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SOLAR DRYING OF HERBAL WEALTH IN EASTERN HIMALAYA: A REVIEW

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ABSTRACT

Solar dryers have proven to be one of the best environmentally friendly approaches for drying purpose of medicinal plants and agricultural crops. Use of solar radiations in drying purpose of plant parts has proven economically as well as environmentally responsible and sensible application. Plants are the treasure of nature with hidden medicinal properties to treat diseases. Plant material should be processed properly for extraction of medicinal molecules in terms drying to decrease the manufacturing loss and to increase the standard of product. Cognizances of ethnobotanical knowledge on plant wealth are extremely beneficial in utilization and exploration of natural resources. Conventionally, low drying temperatures between 30-40˚C, with economically beneficial techniques are required to protect sensitive active ingredients. Therefore, the objective of reviewing research in medicinal plant drying is to find out optimum drying temperature and best solar dryer for drying purposes of plant parts in terms of quality and drying costs. Rendering to human requisites, solar appliances for drying purposes will be used as the best alternative to standard sun-drying technique. This review focused on effective drying is demand of present scenario for the application of heat trapped from solar radiations for drying purpose in order to maintain the quality and active ingredients of plants. Conventionally, low drying temperatures between 30-40˚C, with economically beneficial techniques are required to protect sensitive active ingredients. Indirect type of solar dryers can easily fulfill all the terms for dying plant products in terms of standard and yield.

Keywords: *Renewable energy, Solar drying, Biodiversity, Technology adoption, Types of dryers.*

1. INTRODUCTION

Medicinal plants have shown to be a boon to humanity, acting as a panacea. People have relied on nature to find drugs and relieve pain, as well as to heal various diseases, since ancient times (Petrovska, 2012).Initially, all the treatments were based on their experiences, gradually humans gathered knowledge of the application of plants according to their needs and thus information is passed from generation to generation (Jamshidi-Kia *et al.*, 2018). India has been a warehouse of several imperative medicinal plants (Pandey and Mandal, 2010).

The Indian religious texts, Vedas mention the usage of plants in curing diseases, as the flora biodiversity is abundant within the country. There are lots of spice plants viz. nutmeg, pepper, clove, etc. trace their origin to the Republic of India (Tucakov, 1971; Petrovska, 2012).Indian traditional medication has a rich ancient heritage like *Materia Medica* providing a great deal of information on folklore practices of natural products (Murti *et al.*, 2012). Aromatic and medicinal plants account for a substantial percentage of the pharmaceutical market(Vaidya and Devasagayam, 2007; Efferth, 2010). Modern pharmaceutical research has revealed the requirement of plant based products (Sharma *et al.*, 2022; Najmi *et al.*, 2022). Today, chemical and pharmaceutical investigations have added a great deal of status to the use of medicinal plants by revealing the presence of the active principles and their actions on human and animal systems. Alkaloids, phenol compounds, tannins, and steroids are examples of bio compounds, all of these compounds are produced and stored in specific parts or in all parts of plant. Complex compounds present in plants are very specific in terms of taxa, family, genus, and species as there are huge variations of secondary metabolites plant species found in wild (Parekh *et al.*, 2006).

The brilliant truth is that utilization of natural flavoring medicines are free of all age teams and genders (Rashid and Mahmud, 2015), Himalayan region of India is a major source of medicinal/ aromatic plants and produces, herbs, flowers, and a number of cash crops; which are harnessed in manufacturing of a number of medicinal, cosmetic and commercial products. The processing especially drying of these produces embroils a big amount of energy (Purohit *et al.*, 2008).

Sun is the universal source of light and heat and is still used as the direct source for drying food items and clothes all over world (Thakuria, 2018).Sun based drying innovation for edible products obtained from

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plants are a hygienic and economically beneficial substitution for extremely high energy required warm dryers utilized in agri-food processing system (Jha and Tripathy, 2020). Earlier the plants with beneficial qualities were collected by the local people. At present, 90% assortment of restorative plants is from the wild, creating around 4,000,000 man day's business (Dhar *et al.*, 2002; Pandey, 2017). Plants have a specific life spans means they are available for specific period of time in nature. Thus, it is necessary to preserve them for their off-season use. Varieties of exogenous as well as endogenous factors are responsible for composition of chemicals (curing agents) present in medicinal plants which provide cure to several diseases and one of the main factor is drying process (Rocha *et al*., 2011).Drying is the most fundamental method of preserving plant products and is a perfectly natural procedure for increasing the usage of food material for a longer period of time.

Using the drying method human society can enjoy their favorites in offseason as the product will acquire its taste back on adding water. The process of drying involves the vaporization of water content from the agricultural product so as to provide a final product for further use in the near future (Babu *et al.,* 2018). The traditional drying technology creates various problems, among them are the drying time and the exposition of the manufacture to dust, insects, and sunlight (Akpinar, 2008; Melgar-Lalanne *et al.*, 2019).Although wild-harvested resources of medicinal plants are widely considered more efficacious than those that are cultivated still cultivation provides an opportunity to use new techniques to solve problems encountered in the production of medicinal plants, such as toxic components, pesticide contamination (El-Sebaii and Shalaby, 2012), low contents of active ingredients (Raina *et al.*, 2011; Chen *et al.*, 2016), etc.

The sun, an unlimited source of energy is a circle of very hot gaseous, vaporous matter with a width of 1.39 × 109 m (Goswami *et al.*, 2000; Kumar *et al.*, 2015). Radiant light and heat from sun that is natural source of energy using a range of ever changing and developing technology such as solar thermal energy, solar architecture (Crabtree and Lewis, 2007), solar heating, molten salt power plant, and artificial photosynthesis. Modern technologies must focus on the usage of many more natural resources energy including shale and wind as these energy resources are abundantly present in our environment at free of cost without polluting our mother nature (Akinola, 1999; Akinola and Fapetu, 2006; Akinola *et al.*, 2006). Solar dryers are the best means of the usage of solar energy applications (Mustayen *et al.*, 2014), which is used in lots of implementations that requires temperature at low level (below 80°Celcius), such as crop drying and space heating (Kurtbas and Turgut, 2006). Thus, removal of moisture content from edible plant parts by using drying method is a perfect way to deliver and store the quality of medicinal plants and agricultural product (Sivakumar *et al.*, 2016), for a longer duration (Vadivambal and Jayas, 2007). A solar dryer is another application of solar energy, used immensely in the food and agriculture industry (Sivakumar *et al.*, 2016). This review provides a detailed overview on importance of drying medicinal plants with solar energy for encapsulation of chemical agents in plants without affecting their tendency to cure diseases even in offseason and after removing moisture content. Different types and working of solar dryers proposed by various researchers with their pros and cons were defined, as well as illustrated in the present review. The plants whose habitat is in the mountains of Eastern Himalaya have been reviewed under this paper instead of research done on them. Medicinal plant collectors and crop producers can use this sustainable and renewable technology as cost benefit approach which will ultimately increase the economy of developing countries.

2. BASIC OF SOLAR DRYING SYSTEM

The sun and heat focused radiation instances on the lopsided surface on which the harvested plant material is maintained for drying are reflected back in open sun drying. Harvested product stored for drying consumes the sun's residual light and heat energy at the surface. The harvested crop is dried by the sun's rays hitting the land, and the blowing ambient breeze passes by striking the harvest's surface, providing some cooling and allowing the crop to absorb some heat by conduction.(Kalogirou, 2004) and (Sanford, 2011). Fig. 1 shows how the agricultural product dries by evaporation. When the harvest absorbs heat, the interior temperature of the crop rises, causing vapour to develop. This vapour, which is created as a result of moisture inside the crop, diffuses out of the harvest region, reducing overall biomass.

Finally, the moisture is got removed from the harvest, the less is the moisture level of harvest, less is the weight of harvest and the increase in the sound produced while strikes over the tray surface. The time required for this whole process of evaporation, conduction, and diffusion depends on the thickness and quantity and state of plant material (Sodha *et al.*, 1985; Tiwari, 2002). While drying plant products under open sun, the plant material is prone of entering foreign particles like dust, bacteria and other unwanted materials blown up by air. Discoloration of harvest is one of the major aspect which got affected by open sun moisture removal technique (Tiwari and Tiwari, 2016) thus, different types of sun based approaches are invented eradicated merits with an enclosure in sun heat -based drying apparatus.

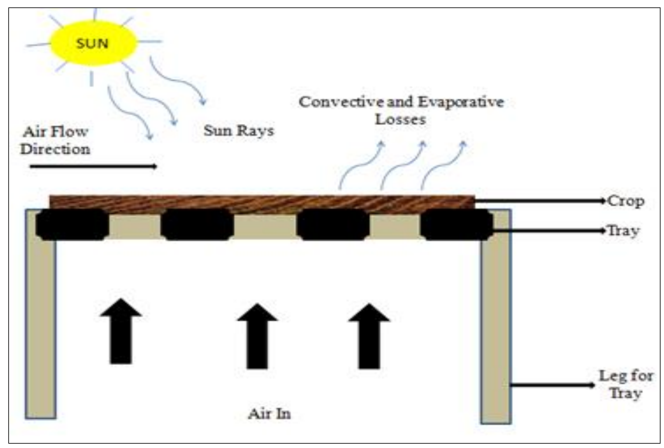

Fig. 1 General structure of open solar radiations based drying in a pictorial view [Source: Sahdev(2014)].

Solar dryers are one of the best solutions for drying plants items using sun-based heat. They are also one of the safest options in terms of manufacturing safety from insects, dust, and rain (Thakuria, 2018). The prime objective of drying apart from extended storage Life can also be a quality enhancement, ease of handling, further processing, and sanitation and is probably the oldest method of food preservation practiced by humankind. According to convince of drying products in solar dryers, classified as direct solar dryer and indirect solar dryer as shown below in Fig.2 [Phadke *et al.* (2015); Tiwari(2016)].

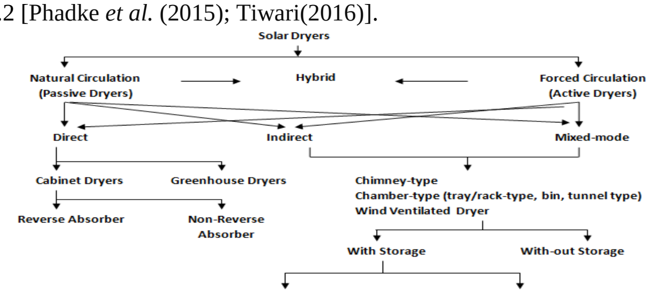

Fig. 2 Classification of solar radiations based solar dryer [Source :Phadke *et al.* (2015); Tiwari(2016)].

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Sun-powered radiation enters the dryer through the glass walls, is transmitted to the aluminium sheet that serves as a cover, and is subsequently converted to nuclear power, such as long wave radiation. The long wave radiation will not pass through the glass since it reflects all of it; it will repeatedly contact the shield until it is converted to heat (Visavale, 2012) and (Islam and Morimoto, 2018).

The most convenient method for the analysis part of drying reason to show moisture for numerical counts is on a dry basis for rural items of agricultural product's moisture content regularly is communicated in wet premise or wet basis(Toğrul and Pehlivan, 2002; Şevik, 2013). Wet basis of product and a dry basis of the product have a relationship between them as shown in Fig.3 (Perry, 2007).

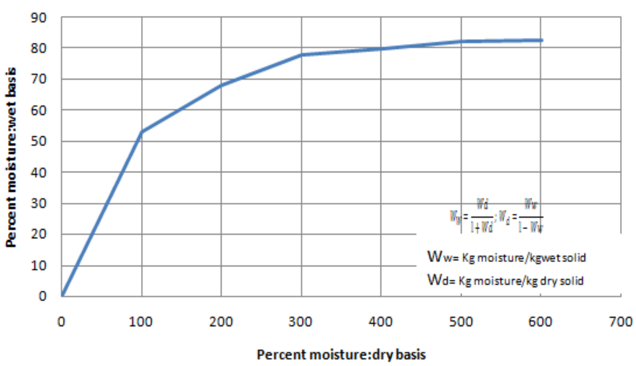

Fig. 3 Relationship between wet-weight and dry weight basis [Source: Perry (2007)].

3. LITERATURE REVIEW ON NATURAL CIRCULATION DRYERS

Natural air absorbs heat from the sun's rays, which is subsequently delivered to passive dryers via buoyancy force or wind pressure. Normal and non-reverse absorber cabinet dryers, as well as greenhouse dryers, function in a passive mode (Sharma *et al.*, 2009). Passive drying of harvests is still in like manner practice in the numerous Mediterranean, tropical and subtropical areas particularly in Africa and Asia or in little horticultural networks (Visavale, 2012). Airflow rates in passive dryers may be increased marginally through the addition of a solar chimney on the discharge end of the dryer to increase the whole density difference (Bassey *et al.*, 1994).Natural circulation dryers can be used in an emergency case when there is no provision of electricity (Fuller, 2000).

3.1 DIRECT SOLAR DRYER

The only difference with this type of dryer is that the food item is protected by a glass cover. When sunlight strikes a glass surface, three things happen: some light is absorbed, some light is reflected, and some light is transmitted. The remaining solar radiations are assimilated by the tray's surface, which dries the crop harvest, resulting in an increase in temperature. The use of glass walls in solar dryers lowers direct convective losses to the environment, allowing the temperature inside the dryer to rise (Balasuadhakar *et al.*, 2016). The item from which moisture removal is required is kept openly or is directly exposed to solar light through a transparent material that covers the structure as shown in Fig. 4. The heat generated from solar energy is used to dry the crops or food items and also heats the surroundings. The main disadvantage of using the direct mode is that the heat that will be absorbed by the item cannot be controlled. These solar dryers are available in many sizes, ranging from kilograms to metric tons, the simplicity of the product and its affordability. A convenient and practical direct sun powered dryer working under common convection sun radiations based dryer has been planned (Othieno, 1987). On the basis of previous study and comparison, direct solar with have some limitations in the use of direct solar dryer. Some of these limitations are mentioned in table 1 in accordance to the experimental work performed.

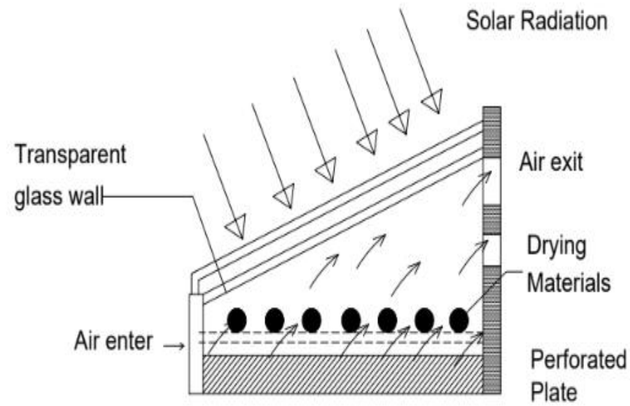

Fig. 4 General Structure of direct type natural convection food solar radiations based dryer [Source: Sharma *et al*.(2009)].

3.2 SOLAR CABINET DRYERS

Solar cabinet dryers are simple and inexpensive equipment with a wide range of applications in the home. These dryers are designed to remove moisture from harvested crops, spices, and herbs, and are typically made with a one to two metre square tray surface.These trays can hold the plant material of ten to twenty kilograms per shift. This experiment has a glass sheet covered over the trays which act as heating material. When sun rays falls on glass sheet it allows the part of radiations to fall on the black colored material of tray and its surrounding. The radiations got absorbed by dark surface as well as the crop surface. During the whole heating process coolness is provided by the air which gets enter in system from environment and circulated all over the system and leaves the system by a vent present above dryer and again generating suction of fresh air from the base inlet(Hughes *et al.*, 2012). They are generally used for drying all the agricultural products, such as herbs, rhizomes, stems, flowers, roots, fruits, sap, bark, spices and all veggies with chlorophyll and carotenoids contents, in small quantities (Arun *et al.*, 2020). A general view of solar cabinet dryers with its major parts is shown in Fig. 5.To extend the drying process into the non-sunny hours of the day, heat storage should be employed. Water vessels have been used as a relatively low cost means of heat storage (Puiggali and Lara, 1982).

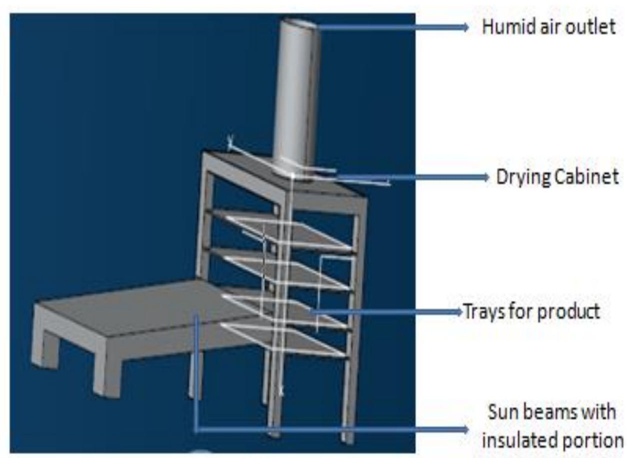

Fig. 5 General view of solar cabinet dryer showing its parts [Source: Tiwari, (2016)].

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Sreekumar *et al.* (2008) planned for the execution of a new version of solar radiations based dryer belongs to the class of indirect solar dryer with cabinet system for increasing the quality of dried product, which specifically made and used for moisture removal or drying of plant based product at natural level. The entire dryer utilised in the experiment was divided into two primary parts: one side is designed to absorb sunlight-based radiations, resulting in nuclear power, and the other part includes the tray component, which diffuses the pant-based material for drying reasons.

3.3 GREEN HOUSE DRYERS

These dryers, which are tunnel greenhouses with foil coverings, can also be used to dry agricultural products. They always include a fan to ensure a constant flow of air, which is occasionally partially adjusted. When sensitive materials need to be dried, a belt or a conveyor is used to carry shading across the drying room. Greenhouse type solar dryers having titled flat-roof surfaces have been developed for drying herbs and aromatic plants. These feature roof integrated plastic collections and air recirculation. These are also called as tent dryers and basically, they are greenhouses with slight modification. These dryers are designed with vents of appropriate size and position to have a controlled airflow. They are characterized by the fluorescent glazing appearance by the transparent cover of polyethylene sheet (Doe *et al.*, 1977).

Janjai *et al.* (2009) done an experiment on solar dryers for the purpose of banana drying and concluded that total of four days are required to attain standard moisture level in banana chips in Sun radiations based glazed dryer, for attaining the same standard level of moisture in banana chips by using open solar radiations it took five to six complete days. Whether the dried quality of plant based items obtained from sunlight drying is high in terms of color as well as taste. The structure as well as the dimension of glazed transparent polythene sheets on light dryer used for the drying of bananas as appeared in Fig. 6.

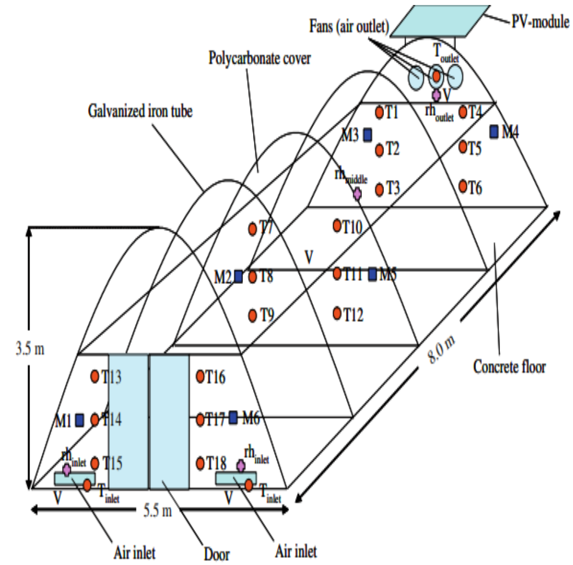

Fig. 6 General view of the green-house dryer with dimensions and thermocouples (T), hygrometers (rh), air speed (V) and product sample for weights (M) [(Source: Janjai *et al.* (2009)].

Table 1 Described work of various authors on plant drying by using direct solar dryers with their results and limitations.

S. No.	Author	Type of direct solar dryer	Temperature	Results with benefits	Limitations
1.	(Sandali *et al.*, 2018)	Cabinet type solar dryer	46-58°C	Integration of heat exchanger improves significantly the solar dryer performance, and can use at night hours	Temperature cannot be maintained in rainy season
2.	(Téllez *et al.*, 2018)	Cabinet type solar dryer	42-53°C	Natural convention method is more efficient for removal of dampness from sample with value of 0.1405 kg water/kg dry mater. The product was reached at equilibrium between 550-600 minutes	Prolonged time of drying causes decrease in nutrition of product and leads to inconsistent color of product.
3.	(Nabnean and Nimnuan, 2020)	Direct forced convection solar dyer	35-60°C	Suitable for products which are sensitive to solar radiations	Similar results with more benefits can easily achieved by using indirect solar dryer in less time. It requires long duration of time.
4.	(Muruganantham *et al.*, 2021)	Chamber-tunnel type solar dryer	52.5-53.7°C	As the mass of plant product is increased in tray, the temperature of tray decreases with an increase in drying period	Solar heat used for drying cannot be stored for longer time because it completely depends on weather conditions.
5.	(Ayua *et al.*, 2017)	Chamber-tray type solar dryer	37-59°C	Obtained plant product is dust free and free of contamination from insects, as the dryer is fully covered during the whole drying process.	Variation in temperature is analyzed and it can decrease the quality of plant product.

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3.4 INDIRECT SOLAR DRYER

Indirect type of solar dryer differs from direct dryer by heat transfer and vapor removal. In this method the air present in atmosphere is heated in a flat plate collector, and then the collected hot air from a flat plate collector flows in the cabin where products are kept for removal of moisture by drying. Convection and diffusion are used to eliminate moisture from this type of dryer (Balasuadhakar *et al.*, 2016). As the name suggests, this method does not expose the crop directly to the sunlight. The sun -oriented radiation is retained and changed over into heat by another surface (a black colored dark top) for the most part called the collector as shown in Fig. 7. Air that will be utilized for drying is passed from this surface and gets warmed, which is then used to dry the food thing inside the dryer. The main advantage of the indirect mode of drying is that the temperatures can be controlled. The sizes can vary from kilograms to metric tons, but it is very high priced and its construction is complex than the preparation of direct solar dryers (Phadke *et al.*, 2015).

El-Sebaii *et al.* (2002) designed and formed a natural convection indirect type of sun based radiation dryer. The whole system of sun radiations based dryer is formed by adding a flat sun based heater to produce temperature and this is joined by a sac whereas product is kept for drying. When the method is utilized with and without storage material, the unchanged moisture content (Me) for sample seedless grapes are obtained after 60 hours of drying period and 72 hours of the drying period. Results concluded that there is a gradual decrease of 50 % in the drying time by using this dryer for drying of seedless grapes. After the collection of seedless grapes, they are washed and cut into pieces to increase the surface area of absorbing solar heat and dipped into chemical as they were immersed in boiling water container with 0.4% ozone.

For some crops, particularly herbs and some spices, the last quality is diminished if the item is presented straightforwardly to sun powered radiation. The spice cardamom is one such example. Exposed to direct sunlight, the pods are prone to split and the chlorophyll is destroyed. Premium prices however are paid for cardamom pods which are whole and have a greenish color. The solar dryer class is therefore more suitable for this crop (Fuller, 2000). For fast drying as well as for cloth drying indirect class of solar dryer is used. A compact portable dish type solar radiations based heating apparatus is directly connected to the tray portion in which apricots were kept for drying. By doing so, the resulted drying effectiveness was improved from 20% at normal stream pace of 0.01kg/sec to 42.6% at a high convective stream pace of 0.21 kg/sec. apricots took 13 hours for removing moisture from 85% to 8% (Pangavhane and Sawhney, 2002).

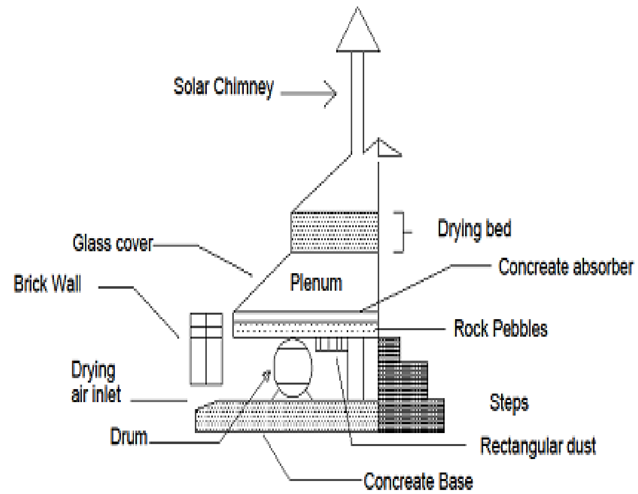

Fig. 7 Cross-sectional view of indirect sun oriented dryer through the burner, collector, drying chamber and sunlight based fireplace[Source: Phadke *et al*.(2015)].

Among all the other types of solar dryer techniques, indirect use of solar radiations for drying plant products is most commonly used in present scenario for removal of moisture content from plant products. It has proven one of the best techniques over the direct use of solar radiations for drying agricultural products (Jangde *et al.*, 2021).Some limitations for the use of indirect solar dryer are mentioned in table 2.

Table 2 Described work of various authors on plant drying by using indirect solar dryers with their results and limitations.

S. No.	Author	Type of indirect solar dryer	Temperature	Results with benefits	Limitations
1.	(Téllez *et al.*, 2018)	Chamber-tray type (Weibull model)	48-57°C	It provides superior conditions and time for drying plant product. Equilibrium was reached between 250 and 270 minutes.	Drying time can be increased as per the seasons and climatic change.
2.	(El-Sebaii *et al.*, 2013)	Chamber tray type Passive mode dryer	39-54°C	It can be used in those areas where there is less availability of electricity as it is passive in nature. This dryer is best for describing the thin layer solar drying technique.	Excess heat can decrease the quality and self life of product.
3.	(Shalaby *et al.*, 2020)	Chamber- tray type forced convection mode dryer	32.6-46.5°C	Use of paraffin wax maintained the temperature for drying after 3 hours of sunset. It is capable of drying plant leaves in less period of time in comparison to natural convention dryer as the drying environment is controlled in terms of temperature.	It cannot be used in those areas where electricity is not available.

3.5 MIXED MODE DRYER

The qualities of both the direct and indirect classes of solar dryers are combined in the mix mode class of sun radiations based drying, which is also known as the hybrid solar dryer class. Product is dry by direct exposure to the sunlight and also by hot air supplier on it. Mixed mode solar dryers probably have superior performance to direct or indirect mode solar dryers, in practice, the additional cost and complexity of these systems tend to make them uneconomical and less popular in practice than the other two modes of the dryer (Fuller, 2000).This kind of sunlight based dryer comprises of a sun-based warming unit with sac like structure for drying is used to dry the product as shown in Fig. 8. The environmental air passes and get entered with the flow where it get heated in a chamber called as collector from here this heated air is directly supplied to a chamber where actual drying takes place and its top is made up of transparent glass sheet which can directly absorb solar radiation.

In this way, drying rate is higher as compared to direct solar drying (Balasuadhakar *et al.*, 2016).A straightforward and economical mixed mode sun powered dryer was planned and developed (Bolaji and Olalusi, 2008). As the sun rises in the east and sets in the west there is great variation in heat provided to the product. Even the temperature measured inside the drying sac and air radiator is very high in comparison to the temperature measured for the surface on which the product is kept. This temperature is varied in both places on an hourly basis due to the movement of sun from east to west. There is an increase of 70 % (24° C) in level of temperature measured at interior the drying sac. The time of measurement was selected at 3:00 pm that is just three hours after the mid noon (12:00 pm). For the analysis of dried yam chips by using mixed mode or hybrid class of sun based dryers. The rate of drying is analyzed in two terms firstly on the basis of efficiency of collector and secondly based on moisture which is removed from product (dry basis), and was calculated as 57.5 % and 85.4% respectively. The dryer showed an adequate capacity to dry food things sensibly quickly to a standard moisture level, at the same time it guarantees a prevalent nature of the dried item. Fig. 8 is showing all the eminent features with other essentials required for the preparation of mixed mode solar dryer, consisting of drying sac (cabinet), collector of solar radiated heat, tray surface where product is kept for drying. The main purpose of experimenting on this class of dryers is to decrease the timing of drying or instant drying of the product (Tiwari and Burnwal, 2008).

Forson *et al.* (2007) gives information of dryer in which flat plate collector placed in series. They used this dryer for drying potato slices.The experiment measured the size of potato slices before executing the solar drying approach as was measured on the diameter and thickness basis, which is calculated as 0.05m and 0.01,respectively. To improve the process of moisture removal by solar radiations based drying efficiency, recycling was adopted. The quality of dried grapes is obtained by using the same dryer quite well. The whole time required for the drying of grapes is greatly reduced to 30–40 h (Tsamparlis, 1990).A hybrid semi sun radiation- based dryer is utilized for the experimentation(Amer *et al.*, 2010).

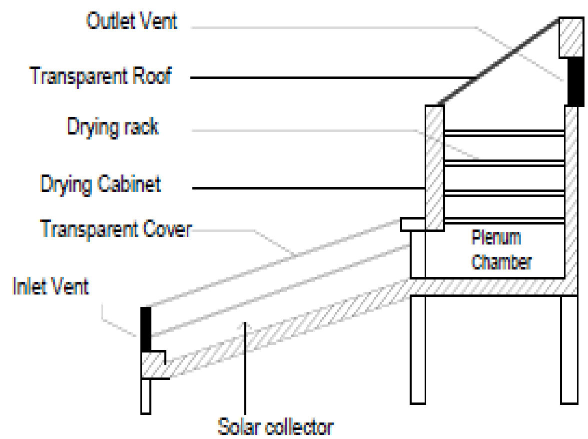

Fig. 8 Mixed-mode solar dryer with its sectional view[Source: Bolaji and Olalusi, (2008)].

The weight holding capacity of apparatus was thirty kilograms per shift at a time; plant material used in experiment was chips of ripe banana. The class of solar dryer used in the drying of ripe bananas uses the water storage tank based heat system to increase the temperature level for reduction in water level inside banana chips. The experiment was kept as it is in dark period. The results analyzed the use of experimental dryer for reducing liquid level of banana chips at wet basis from initially calculated 82% to less than 18% as finally measured percentage, the time duration of experiment was of eight hours only. Lakshmi *et al.* (2018) have planned, prepared and experimented on the hybrid solar radiation based class for the analysis of quality based drying of plant rhizome of dark *Curcuma* species. In experiment, the paraffin wax was applied on the surface of product holding material to increase the level of heat. By analyzing results of experiment it was concluded that the moisture level is clearly decreased on wet basis from an initial 73.4% to the final 8.5% at the time interval of only 18.5 hours. Solar drying experiments of plants products by using mixed mode dryer with results and some limitations are mentioned in table 3.

Table 3 Described work of various authors on plant drying by using mixed mode-solar dryers with their results and limitations.

S.No.	Author Name	Type of Mixed mode Solar dryer	Temperature	Results with benefits	Limitations
1	(Ayua *et al.*, 2017)	Chamber-tray type	40 ˚C -72˚C	Vegetables can be dehydrated with final moisture content of less than 10% and increase the self-life of product. This dryer can be easily used in rural areas where electricity is not present.	Prolonged drying times results in inconsistent colors and lower nutritional value of products.
2	(Lakshmi *et al.*, 2019)	Chamber-tray type	47.1 °C	Better drying efficiency was achieved with the use of this dryer. Antioxidant property of dried *Stevia* leaves was increased.	During the final drying stage, the drying rate becomes slow, with time because the energy required to break the inter-molecular bonds of *Stevia*leaves increased.

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3	(Phoungchandang *et al.*, 2009)	Chamber-tray type	60-62.82°C	It provides high potential performance for drying of ginger. A biocompound (6-gingerol)is retained in plant product in shortest drying time.	Low rehydration ratio was reported because of high temperature which leads to cell damage.
4	(Rani and Tripathy, 2021)	Chamber-tray type	105 °C	Air velocity plays an important role to increase the efficiency of solar collector and drying chamber.	Structural parameters of the system need to be modified as there is significant wastage of energy is reported.
5	(Ekka *et al.*, 2020)	Chamber-tray type	40-60°C	The initial moisture content (73.4%) reduced to 3.7% final moisture content on wet basis. Shorter time duration is required to achieve standard moisture content in plant product and saves the electricity energy consumption.	It requires latent heat storage apparatus for drying, which increases the total weight of solar dryer; it becomes difficult to move from one place to another.

4. LITERATURE REVIEW ON FORCED CIRCULATION DRYERS

Active solar drying systems are designed incorporating utilized for external purposes, similar to siphons or blowers, for rescheduling the sunlight based radiations leads to the warmer environmental air for drying beds (Prakash and Kumar, 2013). In all of the solar radiations based apparatus for drying purpose uses the environmental heat which passes through a medium to reach the surface of product which is much heavier and thus acts as sink. A commonplace dynamic sunlight based dryer relies upon sun powered energy just for the warmth source, while for air circulation uses motorized fans or ventilators. These dryers discover significant applications in huge scope business drying activities in combination with conventional fossil fuel to have a better control over drying by consolidating the effect of fluctuations of the solar insulation on the drying air temperature(Hii *et al.*, 2012).Solar radiation and its flow in whole drying apparatus is a crucial part of drying system as it is the base of removal of moisture from the product in both the class of solar radiations based dryers, active as well as the passive solar radiations based dryers as shown in Fig.9. The disadvantages of a forced convection system are the increased capital and running costs and the requirement for electricity. In commercial solar drying systems however the advantages mentioned usually far outweigh the disadvantages, and an electric fan is used if possible(Fuller, 2000).

Sun oriented dryers are utilized to empower the conservation of horticultural yields, food handling businesses for parchedness of foods grown from the ground, food obtained from the animal based product drying, the wood material used in construction purposes is produced from the proper drying of initial wood to final timber at industrial level, even the milk is produced in form of powder with the process of drying in dairy enterprises(Norton, 2017). Zomorodian *et al.* (2007) designed, verified, and evaluated a functioning blended mode dryer for drying harsh rice. The whole solar radiations based apparatus is formed by the attachment of various selected parts like a sac with trays for drying product, there is an inlet as well as outlet pin is inserted for maintaining the equilibrium in environmental air flow. The results concluded that the apparatus could remove 21.24 % of liquid concentration on the basis of its efficiency and the total amount of energy in percentage was calculated as 6-8%. The discharge rate of crop drying found very impressive with the maximum efficiency of the system 21.24%, and the energy consumed during the drying process was 6 to 8%. (Fudholi *et al.*, 2010).

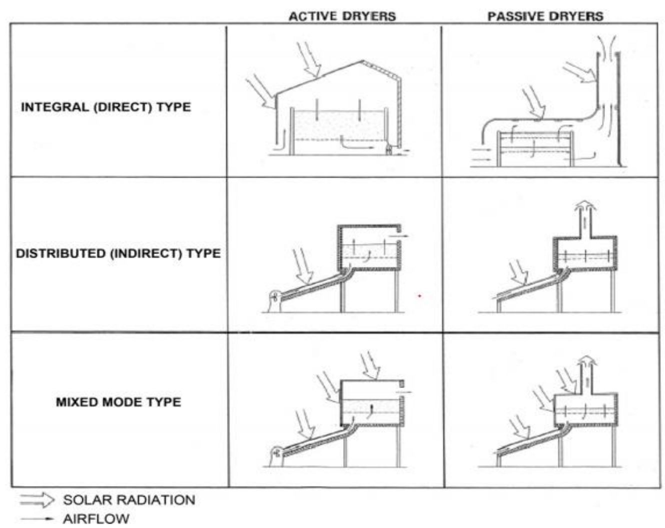

Fig. 9 Introduction of the diverse working modes and kinds of sun based dryers[Source: Ekechukwu and Norton, (1997)].

Afriyie and Bart-Plange (2012)done an experimental preliminaries on execution examination of a chimney stack subordinate direct sun oriented yield dryer for various bay regions with a fixed outlet territory and results showed that the gulf zone of the immediate mode dryer can be set properly along with the utilization of a sun powered chimney stack and an appropriate point present on the highest point of sac of drying so that the process of ventilation cam be improved in natural drying apparatus. Nonetheless, this mix would just be successful for improving the drying execution of the immediate mode dryer in territories of low relative moistness, as the immediate mode dryer is profoundly delicate to the natural relative stickiness. In all the trials, the dryer with roof angle 51° in comparison to 64° and 81° and inlet gap 70 mm showed the best performance in comparison to 50 mm and 30mm respectively.

Islam *et al.* (2018) done experiment on fabrication and working study of direct type sun based dryer and during the 36 hours experiment period, the everyday normal estimations of the surrounding temperature, drying chamber temperature, encompassing relative dampness, and chamber relative humidity were range from 20°C to 28°C, 18°C to 43°C, the range of 50% to 80% and 30% to 52% in natural convection mode. The weight of the products (potatoes and bananas) decreased rapidly as the moisture is removed through drying.

An experiment has been conducted by(Sreekumar *et al.,* 2008),on execution of indirect sun powered cabinet dryer, the whole apparatus was prepared in such a way that it can absorb maximum of the heat coming from the sunlight and thus increasing the temperature. For this purpose, the size of the absorber sheet was widened. The sheet where sunlight is absorbed is accomplished with accurate temperature of 97.2 °C. The solar apparatus of drying used in this experiment was accomplished with trays with holding capacity of 4 kilograms and plant product used was gourd pieces with underlying dampness concentration of 95 %at the time rate of total six hours. The same concentration of dampness concentration present inside gourd pieces was obtained at total 11 hours by allowing the drying in open solar radiations. The results concluded that the indirect class of solar radiations-based drying is much more efficient in terms of time as well as the material tone keeping of item. The cost is also estimated for the drying of gourd slices as was measured Rs 17.52 for traditional drying and Rs. 41.35 on account of indirect sun light-based radiations dryers. The usable time duration expectancy of the experimental sun powered dryer was estimated for about 20 years. The nature of the item dried in the sunlight-based dryer was serious with the marked items accessible on the lookout. An examination between the direct common sun powered bureaus dryer and the indirect one was made by (Bennamoun, 2011),According to the analysis of results 70% of black pepper is attained in 72h for indirect solar dryer against 243 h for the indirect dryer. For the purpose of drying grapes by using an indirect class the standard liquid concentration was attained at 318 hours, and 268 hours by the use of another class of solar radiations-based dryers that is direct solar dryer. The vervain was extracted from the dried plant-based product. Thus, the time required for the extraction of vervain in indirect class of sun-based radiation apparatus was estimated at 48 hours with 67 % of humidity, weather by using the traditional sun-based radiation apparatus leads to the use of only 30 hours at the rate of 75% humidity for extraction of vervain compound from grapes.

Prakash and Kumar (2013) detailed a comprehensive examination of the many plans, development nuances, and operational standards of a wide range of relevant plans for sun-based energy drying frameworks. Passive or natural flow sun oriented drying apparatus and active or force convection sun based drying apparatus are two major groups of sunlight based drying apparatus. Sun-based drying apparatus are simple to understand, build, and use, making them suitable for limited-scope manufacturing lines or for use in provincial farming towns. These minimal effort foods drying advances can be promptly utilized in country zones to lessen waste and improve item quality hence bringing about generally speaking handling cleanliness. Experimentally planned dynamic sun-based dryers are discovered as most powerful apparatus with full control than other normally designed dryers. All the normal sun radiations based drying apparatus has a fan like structure which works by sun powered photovoltaic cells. The presence of these characteristics in dynamic dryer is autonomous so that they can be preferred against non-renewable energy source/power. Along these lines, sunlight based photovoltaic-warm drying apparatus is consented as reasonable for provincial town ranch application in most non-industrial nations.

5. MARKET FOR SOLAR DRYERS IN HIMALAYA: FOOD AND MEDICINAL PLANTS

Indian Himalaya is the abode of both food and medicinal plants. The Himalayas, the world's highest mountain range with elevations exceeding 8000m (Joshi *et al.,* 2016). People inhabiting the Himalayas collect the medicinal plants from their mother nature and dry them directly under sun and use them to treat various diseases. Drying research is a remarkable illustration of an intricate field, where it is important to look extensively on the concurrent energy and mass exchange measure that happens inside and on the outside of the material. For proper harvesting and collection of medicinal plants it is necessary to observe special procedures for both domestic consumption and particularly for industrial processing of drugs. Generally, the medicinal plants should not be collected in wet and rainy weather or during dew, but when they are dry. During collection they must not be damaged, e.g., by breaking, but also contact with metals violates vitamin C and tannins. The plants should be collected as the whole, if possible, and cut after drying. Most plants are used after drying, where they will not be soiled by dust, birds, insects etc. (Belessiotis and Delyannis, 2011).To the dried plants addition of fresh plants must be avoided, since the drug gets wet again and may degrade by mold (Aboltins and Kic, 2016). The cost of solar dryer is not very expensive. The cost for a solar dryer is simply afforded by a middle-class human being. Components to construct the Mixed-Mode Solar Dryer and approximate cost was estimated as Rs.6370 (Thakuria, 2018). Spices are as yet burned-through as wellsprings of genuinely great measures of a few supplements (Özcan and Akbulut, 2008),it is broadly acknowledged that spices are critical nourishing wellsprings of minerals.

Babalis *et al.* (2006)studied the drying air qualities on the drying execution, also they examined of the drying attributes has been directed in the temperature scope of (55 – 85°C) and the air speed in the scope of (0.5 – 3 m/s). An Arrhenius-type condition was utilized to decipher the impact of the drying air boundaries on the compelling diffusivity, determined with the technique for inclines as far as energy of initiation, and this was discovered to be uncaring toward air speed esteems higher than 2 m/s. According to (Müller and Heindl, 2006),drying behavior of medicinal plants during convective drying is mainly influenced by the conditions of drying air such as temperature T, RH and velocity v. Velocity of drying air v was varied in a range from 0.2 meter per second to 0.6 meter per second at the rate of 50°C temperature. The relative humidity (RH) of drying also varied in a range from 30 to 70% at the velocity rate of 0.2 meter per second with temperature of 50°C.The temperature also changes from the 30 to 90 degree Celsius at velocity of 0.2 meter per second.

Bala and Janjai (2009) conducted an experiment for measuring the power and dampness concentration of mushroom item. For the drying purpose of mushroom the sun light-based tunnel apparatus is analyzed experimentally for measuring its performance. The tunneled apparatus used in experiment was designed in such a way that the whole absorbing sun radiations based heat is transferred to the tunnel. Three fans like apparatus (with 40 watt) were used to transfer the environmental air to the tunnel so that it can be heated to raise temperature inside it. During the experimental period, the minimum and maximum solar radiations were 273 W/m and 885 W/m respectively. The generated voltages for the 40 W solar modules were 4.5. V to 14.8 V. Temperatures in the drying chamber varied from 37.0 ° C to 66.5 ° C. Mushrooms were dried from about 89.41 % to 6.14 % moisture content (w.b) in about 8 hours. In the equivalent drying period, the dampness substance of mushrooms diminished from 89.41 % to15 % in the customary sun drying strategy. Moreover, the Mushroom being dried in the sun powered passage drier were totally shielded from downpour, bugs and dust, and the dried mushrooms were top notch dried items terms of flavor, shading, and surface. As the fans are controlled by a sun-oriented module, the drier could be utilized in provincial zones where there is no inventory of power from lattice.

Dissa *et al.* (2011)done a comparative study of direct and indirect sun light-based radiations for drying of mango and evaluated that indirect solar drying offered highest drying rates and water diffusivities. Its diffusivities increased with the number of drying days between 1.5 x10-10 and 2 x10-10 m^2/s whereas those of direct solar drying decreased with the drying days number between 5x10-11 and 1.85 x10-10 m²/s. With efficiency from 2 to 48 % indirect solar drying was found to be more effective than direct solar drying with efficiency from 0 to 34 %. Indirect solar drying with an average final water content of 16.6 % (dry basis) and a final water activity of 0.57 was then the most efficient, but also the most expensive. Thus, indirect solar dryer was found to be suitable for industrial or semi-industrial mango drying, whereas direct sun-based dryer was appropriate to a family scale traditional drying of edible parts of mango. The disadvantages faced by the direct class of sunlight based dryers can be eliminated by use of indirect class of sun light based apparatus for drying (Sontakke and Salve, 2015).

Afriyie and Bart-Plange (2012) have conducted an experiment on drying process by free convection of six different medical plants (flowers of garden marigold (*Calendula officinalis*), leaves of lemon balm (*Melissa officinalis*), origanum (*Origanum vulgare*), commonagrimony (*Agrimonia eupatoria*), common lavender (*Lavandula angustifolia*), and common sage (*Salvia officinalis*) is compared. An experiment has been done by (Dhalsamant *et al.*, 2017),for drying purpose of potato by giving pretreatment of chemicals and then the product is rehydrated and allowed to shade dry. There are nanoindentaion properties present in the trays where potato slices are kept for drying and it was found that the water assimilation limits, and rehydration capacity of sun powered drying of potato slices which are affected by the pretreatment and rehydration. The nanohardness of potato slices were positively affected by pretreatment and was measured as 22% contrasted with that of untreated samples.

6. SIGNIFICANT FEATURES AND IMPORTANCE OF SOLAR DRYERS

The world's attention has been drawn to the progress of sustainable power sources such as nuclear energy, sunlight-based energy, hydroelectric energy, geothermal energy, and wind energy, which are all present on our planet(Panwar *et al.*, 2011). The food borne microbes are recognized as the most unmistakable dangers identified with dried items are *Bacillus cereus*, *Clostridium perfringens*, *Salmonella* and Hapatitis A virus in semiarid tomatoes reports in specific case only. These microbes endure and can easily revive in moisture present in food items and connected creation climate(Koopmans and Duizer, 2004; Farakos and Frank, 2014).The activity of these pathogens can be reduced by proper dying of product in specific temperature to remove the moisture from plant product.

As propounded by (Cliquet and Thienpont, 1995)the prominence of solar food drying is likely to intensify as the global population is predicted to exceed eight billion by the year 2025 (Fuller, 2000). The sun radiations-based heat treatment in an open sky for future use of the food and horticultural harvests has been polished from antiquated occasions. For centuries, people of various nations have been preserving fruits, other crops, meat and fish by drying. Drying is also beneficial for hay, copra, tea, and other income producing non-food crops. With solar energy being available everywhere, the availability of all these farm produce can be greatly increased Nwaokocha *et al.* (2018) and(Timilsina *et al.*, 2012). Accordingly, extensive studies ought to be done to beat the current obstructions and issues. Besides, the public authority should uphold and put resources into the necessary frameworks and reinforce the private area to assume a critical part in environmentally friendly power areas (Mohammadi *et al.*, 2014). Medicinal plants and crop losses and spoilage from rain and animals are prevented because the crop is protected within the solar dryer (Fuller, 2000).

7. FACTORS INFLUENCING SOLAR DRYERS

Solar energy is a kind of cost-free energy which man uses for various purposes from centuries. Use of solar dryers is a unique method in which solar energy is applied for drying products. Solar dryer is made by keeping lots of points in our mind (Chavan *et al.*, 2020).Various elements are successful during the time spent planning, building, and utilizing sun-based dryers in various areas. Design used for solar heater is an important factor which plays important role in its working and result. Various other factors including, heat transfer augmentation, efficiency, Thermal energy storage, type, position of solar dryer and its installation with its operating conditions are also major factors on which working of solar dryer depends (Saxena *et al.*, 2015). All these features of solar dryers are especially important for developing countries(Zhang *et al.*, 2011). If we consider physical features of dryer as a parameter then features will directly depend on type, size and size, collector area with no. and area of trays including the convince of loading and unloading. The thermal performance will also depends on the efficiency of dryer with the drying rate and time consumed (Visavale, 2012).

8. MODELS OF SOLAR DRYER

8.1 THIN LAYER SOLAR DRYING

The solar models of thin layer drying are new sun dryers used for drying purposes that fall into three categories: hypothetical, semi-hypothetical, and experimental, expanding to our understanding of horticulture materials' drying properties. The hypothetical methodology is concerned with the dissemination condition or simultaneous warmth and mass exchange condition, the theoretical approach is concerned with approximated hypothetical conditions, and observational conditions are effectively applied to drying reenactment because they rely on exploratory data. The hypothetical techniques only address the item's internal protection from dampness movement, whereas the theoretical and observational approaches only consider the item's external protection from dampness movement(Usub *et al.*, 2010). Recently, many researchers have focused in their experiment on the mathematical measurement with full working of thin layer solar radiation based drying apparatus used for drying of plant based products (Bala and Mondol, 2001; Belessiotis and Delyannis, 2011), green pepper, bean and squash (Bena and Fuller, 2002), *Eucalyptus globules* (Bennamoun and Belhamri, 2003), mint, verbena, and sage (Beuchat, 1981), pistachio (Baird *et al.*, 1981; Ayensu and Asiedu-Bondzie, 1986) and prickly pear fruit (Böer, 1978).

8.2 DEEP BED SOLAR DRYING

In this model of solar radiations-based dryer, the solid phase is stationary and remains in the dryer for a certain time while gas flows through it continuously. Drying begins at the inlet end of gas and progresses through the entire bed, as temperature increases inside the dryer the proper ventilation to the product is provided by the specially designed chimney for solar radiations based dryer (Ekechukwu, 1999; Chen and Qu, 2014).Clearly the product kept at lower zones dries more quickly than other zones. The environmental air gets inside from the lower to the upper zone and expands its dampness substance and cools because of evaporation process. Along these lines a slope of heat and humidity is shaped between the above as well as downward zones. Final unchanged liquid concentrations the average dampness concentration for both zones. Major points of solar drying, on which drying depends are the rate of blowing of environmental air, ambient temperature of dryer, and height of the tray where product is kept for drying. If we analyze all these parameters of a solar dryer a simple and easy to use sun based drying apparatus can be easily prepared with decreased waste material and increased standard quality of plant material.

An experiment has been conducted (Kumar *et al.*, 2012), on transfer of heat and contact factor ie. friction of sun powered air warmer in which discrete multi angular rib has been placed. It is inferred that by giving hole in the multi angular rib plan, generous upgrade in the warmth move of the roughened channels is noticed. Nusselt number of

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roughened conduit when contrasted with that of smooth channel has been discovered to be expanded somewhere in the range of 5.54 and 6.32 for the scope of boundaries explored. The most extreme estimation of Nusselt number and grinding factor has been discovered to be happen compared to a relative hole width of 1.0. Further, discrete multi angular rib unpleasantness has been discovered to be thermo-using pressurized water better setup in contrast with different ribs arrangements explored by different specialists under comparable working conditions.

Pirasteh *et al.* (2014) contemplated distinctive sunlight based drying applications in Malaysia. They have talked about the efficient, political, and natural parts of utilizing sun-based dryers. They have introduced and contrasted various techniques with monetary examination of sun based drying applications, which have been utilized in various nations. The effect of various nanofluids and geometrical parameters on energy efficiency is discussed and a detailed study on parabolic collectors was done by numerous investigators so that energy efficiency is increased by using fins, twisted tapes, and nanoparticles of different sizes, shapes, and orientations with which the energy efficiency was increased(Kumar *et al.*, 2020).

Drying is the most well-known technique for therapeutic plant safeguarding and, because of high speculation and energy costs, drying is likewise an enormous cost in restorative plant production. Thus, solar drying for preservation of medicinal plants is a best option (Esper and Mühlbauer, 1998).Drug quality and consequently income are altogether affected by the drying system. Expectedly, low drying temperatures somewhere in the range of 30 and 50°C are prescribed to secure delicate dynamic fixings; however the decelerated drying measure causes a low limit of drying establishments (Müller and Heindl, 2006).

The fabricator's experience and judgement are used to make the ultimate decision, which is dependent on the available insulation rate, production throughput, flexibility needs, cost of fuel to run accessories, and the fabricator's experience and judgement (Visavale, 2012).

Moisture removal is the one of main aspect for drying medicinal plant parts after their collection from nature. In the end of drying final moisture content will provide the actual medicinal property of plant, by loosing moisture at a specific temperature for a specific duration of time (Lekhal *et al.*, 2003). The drying rate of product can be increased by the expansion of arrangements of sugar and starch levels (Beuchat, 1981). Fennell *et al.* (2004) examined the impact of drying out rate on the protected stockpiling of spice and discovered drying as a fundamental part which targets diminishing dampness content, keeping away from enzymatic and microbial action, and thus saving the item to broaden time span of the product. Mbondo *et al.* (2017) done an experiment on impact of drying techniques on the maintenance of bioactive mixtures in African eggplant and researched the impact of four drying strategies (sun powered oven, vaccum and freeze) on the maintenance of total phenolics.

Table 4 Showing review of solar drying studies carried out Medicinal Plants of Himalaya.

Plant name	Part of plant used	Drying Temp.	Type of dryer	Duration of drying	Reference
*Hemerocallis lilioasphodelus*L.	Flower	90°C	Direct solar dryer	48 hrs	(Liu *et al.*, 2017)
*Zingiber officinale*Rosc.	Rhizome	34°C	Open sun drying	9 hrs	(Ghasemzadeh *et al.*, 2018)
		47°C	Solar tunnel drying		
		180°C	Hot air drying		
Metha sp.	Whole plant	32.6°C	Direct solar dryer	3 days	(Sallam *et al.*, 2015)
		46.5 °C	Indirect solar dryer	3 days	
Vitis sp. L.	Fruit	46°C	Direct solar dryer	228 hrs	(Doymaz, 2012)
Moringa oleifera L.	Leaves	46.5°C	Solar tunnel dryer	4 hrs	(Vaghela, 2018)
		32.2°C	Open sun dryer	7 hrs	
*Valerianajatamansi*Jones (Syn.V.Wallichii DC.)	Rhizome	43.11°C	Sensible heat storage material is used in indirect forced convection solar dryer	120 hrs	(Bhardwaj *et al.*, 2019)
Andrographis paniculata(Burm.f.)Wall.exNees	Whole plant	35- 75°C,	Parabolic-shaped solar tunnel dryer	18 hrs	(Srisittipokakun *et al.*, 2012)
Mentha piperita L.	Leaves	40°-60°C	Greenhouse type solar dryer	4hrs	(Müller *et al.*, 1989)
*Salvia officinalis*L.				3hrs	
*Humuluslupulus*L.				3 hrs	
Mushroom	Whole plant	37- 66.5° C.	Solar tunnel dryer	8 hrs	(Bala *et al.*, 2009)
Moringa sp.	Leaves	25°C	Indirect forced convention solar dyer	24-30hrs	(Amedorme *et al.*, 2013)
Moringa oleifera	Leaves	35-40°C	Solar greenhouse dryer	9 hrs	(Rajesh and Sivakumar, 2020)
*Azadirachtaindica*A.Juss.					
*Trigonella foenum-graecum*L.	Leaves	40-45°C	Solar cabinet dryer	900 min	(Bishnoi *et al.*, 2020)

9. SOLAR DRYING OF AROMATIC PLANTS

The therapeutic and fragrant aromatic plants hold a huge prominence for both the drug business and the conventional use. Müller (2007), stated that drying is the most appropriate method of preserving aromatic plants (MAP) due to its fast conservation of active constituents in the plants when the appropriate drying treatments are administered. Drying, in essence, does not only prepare the MAP for storage, but also for an immediate pharmaceutical application that cannot be provided when the aromatic plants are in the fresh form (Lorenzi and Matos, 2002). Open sun or shade drying is prone to dirt and interference from both weather and animals that prolongs the period of drying (Ndukwu *et al.*, 2021).Therefore, researchers identified that among all the accessible energy for solar drying is the most economical because it provides boundless, free and clean energy with a little investment (Ramde, 2003; Ndukwu *et al.*, 2021).

Nourhène *et al.* (2008), found the effective diffusivities of different varieties of olive leaves found in Tunisia to be 2.95×10^{-10}–3.60×10^{-9} m2 /s. The products were dried using an indirect class of sun radiations based drying apparatus which ranges from 40- 60 °C of temperature and humidity of 29–32% with environment air flow rate of 0.0556meter cube per second. The activation energy ranged 52.15–83.60 kJ/mol with a page model as the best fitting model for moisture ratios. They concluded that the effective diffusivities are a function of temperature and variety.

The leaves of *Ocimum basilicum* were dried by using direct solar dryer at the temperature of 31.2-70.8°C(Ozcan *et al.*, 2005).For *Ocimum basilicum*, a gradual decrease of hue from 96 to 91 was observed with drying temperature from 35-50°C(Rocha *et al.*, 1993). For *Urtica dioica*, hue decreased from 125 to 111 for an increase of temperature from 50 to 125°C (Alibas, 2007). Midilli-Kucuk model of indirect solar dryer was used for drying medicinal leaves of *Urtica dioica* for 50-260 minutes at the temperature range of 40-60°C (Lamharrar *et al.*, 2017).Final liquid concentration of product is decreased at the level of0.0975 – 1.584 kilogram (water per kilogram dry matter)is found that the best model of solar drier is Midilli-Kucuk, for the drying of Citrus leaves, bends Jew's mallow, spearment and parsley (Fatouh *et al.*, 2006).Drying examination of *Clinacanthus nutans* leaves in heat siphonhelped sun powered dryer provides the experimental strategy for the extraction purpose of vitexin and orientin (Ng *et al.*, 2018).The sample dried under sun radiations where a specific heat pump producing warmth leads to decrease dampness at the level of 31.14%. Results analyzed the dried outcome in sun-drying was 35.84% at 28.1 - 46.2°C temperature, and 28.7 – 48.0 °C temperature in solar dryer with presence of heat siphon. *Eryngium foetidum* are highly medicinal aromatic plants of Himalaya. Aerial parts of these plants are used to treat diseases by local people. An experiment was done to remove the dampness from aerial parts *Eryngium foetidum* by using direct solar dryer for eight hours to achieve the standard product (Banout *et al.*, 2010).

Mohamed *et al.* (2005) chose aberrant constrained convection sun-oriented dryer in order to get dried leaves of *Citrus aurantium*. The degree of warmth of solar dryer is the primitive factor of whole dampness removal technique.

The dryer with provision of heat pump is used to remove the dampness from plant material. The solar radiation bases dryer with holding capacity of 28 kilogram per meter square area resulted in the standard outcome in terms of quality as well as quantity at temperature of 55 degree Celsius with speed of 2.7 meter per second Beans of coffee were also analyzed for the removal of moisture content under solar drying by using direct solar dryer and indirect solar tunnel dryer for six days at the temperature of 40- 70°C (Bala and Janjai, 2009).the leaves of *Laurus nobilis* were also dried at the temperature of 40-60°C in an indirect solar dryer for six days to get the standard dried product (Ouafi *et al.*, 2016).

10. SOLAR DRYER AS COLOR INFLUENCER

Solar drying also influences the color yield of the plants. As many medicinal plant species are used as tea, color is an essential quality criterion because it is directly apparent to consumers. In a comparison study of these parameters involving ranking by a panel of specialists, hue proved best to represent quality in terms of color of dried *A. dracunculus* (Arabhosseini *et al.*, 2005).

Shading is the significant part of value all through farming and food industry. Since shading is firmly connected with variables like newness, readiness, attractive quality, and food handling. It is regularly the essential thought of customers when settling on buying choices (Koç *et al.*, 2018).The color change kinetics of food is a complex phenomenon and there are not much reliable models to predict color change, which can be used in engineering calculations (Arabhosseini *et al.*, 2011). Thermal processing is quite possibly the most broadly utilized and significant technique for food conservation and it influences the food quality as estimated by tangible assessment or instrumental strategies (Guiné *et al.*, 2009).The impact of warm preparing on the shade of food material has been concentrated by different scientists, and diverse shading frameworks have been utilized for portraying shading changes of food material (Arabhosseini *et al.*, 2011).Sometimes the quality of the dried product is decreased if high temperature is used in drying process (Nindo *et al.*, 2003).Thus, the quality of final dried product can be maintained by lowering the temperature of dryer. In this way the quality of product is improved at high level (Beaudry *et al.*, 2004).Color can be utilized for warm handling conditions for augmenting item quality if its debasement energy is resolved. Drying should be executed cautiously in light of a legitimate concern for holding the taste, fragrance, shading, appearance, just as dietary benefit of the plants to greatest conceivable degree (Jin *et al.*, 2018). The use of indirect solar dryers preserves the dried product's active principles, color, and protects the product from external factors and helps in retention of nutrients (Zoukit *et al.*, 2019).

The analysis has been done based on rate, mass and two unique zones incline points. The result concluded that there is a 19% increase in the warmth acquired above the hypothetical digit. The purpose of idea behind experimenting on a solar nursery drying apparatus is to maximize reduce and drawbacks of open-air drying, such as residue, defilements, and issues with final dried product(Rajesh and Sivakumar, 2020).

11. SOLAR DRYING OF FRUITS, VEGETABLES, AND CROPS

Sun oriented energy epitomizes one of the contamination free and down to earth cost-effective fuel sources which are really requesting area around the globe. During the time spent for crop yield creation, post collect drugs are significantly referenced by warm strategies in a couple of food planning applications. A comparative analysis was done on the basis of different research in which various crops are used for drying purpose and after application of temperature from solar energy the moisture content of crop is reduced from initial content of moisture. To avoid the side effects of chemicals the product must be kept in heat for some time prior to chemical treatment process (Grabowski *et al.*, 2003).

Manikantan *et al.*(2014) performed an experiment to analyze the effect of solar drying on dampness removal on grains of paddy by using an integrated solar dryer. The temperature of solar dryer was maintained between 30-35°C for 5-9 hours to reach the standard product. Indirect solar dryer was prescribed for the drying of different species of Capsicum at the temperature range of 25-66°C (Bala and Janjai, 2009);(Prakash and Kumar, 2014); (Rabha *et al.*, 2017). Thus, indirect solar dryer is the best dryer for the drying purpose of chillies. Mango pulp is also dried by using indirect solar dryer at the temperature of 65°C for three days (Bala and Janjai, 2009).

Slatnar *et al.* (2011)they observed that the solar radiation dryer as there is a possible scope to change the structure according to the need of drying products and can produce slight modifications according to their need in terms of size and accessibility. In this way these solar radiations based dryers completely fulfils the necessities of farmers(Sharma *et al.*, 2009).

Chouicha *et al.* (2013)successfully completed the drying experiment on a modified stem (potato) by using indirect solar dryer with convection for only three hours at the temperature of 42.8-50.4°C.The chemical compound processing of grapes fruit for drying purpose decreases the drying time to reach the specific drying rate(Jairaj *et al.*, 2009).

El-Beltagy *et al.* (2007), successfully completed an experiment on the working of indirect solar dryer under different weather conditions of Minufiya, Egypt, and obtained good quality dried strawberry. The working of solar dish to dry the strawberry is satisfactory and the ambient temperature at its peak level, used for the drying of strawberry was 47-48°C.All the vitamins shows their activity user specific temperature. Vitamin A, C and thiamine and riboflavin are sensitive towards the heat and are very specific to oxidative degradation. The sulphuring of vitamins will lead to the destroying of thiamine and riboflavin and even the pretreatments of sulphite and blanching will ultimately leads to the reduction in content of vitamins during the drying process. The product which is passed through the steam blanching has higher amount of vitamin C in comparison to the untreated sample or sample treated with hot water blanching (Ramesh *et al.*, 2001). Thus, solar dryers with required temperature should be used for drying purpose without losing nutrient quality. Shade drying (by covering solar dryers), in dark surrounding leads to the better withholding capacity of nutrients in product (Sablani, 2006). *Zea mays* and *Cicer arietinum* were also analysed for dampness removal purpose by using indirect type solar dryer and mixed mode dryer respectively (Lopez *et al.*, 2014). (Elicin and Sacilik, 2005) done an experiment on drying *of Malus spp* by maintaining the temperature between 21.6-39°C. Indirect solar drying technique is analyzed as best technique to attain proper color and nutrition in final plant product over open sun drying technique. Indirect solar dyer gives better results in less period of time(Elicin and Sacilik, 2005).

12. SOLAR DRYING FOR OIL YIELDING PLANTS

The yield and chemical composition of essential plants square measure associated with sprees of internal and external factors, as an example, the drying(Singh *et al.*, 2015). Drying is the most used way to preserve quality of aromatic and medicinal plants. The methods choice of drying in an optimal temperature is a central economic and ecological criterion. Most of the studies focus on the drying of many plant species with presence of essential oil, revealing the proper temperature to increase the oil yield for various species(Singh *et al.*, 2015).

Singh *et al.* (2019) have done an experiment to analyze the drying capacity of open sun drying method and evacuated tube collector based solar dryer. The higher mean drying rate for selected plants is for evacuated tube collector solar dryer which is clearly higher in comparison to open sun dying method. Maximum efficiency of the whole set up of experiment was calculated as 55% at the temperature of 35.4°C.

An experiment on drying application on techniques to check final yield and chemical constituents of oil obtained from *Mentha longifolia* leaves (Singh *et al.*, 2015). Generally, the increased temperature influences the quality as well as the amount of essential volatile oil in medicative and aromatic plants not solely throughout the drying process, the active ingredients present in plant material reduces as the storage time is increased. According to Muller, (Müller *et al.*, 1992),done an experiment in order to calculate the maximum drying temperature of *Salvia offcinalis* and declared it as 30±C. The 15 % of essential oil is increased and the color of drug also changes from green to gray with respect to enhancement in temperature from 30°C- 55°C. Drying temperature typically has associate degree influence on the temperature wise elements of volatile oil present in plant sample.

The maximum plants belongs to Lamiaceae family which are used as drying product for solar dryer followed by Solanaceae family and is clearly visible in pie chart in Fig.10. Lamiaceae or Labiatae, also called as the mint family, is a family of flowering plants. It had traditionally been considered closely related to Verbenaceae (Harley *et al*., 2004). Labiaceae family comprised of plants including herbs as well as shrubs, and some members of this family have a great aromatic smell (Rajah, 2012).

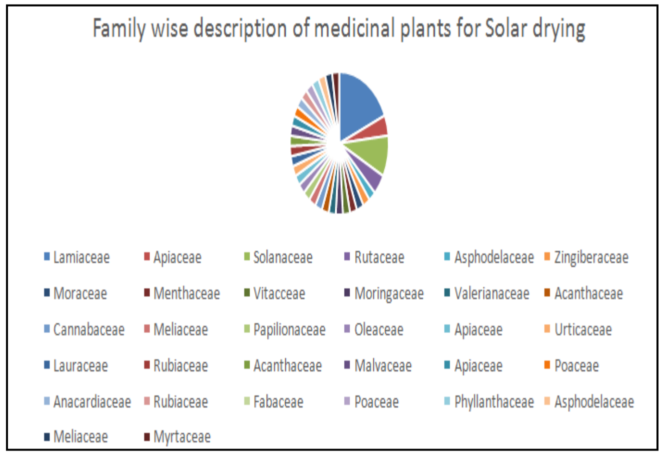

Fig. 10 Pie chart showing family wise description of medicinal plants used for solar drying.

13. FINANCIAL AND TECHNICAL SUPPORT NEEDED TO PROMOTE ADAPTION OF SOLAR DRYERS

Drying plant-based products using a solar-based approach is a great and completely eco-friendly technique that can be easily applied in all parts of the world, including the Himalaya, to boost the state's income. By using this low-cost technique, high-rate income can be achieved in a short period of time with good quality dried products full of nutrients that can boost human immunity, which is in high demand at the moment. It is generally known that due to a lack of contemporary amenities, individuals in some mountainous places have a difficult time adopting newly adjusted procedures. Adoption of solar-radiation-based dryers is achievable, but only with the assistance of new government policies aimed at the general people.

Money, income, technological application, legal framework, norms, and legislations are only few of the limitations to this strategy that may be readily overcome. Policies that can check at frequent intervals after the adoption of approaches that they are operating properly and giving advantage to the user are in high demand. As a result, in order to rescale solar drying, certain steps are required, such as the government encouraging the use of sun dryers since they may enhance the state's and nation's economic rates at extremely cheap costs. It is the responsibility of government to ensure that everyone is aware of such technology and that they are used in accordance with their demands, including agricultural sectors.

There should be a competent system in place for awarding loans to needy persons on a small to medium scale. Before implementing regulations for public welfare, a good agenda should be created based on debate. Researchers, farmers, government agencies, nongovernment groups, and nonpublic organisations should all be represented on this discussion panel.

14. CONCLUSIONS

- Solar dryers have proven to be one of the best environmentally friendly approaches for drying purpose of medicinal plants and agricultural crops. This paper has also presented the ease to construct a solar dryer and provided an idea of its cost.

- As per literature review, it has been concluded that the best option for drying purpose is forced mode drying in comparison to natural sun drying. Including this, forced mode drying is best for the preservation of nature's treasure, as it is faster approach because of presence of glazing over collection area, it is a more efficient and hygienic as the drying material is covered and out of reach of dust. These dryers provide better financial returns to the farmers or collectors of medicinal plants (Sharma *et al.*, 2009).

- The two majors widely known groups of solar dryers are active and passive solar dryers also known as forced convention solar dryer and natural circulation solar dryer, respectively. The present paper has additionally provided the benefits to construct the solar dryer and given the reviewed idea of its cost.

- Indirect solar dryer is more proficient than other dryers and give very good quality of product in minimum cost. It is very vital work area where researchers should focus to enhance the working plan of solar dryers to its application for drying of agriculture products and giving them best price for their product and it requires very less space. It is also use for domestic purpose for drying seasoning products.

- Lamiaceae family has a great economic importance. These kind of low cost and benefit providing solar dryers should be introduced in pharmaceutical companies and rural areas for reduction of plant part spoilage, increase in product yield as well as quality and ultimately will leads to enhanced hygiene. The data presented in paper can be utilized by various pharmaceutical and perfumery industries in their pre and post harvesting programs.
- By keeping all these points in view solar dryer construction and use has emerged as a best replacement to ordinary sun radiations based drying technique. Finally, we can say that the force circulation technique for dampness removal from product gives standard result than natural circulation solar dryer.

- The use of sun radiations-based dryer is the best cost benefit dampness removal approach to preserve the plant based food material, other products including the edible parts of medicinal plants as well as agricultural harvest for longer period of time with minimum harm to the merchandise. Ultimately there is a great requirement of successful cooperation and coordination of communication between research and development authorities, researchers, crop producing farmers, engineers, and food processing industries to maximize the adoption of natural resources at its peak level without polluting environment in Himalayan region.

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