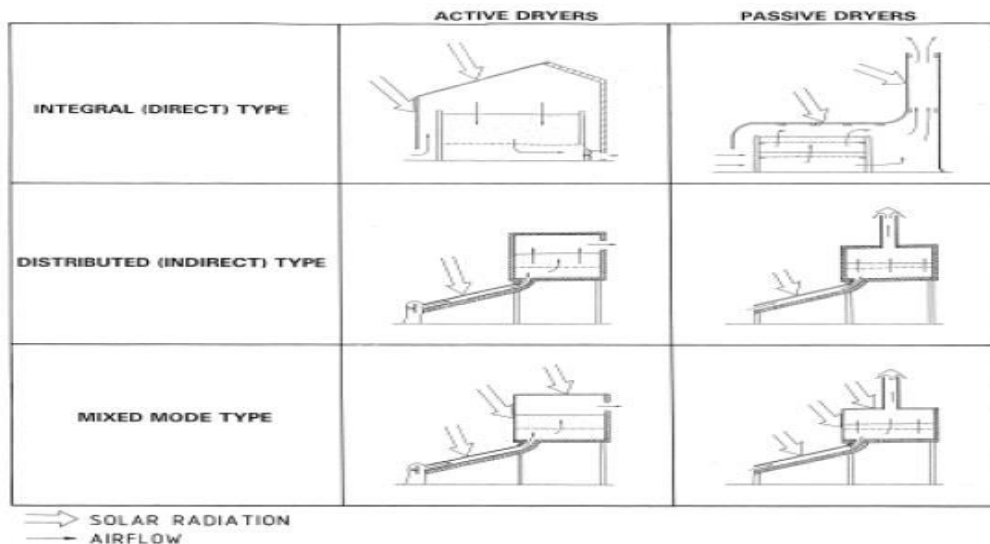


Figure No. 1: - Typical solar energy dryer designs (Ekechukwu and Norton, 1999)

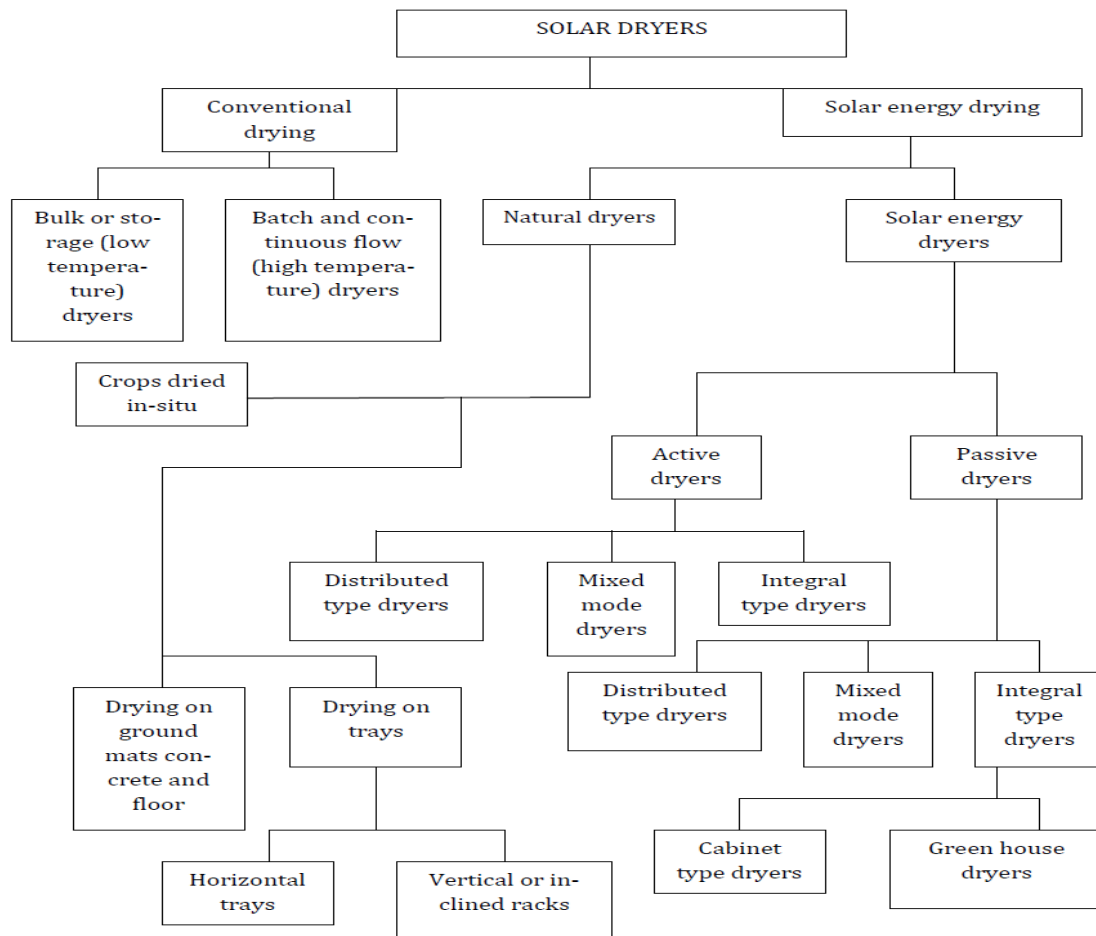


Figure No. 2: - Classification of Solar Dryer [2]

### V. SOLAR DRYING OF DIFFERENT PRODUCTS USING VARIOUS SOLAR DRYERS AND OTHER DRYERS

In Table, various solar dried commodities are listed with the observed changes in quality during drying [4].

Fruits and vegetables	Type of solar dryer	Major findings	References
Wild coriander	Direct cabinet solar dryer and indirect cabinet solar dryer	<ul style="list-style-type: none"> <li>- The highest retention of natural colour and absence of browning were observed from samples using indirect solar dryer.</li> <li>- Essential oil from samples dried in the indirect solar dryer was closer in its composition to those obtained from oven or the fresh one.</li> </ul>	Banout et al. [4]
Olives leaf	Indirect forced convection solar dryer	<ul style="list-style-type: none"> <li>- The values of L* parameter of the solar dried olive leaves increase compared to the fresh one.</li> <li>- The luminance of the leaves was improved by solar drying but the greenness of the leaves reduced.</li> <li>- The olive leaves dried at 40°C (1.62 m<sup>3</sup>/min) exhibited the lowest DPPH radical scavenging activities.</li> </ul>	Bahloul et al. [7]
Coffee	Solar dryer with black transpired air solar collector	<ul style="list-style-type: none"> <li>- Coffee beans dried faster in the solar dryer with acceptable quality and no serious defects.</li> <li>- No OTA (Ochratoxin) forming fungi was found in solar dried sample.</li> </ul>	Chapman et al. [9]



Grapes and figs	Indirect and direct solar dryers	<ul style="list-style-type: none"> <li>- Vitamin C content of solar dried fruits was low due oxidation, especially when the samples were either scalded or sulfurized.</li> <li>- The colour of solar dried grapes showed high acceptance as compared to the natural dried sample (medium acceptance).</li> <li>- The texture and colour of figs dried using mixed solar dryers showed better acceptance than the sun dried samples.</li> </ul>	Gallali et al. [10]
Vanilla	Solar greenhouse dryer	<ul style="list-style-type: none"> <li>- Export quality standard (Grade A) with vaniline content of 2.36% was obtained.</li> <li>- Average drying time for vanilla pods was between 49 to 53.5 hr with drying temperature ranging from 33°C to 65°C and RH of about 34% during day time.</li> </ul>	Abdullah et al., [11]
Pistachio nuts	Direct solar dryer	<ul style="list-style-type: none"> <li>- Both solar and sun dried samples showed splendid taste as compared to hot air dried sample.</li> <li>- No aflatoxin was found in both sun and solar dried pistachio nuts.</li> </ul>	Ghazanfari et al. [13]
Sweet potato	Green house solar dryer	<ul style="list-style-type: none"> <li>- Solar dried sample showed negligible losses in total carotenoids as compared to sun and hot air dried samples.</li> <li>- Sun dried sample showed the lowest retention value.</li> </ul>	Bechoff et al. [17]
Henna, rosemary, Marjoram and Moghat	Unglazed transpired solar dryer	<ul style="list-style-type: none"> <li>- Oil obtained from medicinal plants dried in the solar dryer were higher in quantity as compared to the traditional drying methods.</li> <li>- Higher test scores for sensation were obtained for the solar dried plants (marjoram, moghat and rosemary) in terms of colour, odour, and taste.</li> <li>- Overall quality evaluation (flavour, acidity, fermentation index, appearance and odour) indicated that loading of 20 kg cocoa beans is optimum.</li> </ul>	Hassanain [18]
Cocoa beans	Direct solar dryer	<ul style="list-style-type: none"> <li>- At this load, drying time was shorter and this reduces the risk of putrefactive development in the beans due to unfavourable weather condition.</li> </ul>	Hii et al. [19]
Lemon slices	Solar dryer associated with the PV Module Forced Convective solar dryer	<ul style="list-style-type: none"> <li>- Dried lemon samples with bright colour were observed under complementary solar drying using gradual temperature increment (36°C-52°C).</li> <li>- Lesser browning was observed in solar dried samples with comparison of hot air dried sample at 60°C.</li> </ul>	Chen et al. [22]
Indian gooseberry	Convective solar dryer	<ul style="list-style-type: none"> <li>- Flaking treated sample retained maximum ascorbic acid (76.6%) because of reduced exposure of the sample in the drying air.</li> <li>- Flaking and pricking treatments showed minimum loss of taste and flavour.</li> </ul>	Verma and Gupta [24]
Chilli	Solar assisted biomass drying	<ul style="list-style-type: none"> <li>- Overall drying efficiency of the system was estimated at 10.08% as compared to solar cabinet drying at 7.4% and sun drying at 4.3%, respectively.</li> </ul>	Leon and Kumar [25]
Thyme	Solar dryer using wire basket	<ul style="list-style-type: none"> <li>- The essential oils extracted from the oven dried and solar dried samples were 0.5% and 0.6% (per 100 g dry wt), respectively.</li> <li>- The oleoresin and ash content were 27% for both drying methods and 1.6%, 2.03% and 2.25% for the fresh, oven dried and solar dried samples, respectively.</li> </ul>	Balladin and Headley [26]
Corn	Solar assisted heat pump in store dryer	<ul style="list-style-type: none"> <li>- To reduce the moisture content of the corn from 16.6% to 14.5% (w.b), elapsed drying time was 240 hr.</li> <li>- Power consumption per grain ton to reduce the moisture content by 1 % was 1.24 kWh and the value was much lower than the official standard (2.0 kWh).</li> </ul>	Li et al. [27]
Pegaga leaf	Solar assisted dehumidification dryer	<ul style="list-style-type: none"> <li>- The colour of solar dried pegaga leaf did not become darker due to the lower air temperature and Rh used (T&lt; 56°C, RH&lt; 36%).</li> <li>- Pegaga leaf dried at 65°C using hot air became darker.</li> </ul>	Yahya et al. [30]
Papaya latex	Solar air dryer	<ul style="list-style-type: none"> <li>- A protease activity of 2655 units/g was obtained at pH 5.5 and 285 units/g only at pH 9.0.</li> </ul>	Macalood et al. [32]





Rice	Mixed mode passive solar dryer	- Higher degree of whiteness was found in solar dried rice than sun dried rice. - Similar flavour was found in both sun dried and solar dried sample.	Mehdiza et al., [33]
Green Leaves	Indirect solar dryer	- Solar dried sample showed higher losses of $\beta$ -carotene and ascorbic acid as compared to hot air cabinet drying upon storage because of prolonged drying time. - Chlorophyll loss was also higher in solar dried sample. - Faster drying conditions showed better retention of the quality parameters of leafy green vegetables. - Longer drying time leads to higher loss of $\beta$ -carotene	Negi and Roy [34]
Carrots	Solar cabinet dryer	- Exposure to light resulted to oxidation. - Low rehydration ratio was observed due to greater shrinkage in solar dried samples.	Prakash et al. [35]
Turmeric	Solar biomass dryer	- Dried turmeric rhizomes resulted from solar drying by two different treatments viz. water boiling and slicing were found similar in terms of physical appearance. - Open sun dried sample was found having lesser volatile oil.	Prasad et al. [36]
Cocoa beans	Indirect and direct type solar dryers	- The dried beans from the direct solar dryer were more brittle and higher in acidity than the open air and indirect solar dryers. - Dried beans from the indirect solar dryer showed the highest overall quality.	Bonaparte et al. [38]
Plums	Greenhouse Dryer	- Both solar and open sun drying of plums pre-treated by combination of 1% potassium hydroxide and 60°C dipping temperature or by combination of 1% sodium hydroxide and 60°C dipping temperature ensued in relatively higher values of redness and yellowness as compared to hot air drying. - The combined effect of solar radiation and these pre-treatment combinations reduced the darkish colour of plums during solar drying and open sun drying.	Tarhan [43]

## VI. SELECTION OF SOLAR DRYERS

Selection Procedure of solar dryers is as follows:-

### 1. Initial selection of solar dryers.

The initial selection can be of the type of solar dryer that appears best suited for handling the wet material and dry product, that fits well into the continuity of the process as a whole, and that produces the product of desired properties.

### 2. Initial comparison of solar dryers.

The solar dryers selected in step one should then be evaluated from the available cost and performance data selecting a few. The rests should then be eliminated from further considerations.

### 3. Solar Drying tests.

Drying tests should then be conducted in small-scale units based on the solar dryers selected in step two. These tests are expected to establish the optimum operating conditions, the ability of the dryer to handle the material physically, product quality and characteristics, and dryer size. Occasionally, simple laboratory experiments can serve to reduce further the number of dryers under consideration, as there is rare scope for changes to be made once the dryer is installed. Based on the results of these drying tests that establish size and operating characteristics formal quotations and guarantees should be obtained from dryer manufacturers. Initial costs, installation costs, operating costs, product quality, dryer operability, and dryer flexibility can then be given proper weight in final evaluation and selection.

### 4. Final selection of solar dryer.

From the results of the drying tests and quotations, the final selection of the most suitable solar dryer can be made. The physical nature of the material to be handled is one of the primary features for consideration as these are different for coarse solid, slurry and sheet material. After the preliminary selection of the suitable type of solar dryer, a further analysis for reevaluation of its size and cost should be done to select the most economical one. After analysing adequate data on the cost and performance obtained from the equipment manufacturers the factors governing their performance

should be due considered. This may involve at times compromising certain steps that precede or follow drying process, like sorting, conveying or packaging and hence must be considered carefully.

### 5. Economics of Solar Dryers

Solar dryers are generally capital intensive and therefore the financial viability is the key to successfully compete with any of the other dryers. The financial analysis generally includes the cost of dryer (fixed cost), cost of drying (operating expenses) and payback. They can be viable only if the annual cost of extra investment (on the solar dryer) could be balanced against fuel savings, or if the equipment cost could be reduced. The user or dryer designer looks for a favourable combination of cost, energy efficiency, quality, and price of the final product. Payback is the measure of time (number of days/months/years) it takes to recoup the total investment made on a dryer, in the form of operational cash inflow. Payback analysis does not measure the profitability of dryer as it does not take the service life of dryer into consideration. Continued use of the dryer rather than seasonal use will decrease the drying cost and payback. Economic analysis on a solar dryer should also incorporate the cost benefits due to improved quality, higher yields, less floor area and quicker drying.

## VII. CONCLUSION

A comprehensive overview of the drying process with classification of the practically realized various designs and selection of solar dryers for drying of products has been presented.

- The classification clearly illustrates that the solar dryer designs can be grouped systematically according to their operating temperature ranges, heating sources/modes and operational modes.
- It is difficult to have one single criteria for the selection of a solar dryer for a specific region or a product as solar insolation and other parameters change frequently with geographical location, however the general rules of thumb are mentioned to assist in making the final selection.
- The final selection is generally based on the available insolation rate, production throughput, flexibility requirements, cost of fuel to run accessories as well as on the experience and judgment of the fabricator.
- As the solar dryer has a long life of about 20-40 years, the effect of a poor design can have a long-term impact on the economic health of the dryer.

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