Critical Review On Different Technologies Of Solar Dryers

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Abstract: The storage of agricultural products has long been a problem in developing countries. Because most countries' populations are growing at a quicker rate, food shortages are a possibility in such countries. Many ways of food preservation are utilized to prevent this problem, with solar drying being one of the most prominent. Because solar energy is inexpensive and readily available, it is advantageous to dry agricultural goods in the most efficient manner possible. Direct sunlight exposure to dry things has a negative impact on product quality. It is planned to review a solar dryer technology to achieve higher drying rates in different climates. The primary goal of this study is to review all active and passive solar dryer technologies. Finally, it is concluded that, the food dried in a solar dryer was higher than food dried in direct sunshine. Furthermore, the forced convection solar dryer dried faster than the natural convection solar dryer.

Index Terms: Energy; Renewable energy; Solar energy; Solar dryer; Food dryer; Economical; Food Security

1 Introduction

Food is the most fundamental essential for survival. Minerals are required by humans in order to produce energy. Therefore, this energy assists humans in meeting their demands, whether they are concerned with internal or exterior bodily processes. To sustain life, the human body needs a constant supply of food to maintain a healthy immune system. There can be no compromises in the body's food supply. As the globe progresses, a growing number of studies on the issue of food storage are being conducted [1]. The storage of agricultural goods has been a significant concern in developing countries. As the population is increasing at a faster rate in most countries, the shortage of food can occur in such countries. To avoid this problem, many methods of preserving food are being used, of which the solar drying methods are important ones [2]. In the present era, many methods are being used to preserve food, from which there are some methods in which some reasons do not preserve the minerals of food. The most common reason for the loss of minerals in stored food is harmful rays that are emitted by the sun. So, it is better to go for the method of drying, which does not result in any loss of minerals; as mentioned earlier, "no compromise can be made on supply of minerals to the human body." Storage of food is regarded as the most critical substitute to solve the shortage of food due to the increasing population. The best possible way to prevail in food storage is by consuming solar energy, which is free of cost [1].

It is well known that solar energy is available to everyone and is the cheapest energy source. Thus it is beneficial to consume solar energy in the best possible way to dry agricultural products [3]. In ancient days, people used the direct drying of crops, fruits, and vegetables. Due to direct exposure to sunlight, minerals of fruits, vegetables, and crops were used to burn. It was a significant loss experienced in the method of solar drying. Many scientists took an interest in developing solar drying methods in order to preserve the minerals. Their keen interest in drying methods resulted in an indirect method of solar drying. The research does not stop here; many ideas were also invented that have different merits and demerits of solar drying [4].

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The research will be based on analyzing different kinds of solar drying. The indirect method of solar drying results in no loss of minerals when it is used to preserve food. Since the sun rays are not directly directed on the product to be dried. So, there is less exposure of product with the harmful sun rays. The temperature limit can be controlled as compared to the direct method of solar drying. Cost-effective analysis is to be carried out. Analysis of different thermodynamics terms is to be carried out to compare it with all other types of drying [5]. A. Tiwari [1] carried out an analysis on solar drying process of crops in 2016. Solar energy was used to dry crops in the day time. Thus, no cost for external energy was involved. It helped farmers to stick to the solar dryers to dry crops as it is the most effective and economical method for drying purposes.

2 Solar Drying

Basically, in drying methods, the dehumidification of agricultural products is carried out due to which bacterial activities are slowed down, and food can be preserved for longer times [6]. The method of solar drying is further categorized, as shown in Figure 1.

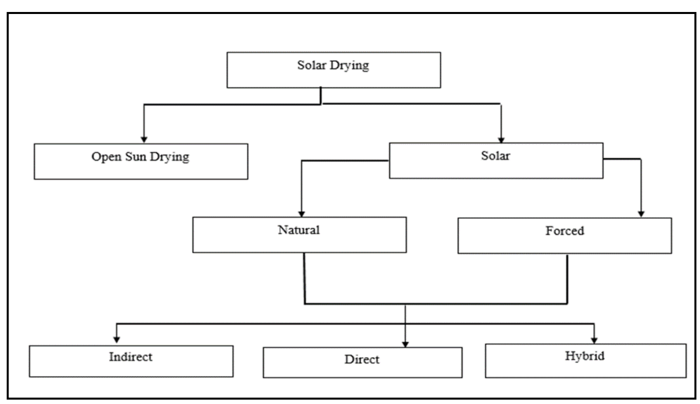

Fig. 1. Characterization of solar drying process [6].

2.1 Classification on the base of air flow

2.1.1. Active solar dryers

In these types of solar dryers, the air is forced into the drying chamber using external energy sources, such as fans, blowers, etc [7]. The illustration of active solar dryer is shown below in Figure 2.

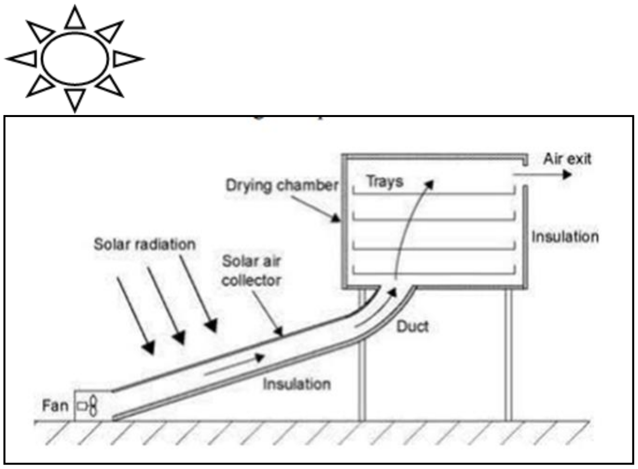

Fig. 2. Illustration of Active solar dryer [3].

2.1.2. Passive solar dryers

In these solar dryers, air is allowed to flow by natural effects, uch as buoyancy. These solar dryers are suitable for a small level of drying purposes, i.e., a small quantity of food [7]. The illustration of passive solar dryer is shown in Figure 3.

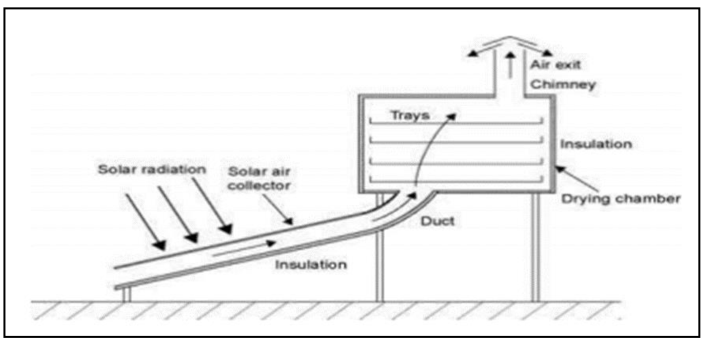

Fig. 3. Passive solar dryer [7].

2.2. Classification on the base of contact

2.2.1. Open sun drying

In this method, the product to be dried is directly placed in open sunlight, due to which the minerals in products get burned. Since UV rays are harmful to crops and foods, thus it is beneficial to avoid direct contact with crops and the sun. Not only this, but there are many chances of crops and food contamination due to insects and changing weather conditions. The quality achieved in dried crops' open sun drying process is a compromise. The food obtained thus does not fulfill the requirements of human supplements. It was the primary method of drying crops and fruits to preserve food [8]. The open sun drying is presented in Figure 4 [9].

Fig. 4. The open sun drying [9].

2.2.2. Indirect solar dryers

An indirect solar dryer contains a drying chamber and a collector. The collector collects the incoming air and sends it to the drying chamber. The product to be dried is placed in a drying chamber. The drying chamber is made of an insulating material that does not allow sun rays to enter through it. The collector has glass on it. The glass is placed on the top of the collector to pass sun rays through it. The air flowing in the collector gets heated due to sun rays. This hot air then goes into the drying chamber. The hot air coming into the drying chamber carries away the moisture of food to be dried along with it and leaves the drying chamber by an exhaust pipe. The indirect solar dryer should be made in such a way so that no moisture could enter through it. The closed structure of this type of dryer also does not allow insects to contaminate the food. Thus, in this type of solar dryer, no compromise is made on the quality of food, and food obtained is enriched with the minerals necessary for humans' requirements. In indirect solar dryers, the drying chamber and collector are separate units, due to which in indirect solar drying, the product to be dried is not directly exposed to harmful sun rays. Thus the quality of the product obtained in an indirect solar dryer is reasonable compared to all other solar drying methods [8]. The indirect solar dryer is shown in Figure 5 [7].

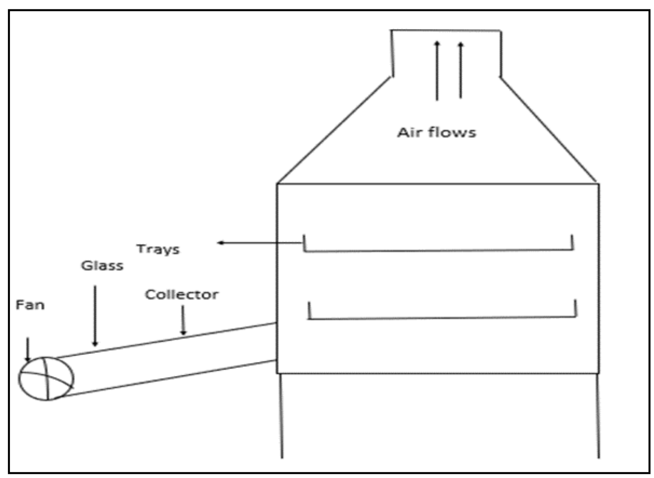

Figure 5: Illustration of indirect solar dryer [7].

2.2.3. Direct solar dryers

The drying chamber and collector are a single unit in direct type of solar dryers. This means that the drying chamber itself is made of glass. The air comes into the drying chamber and gets heated, which then carries away the moisture content of food, and food is then dried. The only advantage achieved in this method is that the food is prevented from insects and changing weather conditions. Although harmful rays may pass through glass and are directed upon food, thus resulting in minerals loss, the advantage is the low initial cost to establish a solar dryer [10]. The illustration of direct solar dryer is shown below in Figure 6 [10].

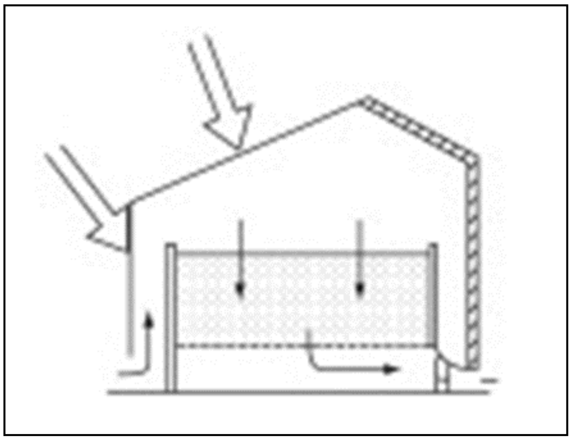

Fig. 6. Illustration of direct solar dryer [10].

2.2.4. Hybrid solar dryer
A hybrid solar dryer is the dryer in which the method of drying is obtained by using both direct and indirect solar dryer techniques. In this method, the temperature of the drying chamber is more than individual direct and indirect solar driers, thus decreasing the drying process time. Though the compromise is made of the quality of food. The high temperature in the drying chamber is achieved because both the collector and drying chamber are exposed to the sun. The air first gets heated in the collector and then in the drying chamber, increasing its temperature. The illustration of hybrid solar dryer is shown in Figure 7 [11].

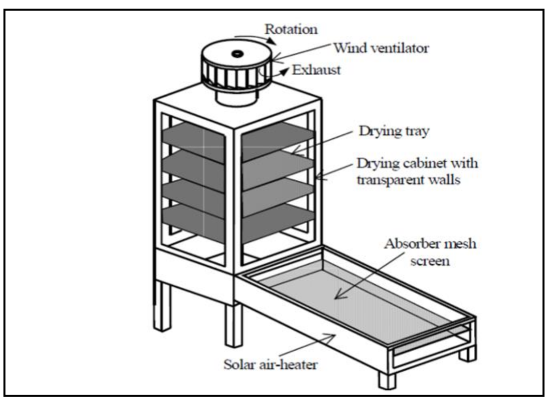

Figure 7: The illustration of hybrid solar dryer [11].

2.3. Classification on the base of energy source

2.3.1. Natural & forced solar convection dryer
In a forced convection solar dryer, an external source is used to increase the heat transfer rate, whereas, in a natural convection solar dryer, no external source is used [12]. The forced convection process usually demands more cost than natural convection solar dryers. Thus, it is not economical to go for forced convection solar dryers. Since in today's era, the world is also facing an energy crisis, so natural energy sources should be used to overcome energy issues. As solar energy is free and readily available, it is beneficial to use solar energy only for drying purposes [12].

2.4. Benefits of solar dryers
Some of the most significant benefits of solar dryers are discussed as follows [12]:

1. The quality of dried food is better.
2. The temperature achieved is high.
3. Due to high temperature, drying time was less.
4. Food is prevented from insects.
5. Food is not exposed to moisture during the rainy season.

2.5. Disadvantages of solar dryers
Followings are the flaws of solar dryers [12]:

1. The use of solar dryers is limited only during the day, although it is made to make it useful at night and by using some storage medium of energy.
2. The temperature achieved in solar dryers is sometimes very much higher than the needs, which may distort food quality.
3. During rainy seasons, the use of solar dryers is not beneficial.

2.6. Applications
It is used in drying spices like chilies, coriander, pepper, and turmeric and dehydrating fruits and vegetables like mango, grapes, banana, carrot, potato, and many others. It is also instrumental in drying herbs that need to be protected from direct sunlight. Medicinal plants used to benefit from the solar dryer. Solar dryers assist in reducing fuel use and pollution and increase the quality of the final product. Another application of solar energy in agriculture is greenhouse heating. Solar greenhouses are designed to use solar energy for heating and lighting as needed to maintain the temperature required to grow plants throughout the winter months. People have been drying fruit and vegetables for thousands of years to save for a rainy day. New technology ushered in new ways, but the growing desire for nutritious, low-cost natural foods, as well as the requirement for long-term income, has pushed solar drying to the forefront as a viable option for excess items.

1. Dried fruits and vegetables, high in vitamins, minerals, and fiber, boost family nutrition; for diabetics, dried fruit cooked without sugar is a healthy alternative to treats.
2. Dried fruit can be eaten as a snack or used in stews, soups, and casseroles. It can also be used to make ice cream and baked goods, and cereals for breakfast.
3. It strengthens farmers' bargaining position. Because they can't store or keep their surplus crops, farmers can sell at relatively low rates during the harvest season.
4. Individuals are encouraged to start their gardens.
5. Drying takes less time because the dryer is warmer than the outside.
6. Because of the speed with which the food is dried, there is a lower chance of deterioration. (If the drying process is too slow, the fruit will ferment and destroy the product.)
7. The item is resistant to insects, bugs, rain, and dust.
8. It saves time and effort.
9. The product's quality is improved in terms of nutrition,

hygiene, and color when kept in the dryer overnight or during rain.

Professional drying techniques can be used in solar drying to meet the genuine needs of huge agricultural productions while also ensuring product quality and consistency. A solar batch convection dryer designed along these lines is given, and its efficacy in drying fruits and vegetables and the methodologies employed to dry these goods are addressed. The drying of materials is an essential and necessary mechanism in the manufacturing process. Fruit and vegetable drying is a time-honored method of food preservation. Aside from agriculture, several industries exist, including automobiles, rubber, paper and pulp, sugarcane, wastewater treatment, lignite/coal, and require heat energy for drying during production processes. The thermal energy required for drying is provided by conventional energy sources such as coal, natural gas, and electricity. Solar energy-based drying systems can be promoted due to the increased expense and pollution associated with conventional sources [13].

2.7. Summary of different solar dryer technologies

The summary of the different solar dryer technologies is presented in Table 1.

Table 1. Summary of different solar dryer technologies.

Authors	Study Objective	System Specifications	Parameters	Outcome	Ref
A.A. El-Sebaii et al. 2012	Solar Drying of Agricultural Products: An analysis.	---	---	Indirect forced convection solar dryers are regarded as better in speed and quality since they dry quickly and well. The solar water heater should be better if it receives an improvement.	[14]
A. Djebli et al. 2020	Comparison of how potatoes dry in the sun.	ITSD has a drying chamber volume of 0.46 m^3, Tray surface area of 0.57 m^2. Duct diameter and length are 0.08 m and 0.8 m respectively. MSD has a Greenhouse volume of 30.6 m^3. In MSD carts, dimensions are 1.1 m length, 0.65 m width, 1.5 m high. Tray surface area and collector surface area is 0.65 m^2 1.82 m^2.	The maximum temperature in the collector surface of ITSD is 69^{o}C, and the flow rate of air is 0.01 m^3/s. The maximum temperature in the collector surface of MSD is 77 ^{o}C equipped with fins. The flow rate of fans used for the collector is 0.0225 m^3/s. The flow rate of circulation and moisture extraction fans is 0.19 m^3/s.	For ITSD, the drying rate of sliced potatoes is better than it is for MSD. ITSD has a better drying time than the MSD, although the MSD performs better than ITSD in terms of thermal efficiency. To obtain the optimal effective diffusion coefficient, we implemented Fourier series and Laplace transformation methods.	[4]
N.Bekkioui 2020	A numerical simulation of three different solar dryer designs and their comparison in regard to economics and performance.	The volume of the drying wood is 1.5 m^3. The area of the D1 solar dryer of opaque and transparent walls are 5.40 m^2 and 18.72 m^2. The area of the D2 solar dryer of opaque and transparent walls is 15.72 m^2 and 8.40 m^2. The area of the D3 solar dryer of opaque and transparent walls is 18.92 m^2 and 5.20 m^2	The heat transfer co-efficient for inlet and exits are 8 W/m^2 & 12 W/m^2	Solar dryers having large transparent cover areas showed a higher drying rate. The use of double gaze configuration results in a decrease in drying rate and an increase in cost up to 130 %. The combined use of Plexiglas-Glass resulted in a decrease in drying rate of 25 % and an increase in cost up to 57%.	[15]
W.Wang et al.2018	Comparative examination of a solar dryer utilizing indirect forced convection and the thermal	Indirect forced convection mode Mango is used as a drying product	Weather conditions (sunny and cloudy). Solar radiations	Analysis on both weather conditions sunny and cloudy. IFCSD has high performance than previous	[16]

	output of the mango.			industrial dryers. Analysis based on theoretical and experimental data.	
S.Singh et al. 2012	The invention of a new method for solar dryer thermal testing: Creating a generic drying characteristic curve.	A 3 phase, 1440 rpm, 0.5 hp electric motor, glass-covered 4 mm glass cover, and aluminium sheet 22 gauge with black paint dryer; size 0.54*0.43*0.46 m for the chamber, size 0.92*0.54 m for the air heater, mixed-mode solar dryer, 0.644 mm aluminium sheet, and a size 0.43*0.46 m aluminium plate.	There were sixteen experimental settings, including a 750 W/m^2 temperature absorbance rate, a flow rate of 0.011 kg/s, an 8 mm thickness, and a loading density of 2.16 kg/m^3.	Dryer performance index DPI is independent of diverse operational parameters and food product properties.	[17]
A. Sreekumar et al.2008	Behavior of indirect solar cabinet dryer.	Using two axial flow fans (which can help speed up drying) and an air input, the drying rate can significantly increase. After no load was applied, the dryer's temperature	(38.1, 38.1, and 1.6 mm) square aluminum block All four walls (bottom, sides, and top) were filled with rock wool insulation. an aluminum sheet covered with black paint in 24 SWG	The drying time was decreased, and the product's original color remained even after the drying process. 42% less money was needed to build a solar dryer than an electric dryer.	[18]

		reached 97.2 ^{o}C, and it was 78.1 ^{o}C when 4 kg of laundry was added.			
V.Gupta et al. 2012	Analysis of an indirect solar dryer that includes a solar air heater.	Mass flow rate in natural & forced convection 0.00653 & 0.019 kg/s. 45 ^{o}C in natural and 40 ^{o}C in forced convection and comparison between natural and forced convection.	1300 mm 600 mm 120 mm made from 12 mm thick plywood. Glass wool insulator having 0.07 W/mk. 40mm thick insulation	Overall efficiency is about 17%. The natural mass of tomato converts 1800 to 180 g, and forced convection it 1800 to 140 g. 0.00653 kg/s & 0.019 kg/s mass flow rate found in natural and forced convection.	[19]
I.Simate 2001	Planning mixed-mode and indirect-mode natural convection solar dryers for optimum performance.	Mixed-mode & natural solar dryer having collector length 1.8m indirect 3.34 m capacity 90 kg drying costs are 12.76 and 16.05 US$/ton	The solar simulator irradiated 635 W/m2 of radiation in the experiments, and the average temperature was 27^{o}C.	ITSD drying is more expensive than mixed-mode drying. Since direct radiation at the top of the grain bed accelerates the drying of the mixed type, the moisture content is consistent.	[20]
S.Sami et al.2011	Extensive mathematical modelling led to conclusions for indirect solar cabinet dryer energy and exergy analyses.	Direct cabinet dryers are known for being very energy-efficient. During lunchtime, efficiency suffers the most. Additionally, the minimum		The outlet air temperature has the most significant value of 69 ^{o}C. In this heat level, the collector outputs 2.5 kW of maximal energy and 1.12 kW of maximum	[21]

		total exergy efficiency was 32.3% and 47.2%, respectively, on the first and second days.		exergy. More airflow via the collector will result in decreased efficiency.	
A.Lingayat et al.2020	Analyzing the Amount of Energy and Exergy Released during Banana Drying with a Natural Convection Solar Dryer.	Indirect type solar dryer, FPSAC is 2 1 0.1 m, chamber is 10.41 m tilt angle was 30, aluminum sheet at the bottom of the absorber.	Solar radiation was from 335 to 1210 W/m^2, and the drying air temperature ranged from 38 to 82 ^{o}C.	Between 7.4 and 46.58 percent of exergy is utilized. There was a 7.4 and 45.32 percent increase in exergy efficiency. A study was done, and, on average, the collector had 724.36 W of heat loss, and it was quite variable, ranging from 163 W to 1208 W.	[7]
W.Chaouch et al. 2018	Experimental testing of sensitive-heat storage active direct and indirect solar dryer for camel meat drying in Saharan environment.	Indirect and direct forced convection, 28° tilt angle, absorber plate of metal of thickness 5 mm with black coating, 95 × 100 × 4 cm duct, 90 × 60 × 15 cm^3 indirect chamber, (50 × 50 × 50)/2 cm^3 direct chamber,	Airflow 120 m^3/h, temp. of −10 to 70 °C, 257 m above sea level, July and November,	On average, indirect drying efficiency was 18.34% in July, while direct drying efficiency was 10.35% and 7.88% in November. The heat storage systems that were good for the user were boosted by 28% of that benefit coming from indirect and direct heat storage,	[3]
				respectively.	
E.El-Sebaii et al.2013	Investigations of a solar dryer for drying thyme and mint, which utilized indirect mode forced convection, were performed.	Mint and thyme curing tool. A double pass corrugated plate blower/v-pump air heater.Forced convection mode, which employs an intermediate fluid	For mint: Weight= 2000 g Drying temperature = 39-54°C Drying time= 5hours Initial moisture content = 85% Final moisture: content= 11+- 0.5% For thymus: Weight =4000g Drying temperature = 39-59°C Drying time = 34 hrs. Initial moisture content= 95% Final moisture content =11+-0.5	How long they need to dry is dependent on how much they contain. Mint cost was 0.025 €/kg to dry, while thymus cost 0.087 €/kg.	[12]
B.Lamrani et al.2020	A case study on the use of solar thermal applications. The case study presents thermal performance and economic analysis of an indirect sun drier of wood integrated with a packed-bed thermal energy storage system.	A new numerical model was built to evaluate the dryer system's thermal behavior, and simulations were carried out using TRNSYS software.	A drying chamber is 5 m long, 3 m wide, and 2.5 m tall, with a total volume of 37.5 m^3, and the wood stack size is 6.48 m^3. The layers are separated by 27 mm.	Wood dryness and overall drying time can be increased by increasing the drying air velocity and the solar collector area. TRNSYS was used to simulate an indirect solar dryer that integrates PBES and wood, and the error between measured and anticipated outcomes was around 2.49 %.	[22]
A.Bhardwaj et al. 2017	A research project focusing on testing the experimen	Valerian jatamansi (herb), Forced convection mode,	Solar intensity, thermal storage material, relative	The product dries its moisture from 89% to 9,	[23]

	tal solar dryer with phase change material (medicinal herb)	used phase change material (paraffin RT-42)	humidity, weight, air mass rate	Phase change m/t reduces the drying time. Phase change m/t helps to supply hot air after sunset (5 PM to 11 PM)	
S.Shalaby et al.2015	Phase Change Material Is Used for Energy Storage in Solar Drying of Nerium Oleander Using Indirect Solar Energy.	Indirect Solar dryer with PCM, (30^o) tilted surface, 3 phase induction motor (2610 r/min), fan (0.3 m diameter), Midilli and Kucuk model for NeriumOleander	Nerium Oleander dried at temp. (50±2.5 ºC), 14 hours drying time,	high thermal conductive particles with paraffin wax as may improve the thermal performance of the indirect solar dryer.	[24]
H.Guler et al.2020	An experimental study and computational fluid dynamics (CFD) simulation of a commercially viable, low-cost iron mesh-based indirect solar dryer	double-pass indirect solar dryer with flat plate double-pass collector and mesh modified double-pass collector, 600 × 400 × 1 mm, box dimensions are box dimensions (700 × 400 × 250 mm), Glass with 4 mm thickness, 0.92 emissivity, 0.05 absorptivity. 40 W DC fan.	0.011 kg/s air mass flow rate, moisture content 22.10 ± 0.30 g water/g dry matter, n 37.69°N latitude and 30.34°E longitude in March, Platform with 32° tilt angle, fan run for 15 minutes. 22.98 °C, 22.50 °C, 14.60 °C and 16.70 °C ambient temp in 4 different experiments.	The mean collector efficiency rates in experiments 1, 2, 3, and 4 were 70.60%, 72.15%, 80.39%, and 78.06%. The collector's thermal performance improves when the mesh is added to it.	[25]

3 Conclusions

In developing countries, agricultural produce storage has long been a challenge. Food shortages are a risk in most countries since their populations are rising at a faster rate. To avoid this problem, many methods of food preservation are used, with solar drying being one of the most popular. Solar energy is cost-effective and readily available; therefore, it makes sense to dry agricultural commodities as efficiently as possible. Exposure to direct sunlight to dry goods has a detrimental influence on product quality. It is proposed to examine a solar dryer technology capable of achieving more excellent drying rates in various climes. The fundamental objective of this research is to examine all active and passive solar dryer technologies. The quality of food dried in a solar dryer was higher than that of food dried in direct sunlight. Furthermore, the forced convection solar dryer dried the food items faster than the natural convection solar dryer. The quality of food dried in the solar dryer was good compared to the open drying process. In the open drying process, the quality of food items was not good since, in direct contact with the solar radiation, the minerals of food items got burned, and discoloration occurred. The weather condition had not affected the quality of food items dried in the solar dryer, while the one dried in an open environment was affected by dust and other weather conditions. Furthermore, both natural and forced convection produced effective outcomes for the forced ones. Food items dried in the natural convection sun dryer took longer than those dried in the forced convection solar dryer. Finally, it was demonstrated that an indirect sun drier with forced convection installation provides the best contribution to drying applications.

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