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A Review on Possible Combination of Solar Dryer Materials for Crops in the Philippines

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ABSTRACT: Direct sun drying, also known as open sun drying, is the most cost-effective and environmentally beneficial technique of agricultural product preservation, but it degrades crop quality. Solar dryers play an essential part in producing high-quality and hygienic products; however, it is cost and maintenance expensive. Also, it has an inadequate drying performance when off sunshine period, night-time, and especially during different seasons. As a result, this study looks at a variety of low-cost options, high-efficiency materials that have been used in previous studies to give further research, an idea on what would be the ideal combination of cost-effective materials that can be used by small-scale farmers in far-flung areas with off-grid. In addition, this study explores several optimization methodologies, procedures, and processes for efficiently storing energy even when solar radiation is low to further optimize and prolong the solar dryers' performance.

KEYWORD: solar air heater, inflatable solar dryer, energy management, energy storage, crops, control system

1. INTRODUCTION

Open sun drying was introduced a decade ago for agricultural product preservation and storage. This method of drying is still widely used nowadays. However, open sun drying faces many inherent limitations like overexposure to the sun, which causes food damage, high losses in yield production due to insects, rodents, and birds, longer drying time, and unpredictable climate conditions [1] [2] [3]. With such disadvantages, solar dryers' implementation has drawn promising effects, especially of high-valued crops [4]. Solar dryers can be viewed as an optimization of the traditional drying under the sun. Thus, many types and models of solar dryers have been studied and developed [5] [6] [7], and different forms of dryer systems depending on the component arrangements, and solar heat utilization mode was classified by various researches and studies [8].

Modes of heating and a process in which energy source is being utilized are two classifications of solar drying (direct mode and indirect mode). These techniques may be categorized into two major methods, the solar drying in passive system and the solar drying in active system [9]. In each significant class, there are three different subclasses (a. primary-form solar dryers, b. spread-method of solar dryers, and c. combined-method of solar dryers). These are defined primarily by the utilization mode of solar energy and the components' arrangement and design. To date the additional disadvantage of solar dryers is the control of humidity and temperature inside the drying chamber and the intermittent drying performance of the dryer during the night-time and off-sunshine periods. Most research focused on maximizing the heat gathered inside the drying equipment, setting aside the condition that there is a constant change in weather or season (dry and wet), resulting in shrinking of products or over-drying during the dry season and raw drying during the wet season. Moreover, intermittent drying condition does not allow solar dryers' continuous function, resulting in incomplete dehydration and unsatisfactory product quality [10] [11]. Thus, a variety of published journals studied the optimization of the solar dryer, taking into account its effectivity during night and off sunshine [12], concentrating on the modelling [13] [14], simulation [15], and experimentation [16].

The goal of this review paper is to assess the various combinations of cost-effective components and a more simple solar dryer optimization technique that local farmers might employ. Thus, the introduction of hybrid solar dryer harnessing photovoltaic panels and integrated solar air heater as a hybrid energy source, inflatable solar dryer as a low-cost drying chamber were extracted in this paper. This study will also look at the benefits of employing these technologies and how they can be implemented holistically in developing countries such as the Philippines because even if there are numerous technologies available, the current state of drying is still based on traditional ways. According to [17], poor handling and preparations are the primary cause of post-production losses in developing countries like the Philippines, resulting in delayed, incomplete, or inefficient drying. Public road dryers are frequently employed to dry crops in rural locations where motorists may drive over and destroy the crop. See figure 1. Thus, the need for solar dryers is a necessity to have a quality crop.

Figure 1. Current drying set-up in the Philippines

3. METHODOLOGY

The lack of a storage facility for agricultural products is one of the most common challenges that local farmers and tenants' encounter. As a result, the authors focused the search on guidelines and circulars, reports, web resources, and scientific papers on the method, state, and underlying difficulties of solar dryer implementation and development. Following that, methodologies and materials on solar dryer concept and performance optimization were found and summarized using peer-reviewed research publications and case studies. Moreover, the authors' perspective on the integration of prospective low-cost technologies from energy sources for off-grid applications, solar air heaters materials, and solar dryer chambers that local farmers can use and adopt is proposed as a result of the analysis of the articles studied.

4. HYBRID SOLAR ENERGY SOURCE

The hybrid solar dryer shows an excellent approach to address intermittent drying inconvenience during the off-sunshine period and off-grid usage. Solar energy is supplemented with another source of energy or an auxiliary source in a hybrid solar preservation system. There are so many combinations of hybrid dryers recorded in the literature. Solar – biomass burners were evaluated and proven effective by [18] to warm the air and dry chili product. The study claims that Co-Generation's advantage, which replaces the electrical extractor, eliminates the use of on-grid electricity and is applicable to rural areas. However, a solar assisted dryer with solar PV and a solar air heater is the subject of this review.

4.1 Solar PV

Solar photovoltaic energy is a clean energy source that has the potential to power a grid that is reliable, scalable, and cost-effective. Solar PV is available in a variety of forms nowadays, and it is continually being investigated. According to [19], monocrystalline modules are the most efficient ongoing and upcoming PV materials, with a 22.5 percent efficiency.

In solar dryers, solar PVs are widely used as an energy source by many studies. A solar photovoltaic and electric (SPE) and improved solar dryer (ISD) hybrid dryer were fabricated in East Africa by [20]. The study found that SPE and ISD were considerably more efficient at drying pineapple products than open sun drying (OSD). A hybrid solar dryer with solar panels and electrical resistances [21], was also used to dehydrate the moisture content of mushrooms. A comparison of drying methods between direct drying under the sun and hybrid solar dryer was explored by [22], to dry tomato slices in Nigeria. The study's conclusion revealed that the use of hybrid solar-energy dryer using photovoltaic gives a promising result and more superior in tomato preservation than OSD. A prototype photovoltaic thermal (PVT) with an evacuated tube collector (ETC) was investigated by [23] for drying cassava slices in India. According to the results, the hybrid PVT with ETC solar dryer can create high-quality dehydrated items that are suitable for export and profit. The use of a combination of photovoltaic panels and solar air heaters as an energy source to dry agricultural products in a solar dryer was investigated in this research.

4.2. Solar Air Heater

Many experts have long examined solar air heaters, which are constantly being researched to maximize their efficiency. Solar air heaters' (SAH) primary function is to produce heat for industrial spaces and establishments [24], textile, and crop drying [25]. Researchers found that SAH's are naturally low in thermal efficiencies due to the air's poor heat capacity and thermal conductivity [26]. Moreover, the concurrent problem with SAH is the reduction of thermal efficiency between the air and the absorber's heat transfer coefficient [27]. That is why various investigations were performed to enhance the dryer by providing and upgrading the absorbing media and thermal transfer features. Thus, design optimization and improvement of absorber plates were studied [28].

The two types of solar air heaters are the solar air heater (SAH) without thermal energy storage (TES) and the solar air heater with thermal energy storage (SAH) [29].

4.2.1. Solar Air Heater without Thermal Energy Storage

Under the SAH without TES, porous and nonporous materials are used. The difference between the two materials is the minute gaps or spaces called pores. In porous materials, pores are more scattered, which allows the passage of air. While in nonporous, pores are tightly bonded, which causes the impossible passage of air between its materials without any obstruction. Nonporous collectors are ubiquitous and have a systematic approach. However, porous collectors have intricate geometries to guarantee linear airflow over and beneath the collector. To increase the solar dryers' output performance, the use of porous material is more efficient than nonporous materials, according to [29].

4.2.2. Solar Air Heater with Thermal Energy Storage

Solar radiation is intermittent and cannot be accessed during night and off-sunshine periods, especially on rainy days. That is why energy storage as backup energy is significant and necessary to prolong and optimize energy usage. The performance of the energy storage is dependent on the materials being used. Thus, the selection of materials is essential to achieve the optimum efficiency of energy storage.

Thermal power is stored in a variety of ways, including sensible heat, latent heat, thermochemical storage, and a combination of the three [30]. Studies assessed these energy storages as a backup energy source for agricultural product preservation alongside the SAH. The following discussions assess the performance and effectiveness of sensible, and latent medium energy storage considering its cost-effectiveness in agricultural solar drying.

4.2.2.1. Sensible Heat Storage

Sensible heat storage (SHS) uses solid materials such as rocks, ground, sands, bricks, wood, iron, or liquids like water and oil to store energy by raising the temperature during loading and reloading. The extent of energy accumulated by the energy storage alters on the capacity or quantity the absorber plate can create [31].

4.2.2.1.1. Solid Sensible Heat Storage

Solid sensible heat storage is an important element that reduces risks of heat storage leakage subdued to lifted temperature. Even though feasible results in using solid storage are seen to be promising at an extreme temperature, just like others, there are still disadvantages in this technology. Some of those are producing a specifically low amount of heat during the heat storage, prone to thermal energy self-discharging in long-lasting usage, and costly maintenance [32].

Solid sensible heat storage is widely used by many authors in regard to dry agricultural products. In drying bitter gourd, solid SHS such as pebble is used by [33]. The study concluded that pebble as a storage of sensible heat results in uniform preservation of bitter gourd slices. Moreover, the SHS lessens the instability of hot air from the heat accumulator to the drying compartment. The use of sand as SHS for drying copra is investigated by [3] for small-scale holders. The study found out that the use of SHS in solar dryers produces 75% MCG1 grade copra. Granite is used as SHS for drying Roselle leaves in Malaysia. The study associated the drying of open sun drying (OSD) performance and granite based multi-pass solar air heating collector (MPSAHC) as SHS. The study recorded that drying roselle leaves in MPSAHC results in 21 hours earlier drying time than drying in OSD [34]. In drying onion, [35] used and placed granite grits below the absorber plate. The granite grit serves as a storage material and provides a stable temperature during the off-sunshine period.

Table 1 demonstrates the thermal characteristics of several solid sensible heat storage used by various research.

Table 1. Solid Sensible Heat Storage

Reference	Material	Temperature Range	Density (ρ)	Specific Heat Capacity (C_P)
[36], [37]	Aluminum	-	2700 kg/m^3	890 J/kg.K
[36], [38]	Iron	-	7850 kg/m^3	465 J/kg.K
[36]	Copper	-	8950 kg/m^3	380 J/kg.K

[36]	Wet Soil	-	1700 kg/m^3	2100 J/kg.K
[36]	Dry Soil	-	1260 kg/m^3	795 J/kg.K
[36]	Limestone	-	2500 kg/m^3	910 J/kg.K
[36], [39], [37]	Granite	-	2400-3000 kg/m^3	790 J/kg.K
[36], [30], [37]	Concrete	200-400	1900-2240 kg/m^3	850-1130 J/kg.K
[36], [38], [37]	Wood	-	480-700 kg/m^3	2000 – 2400 J/kg.K
[36], [38], [37]	Sandstone	-	2200 kg/m^3	710-712 J/kg.K
[36], [39], [30], [38], [37]	Brick	200-800	1600-1800 kg/m^3	837 – 840 J/kg.K
[39], [30]	Rock	20	2560 kg/m^3	879 J/kg.K
[39]	Sand	200-300		1300 J/kg.K
[39]	Pebble Stones	-	1920 kg/m^3	835 J/kg.K
[38]	Clay	-	1458 kg/m^3	879 J/kg.K
[38], [37]	Glass	-	2710-2800 kg/m^3	896 J/kg.K
[38], [37]	Steel	-	7840- 7833 kg/m^3	465 J/kg.K
[38], [37]	Gravelly Earth	-	2040-2050 kg/m^3	1840 J/kg.K
[38]	Magnetite	-	988 kg/m^3	4182 J/kg.K
[40]	Sand-rock Minerals	200-300	1700 kg/m^3	1300 J/kg.K
[40]	Reinforced concrete	200-400	2200 kg/m^3	850 J/kg.K
[40]	Cast iron	200-400	7200 kg/m^3	560 J/kg.K
[40]	Salt	200-500	2160 kg/m^3	850 J/kg.K
[40]	Cast steel	200-700	7800 kg/m^3	600 J/kg.K
[40]	Silica fire bricks	200-7002	1820 kg/m^3	1000 J/kg.K
[40]	Magnesia fire bricks	200-1200	3000 kg/m^3	1500 J/kg.K

4.2.2.1.2. Liquid sensible heat storage

The storage of liquid sensible heat is often used to heat or cool spaces especially buildings, and households. Through the years of development, the application of liquid SHS has grown rapidly, and now, it is used even in agriculture, specifically in drying agricultural products.

In using thermal energy storage, different approaches were presented and evaluated to analyse its storage performance. The use of water reservoirs as thermal energy storage systems was reviewed to preserve jack fruit almonds by [41]. The study recorded that using a water reservoir act as a source of heat for night-time preservation, and the jack fruit almonds are dried within 35 hours between 40ºC to 70ºC. Drying of bananas also used water reservoirs with heat exchangers and electrical resistors. The implementation of the solar dryer with water SHS was assessed and compared to OSD. The study recorded that the overall character of the dried banana is far better than in drying using the OSD method [42]. For medium temperature ranges from 0-100ºC, water is regularly used due to its 4190 J/kg. K high specific heat and cost-effectiveness [30] [36] [39] [43]. However, liquid metals and oil are recommended if higher than 100ºC liquid sensible heat storage material is required [44].

Table 2 presents the thermal properties and complete characteristics of some liquid sensible heat storage used by various research.

Table 2. Liquid sensible heat storage detailed characteristics

Reference	Material	Temperature Scale	Density	Specific Heat Capacity J/kg.K
[36], [39], [30], [38], [37]	Water	0 – 100	982-1000 kg/m^3	4190 J/kg.K
[36], [39], [30]	Ethanol	-117 – 79	780 kg/m^3	2460 J/kg.K
[36], [39]	Glycerin	17 – 290	1260 kg/m^3	2420 J/kg.K

[36], [39], [30], [37]	Engine Oil	-10 – 160	880-884 kg/m^3	1880 J/kg.K
[36], [39], [30]	Butanol	Up – 118	809 kg/m^3	2400 J/kg.K
[36], [39], [30]	Caloriea HT 43	12 – 260	867 kg/m^3	2200 J/kg.K
[36], [39], [30]	Propanol	Up – 97	800 kg/m^3	2500 J/kg.K
[36] [39]	Liquid Paraffin	Up – 200	900 kg/m^3	2130 J/kg.K
[36], [39]	Molten Salt	Up – 400	1950 kg/m^3	1570 J/kg.K
[39], [30]	Isubutanol	0 – 100	808 kg/m^3	3000 J/kg.K
[39], [30]	Isopentanol	0 – 148	831 kg/m^3	2200 J/kg.K
[39], [30]	Octane	0 – 126	704 kg/m^3	2400 J/kg.K

4.2.2.2. Latent Heat Storage

Latent heat storage is defined as the energy gained or distributed when the material changes from one stage to another, such as solid to gas, or the other way around at a constant temperature.

Desiccant and (PCM) phase change material wrapped in the solar air heater to retain the heat for several hours to dry copra by [45] [46]. Bhardwaj et al. utilized a phase change material using a paraffin wax to dry Valeriana jatamansi, a medicinal herb in the Himalayan region, Solan [47]. Similarly, a hybrid solar preservation uses paraffin wax with a solar photovoltaic and electric resistance to dehydrate mushrooms. The thermal efficacy of the solar dryer fluctuates in between 10% and 62%, whereas the collector panel's effectiveness differs in between 10% to 21% [21]. In storage of latent heat, although paraffin wax is attractive to meet the required high melting point, metallic and fatty acids are preferred more.

Table 3 demonstrates the types of frequently employed latent heat storage material recorded in the literature.

Table 3. Latent heat storage detailed characteristics

Reference	Materials	Melting Point	Melting Enthalpy
[38]	Water-salt Solution	-100 – 0 °C	200-300 MJ/m^3
[38]	Water	0 °C	300 MJ/m^3
[38]	Clathrates	-50-0 °C	200-300 MJ/m^3
[36], [38], [40]	Paraffins	-20 – 100 °C	120-250 MJ/m^3
[38]	Salt hydrates	-20 – 80 °C	200-600 MJ/m^3
[38]	Sugar alcohols	20-450 °C	200-450 MJ/m^3
[38]	Nitrates	120-300 °C	200-700 MJ/m^3
[38]	Hydroxides	150-400 °C	500-700 MJ/m^3
[38]	Chlorides	350-750 °C	550-800 MJ/m^3
[38]	Carbonates	400-800 °C	600-1000 MJ/m^3
[38]	Fluorides	700-900 °C	>1000 MJ/m^3
[36], [38]	Animal Fat	20-30 °C	120-210 MJ/m^3

4.2.3. Absorbing Media

Absorbing media in solar air collectors is one of the determining factors in harnessing maximum temperature for solar dryers. In literature, there are different specifications needed to achieve maximum performance. The primary specifications required for constructing a solar air heater are the type of absorber plate, absorber material, absorber coating, and glazing. Although tilt angle also contributes to harvest maximum solar radiation, this paper did not include tilt angle due to differences in solar radiation location in every area. Thus, this section of the paper discusses the characteristics of each factor mentioned to give insight into the best solar air heater material.

4.2.3.1 Absorber Plate

The collection plate, also known as the absorber plate, is usually the collector's most complicated and expensive part. Absorber plates are the surface absorbing the incident solar radiation. The plate absorber performs a considerable and crucial function in harnessing maximum solar radiation for solar air heaters. To date, v-corrugated, finned, and flat plat absorbers are the leading types of absorber plate mentioned in the literature. This section tackles the most common absorber plate used and in what agricultural products they are harnessed.

4.2.3.1.1 V-corrugated

V-corrugated plate absorbers are evaluated by many studies. Differences in absorbing media like v-corrugated, finned, and flat plate were evaluated to achieve an efficient design for agricultural crop drying [48]. The study found that v-corrugated absorbing media was the most successful and effective, while the least efficient among the three was seen in flat plate. The mass flow rate's performance through theoretical simulation is investigated in single and double arrangements using the flat plate and v-groove absorbing media. T double pass collector of v-groove absorbing media recorded the highest efficiency [48]. In drying apple, banana, chili pepper, and grapes, a novel prefabricated solar preservation unit made of v-corrugated absorbing media are investigated to determine the drying efficiency and mean drying rate [49]. While maximizing heat transfer from the SAH’s absorber plate to the air inside, a combination of barriers and a v-corrugated plate absorber was experimented with [50]. The experimental results of a SAH with a v-corrugated plate absorber and barriers curved vertically from 80 to 0 with a 10-degree interval on its base plate are described in this study. The obstacles were found to improve the function of the SAH. Even though the air pressure loss increased, the air temperature and efficiency increased when bent barriers were inserted vertically at any angle.

4.2.3.1.2 Flat Plate

Solar dryers mostly use the flat absorber plate to date due to its efficiency and cost-effectiveness. It has the trait of simple form and massive heat absorption area [51]. In a flat plate solar accumulator set up, air may be permitted to circulate over, under, or on bilateral of the absorber plate. Heat dispersion through the glass is lessen by airflow beneath the plate absorber. While the front covering of the accumulator suffers the most losses since it is subjected to the ambient, the collector sides and back can be well insulated. The performance of the flat plate absorber was thoroughly investigated in reference to different studies. A transient version of a flat plate absorber for a SAH was investigated with and without thermal storage [52]. In determining the temperature of different air heater elements and storage media, analytical expressions are obtained concerning the space and time as a function of air temperature flowing.

Similarly, a study by [53], uses a flat plate solar accumulator to inspect the thermal efficiency and outlet temperature of three types of material as absorber media. In another research paper, a flat plate solar accumulator with a dual purpose is proposed and constructed [54]. The mathematical modelling of the research paper revealed that the temperature of solar drying air can be controlled and enhanced by utilizing the operation method of a flat plate solar accumulator with dual function (FSDF). Through simulation, the operation of a double pass flat plate solar collector was assessed to get the result of the flow rate mass in a SAH. The study shows that in using double pass flat plate, efficiency is 2% lower than in using double pass v-groove collector. A flat plate solar accumulator is also utilized by [10] to evaluate and simulate the solar hybrid dryer's energetic and thermal behavior in heating the air inlet into the drying chamber.

Without energy storage, a flat plate solar accumulator is proven effective for almost six hours [14]. The effectiveness of a flat plate SAH is seen as very low compared to other absorbing materials due to the absence of technology. However, flat plate as absorbing media is proven the best heat transferring device [29] because of its easy-to-install characteristics and economical [55].

4.2.3.1.3 Finned

Finned plate absorber was seen as effective in many articles to optimize thermal efficacy in a SAH. A study performed by [56], uses plate fins with rectangular shape inserted perpendicular to allow good circulation of the fluid and minimize the dead spot between the fins of the same row. Another study conducted by [57], uses longitudinal fins is placed on the plate absorber to maximize the exchange of heat and uniform delivery of the flowing fluid in the channel. Comparison of the thermal efficiency of both solar collectors with and without fins are investigated and proven significant improvement. In a study published by [58] , the rate of heat transfer and entropy generation of a double-pass flat plate solar air heater with longitudinal fins are examined theoretically. The impacts of various significant factors on the property of heat transfer and entropy formation are also investigated. According to mathematical modelling, the thermal efficiency of a double-pass solar air heater with longitudinal fins rises as the height and number of fins grow for forecasting the heat transfer characteristic and entropy generation. As a result, the height and number of fins have an inverse relationship with entropy generation. Another study by [59] explored the effect of external recycling on collector efficiency in solar air heaters with internal fins added in a theoretical analysis. It was discovered that if the process is carried out with external recycling, the desirable effect exceeds the undesirable outcome, a significant increase in collector efficiency can be achieved.

Table 4 presents the characteristics of the commonly use type of absorber plate

Table 4. Different types of absorber plates and some of their characteristics

Reference	Type of absorber plate	Flow Rate	Temperature at the outlet (°C)	Efficiency %
[48]	V-Groove	0.031 kg/m^{2}s	53	68.5
[60]	V-Groove Double Pass	0.06 kg/m^{2}s	-	56
[48]	Finned	0.029 kg/m^{2}s	50	65.0
[51], [10]	Flat Plate	0.030 kg/m^{2}s	48	62.0
[60]	Flat Plate double pass	-	-	54

4.2.4. Absorber Material

One factor considered by research to improve thermal efficacy in a SAH is the absorber plate material of the absorbing medium. A study by [53], compared the thermal ability of the three structures of the SAH. Flat plate absorber media made of aluminum, mild steel and copper are placed at the upper portion of the absorber plate to allow the air to blow.

The solar air heater thermal performance of two absorber materials, like galvanized iron and glass plates, is experimentally studied. Galvanized iron (GI) and glass plate absorber with and without black coats optimized solar air heater thermal performance. Based on the study, the thermal efficiency of glass plate absorber material is 9.4% higher than the thermal efficiency of galvanized iron (GI) sheet absorber material [58]. While [59] used aluminum zinc-silicon (Aluzinc) sheet, which is an excellent absorbent material and has a very high heat capacity. And according to [61], iron sheet metal, which is inexpensive and readily accessible, is ideal for solar thermal applications and reduces costs.

4.2.5. Coating

Another way to increase the thermal operation of a SAH is the selection of the best coatings for the absorber plate. This coating material transforms solar energy into heat or thermal energy. The coating material is composed of selective and non-selective coating. By having a heat sink, the heat loss of the selective absorber coating is being minimized, while in the absence of heat sink in non-selective absorber coating will heat up, and there will be more heat loss.

In a study conducted by [62], a nickel-tin coating material is tested and evaluated to enhance the operation of the SAH. The study compared its obtained instantaneous efficiency with a black-coated plate absorber and found that the yearly mean of the daily efficiency in nickel-tin absorber plate is 29.23% greater than that of the black-coated plate absorber. In another study, the output of locally available absorber and anti-reflection materials for solar thermal collectors was compared to regular commercial black paint. On a natural circulation flat plate, absorber plates constructed of aluminum and iron sheet metals with blackboard paint, commercial paint, and black ABRO spray were tested for thermal performance. According to the findings, the iron sheet and black ABRO spray had the highest absorptance for wavelength and temperature increase at the absorber plate's outlet. Additionally, the price of ABRO black paint is comparable to those other coating materials, and it may be applied to absorber materials' surfaces.

Black painted and no paint in different absorber plate materials were also investigated [58]. Black-coated absorber material increased its maximum value during mid-day, the same as absorber materials with no black paint. However, the comparison of the two shows that the productivity of the black-coated material is superior than that of the material which has no black coat. Thus, the study concludes that black coating in absorber materials is necessary to improve solar air heater efficiency. Moreover, studies from [41] [55] [63] , uses low-cost black gloss paint to increase heat absorption and shows high efficiency in absorption.

4.2.6. Glazing System

The glazing system in a SAH is the top cover in the solar collector and is utilized to limit radiative and convective heat losses on the absorber plate.

Arranged two-layer glass absorber plates to improve heat transfer area, which advances to thermal performance improvement, are introduced by [64]. Glass cover as glazing system is used by [65] is also utilized to improve the effectiveness of solar energy and dry product quality. Similarly, glass cover is assessed by [49] to investigate drying efficiency and drying rate of agricultural products such as grapes, chili pepper, banana, and apple in Northern Cyprus. The same goes for investigating the drying time and product condition in terms of taste, colour, and shape of preserving bananas using low-cost materials that are locally available and biologically degradable [55].

Table 5 displays the specifications of the solar collector recorded in journals. Combinations of different materials are summarized to showcase each efficiency easily.

Table 5. Solar Collector Materials

Reference	Absorber Plate Type	Absorber Materials	Coating	Glazing System
[29]	Flat Plate	-	Black	-
[34]	Flat Plate	-	Matt black	Glass
[41]	Flat Plate	Galvanized metal sheet	Black gloss	Glass (3 mm)
[48]	Flat Plate, Finned, V-Corrugated	Stainless steel	Black chrome	Normal window glass (5 mm)
[55]	Flat Plate	G.I Sheet	Black gloss	Glass
[63]	Flat Plate	Zinc sheet	Black gloss	Glass
[61]	Flat Plate	Aluminum and Iron Sheet	Blackboard paint,	-

			Commercial black paint, Black ABRO spray	
[58]	-	Glass plate and Galvanized iron (GI) sheet	Black	-
[66]	Corrugated	Aluminum sheets	Matt black	Glass wool

5 SOLAR DRYER CHAMBER

Many types of solar dryer chambers used in drying crops are assessed and investigated. However, because of the economic and technological limitations, the application of different drying chambers is not well implemented and developed [17]. As for this review, the researchers focused on utilizing an inflatable solar dryer as it was already proven effective and low-cost in the Philippines based on the study conducted by [67] using rice as a commodity.

5.1. Inflatable Solar Dryer

The University of Hohenheim in Germany first introduced a low-cost solar dryer. This inflatable solar dryer is easy to assemble by local cultivators and craftsmen using ordinary materials and inexpensive tools [68]. Subsequently, it was developed by the International Rice Research Institute (IRRI) and GrainPro Inc. [69] and became a well-known solar bubble dryer. This dryer is a tunnel type, and its performance is determined by sun radiation, ambient air relative humidity, and the moisture content of agricultural products. The inflatable solar dryer (ISD) is self-contained and does not rely on fuel or the electrical grid. The ISD was first introduced to dry fruits for arid zones, but later, it was tested to dry paddy rice and was seen promising [70]. Since then, many researchers have developed and improved the dryer chamber considering the recommendations from previous studies to address the timely problem of ISD in terms of its ability to uniformly mix the dried products without interrupting the drying process by designing a roller bar made of iron pipe [67]. After such improvements in the ISD, the dryer was eventually tested for humid applications [67] [71]

Table 6 organized the application of Inflatable Solar Dryer in dehydrating crops during the past years.

Table 6. Application of Inflatable Solar Dryer in Drying Agricultural Crops

Reference	Journal Title	Crops Dried	Loading Capacity (kg)
[68]	Development of a multi-purpose solar crop dryer for arid zones	Medicinal plants grapes, onions, peppers, and dates	1000
[70]	A solar dryer for paddy rice	Rice	
[67]	Development of an inflatable solar dryer for improved postharvest handling of paddy rice in humid climates	Rice	1000
[71]	Drying performance and Aflatoxin content of paddy rice applying an inflatable solar dryer in Burkina Faso	Rice	900
[72]	Technical performance of an inflatable solar dryer for drying Amaranth Leaves in Kenya	Amaranth Leaves	200
[73]	Performance evaluation of an inflatable solar dryer for maize and the effect on product quality compared with direct sun drying	Maize	1000

5.1.1. Design and materials of the inflatable solar dryer chamber

There are several designs and materials used to construct the inflatable solar dryer. Nevertheless, the most recent type of inflatable solar dryer is based on the commercialized version by SBD 50 of Grain Pro Zambales, Philippines [69].

Table 7 below shows the compiled materials for easier distinction and efficient combination, which was used previously by researchers.

Table 7. Inflatable Solar Dryer Chamber Materials

Ref	Top	Bottom	Fan	Length / Width (Chamber)	Energy Source	Energy Storage
[68]	Transparent foil	Black plastic material	Axial flow fans with backwardly curved blades	20m / 2 m		None
[67]	150 um UV-stabilized transparent polyethylene (PE) film	Reinforced black polyvinylchloride (PVC) film (0.52 mm)	Two 220 V AC axial flow ventilators	25m / 2 m	Grid	-
[71]	Transparent UV-resistant low-density polyethylene (LDPE)	Black reinforced polyvinyl chloride (PVC)	DC axial fans (RDF2589B1 2N185)	25m / 2m	Solar panels (P100,) with solar charge controller (SR-SL 10 A,)	12V and 100Ah storage battery (DIN100SMF)
[72]	UV-stabilized transparent polyethylene (PE) foil (150 µm)	thick reinforced black polyvinyl chloride (PVC) foil (520 µm)	12 V/2.60 A DC axial fans (RDF2589B1 2N18S)	26m / 2m	100 W photovoltaic (PV) modules	12 V/75 Ah battery (GT 12-75C, GasTon Battery)
[73]	UV stabilized transparent polyethylene (PE) film - 150 µm thick	Reinforced black polyvinyl chloride (PVC) film	12-V DC axial flow fan (RDF2589b1 2N18S)	26m / 2m	100-W peak solar panel	75-Ah solar battery

6. ENERGY MANAGEMENT SYSTEM OF THE SOLAR DRYER FOR AGRICULTURAL PRODUCTS

It is complicated to maximize solar resources to satisfy energy demands while simultaneously lowering overall cost and maintenance, increasing savings over the life cycle, and improving thermal productivity. Thus, energy management is vital for solar dryers to improve the operation of each material. Many researchers studied and improved various energy management techniques, including optimization of thermal energy sources, development of drying chambers, and adaptation of stored energy. This section discusses efficient energy management of the gained energy from factors mentioned above, including control system procedures and techniques, the instrument used, and the possible parameters measured.

6.1 Control System of the solar dryer for agricultural products

The solar dryer is proven an incredible and efficient drying equipment, especially for agricultural products, due to its capacity to produce higher product temperature by directly absorbing solar radiation, thus, resulting in reduced drying time and improved product quality [74]. However, those characteristics of the solar dryer still have a disadvantage during the summer season, where solar radiation is too much, during the rainy season, and even during night-time of any season where there is not enough solar radiation. The main problem of the solar dryer is maintaining the constant temperature required for drying during the off-sunshine period. Thus, regulating the humidity and temperature inlet within the dryer, especially in different seasons and low radiation periods, is a practical solution to achieve maximum efficiency.

The control system has been broadly studied recently to optimize the drying operation of solar dryers. To control the flow of air going through the drying compartment, the air temperature, and the evaporated product's moisture content, controlling and adjusting the rotation of the fan is the solution found by [59]. Two sets of instruments are placed at the front and edge of the solar accumulator. The temperature recorded from the two sensors is used to obtain the differential values used by the microcontroller to adjust the volume of the fan. Introducing hardware components to automatically condition the temperature inside the dryer investigated by [74], maintaining the different temperature range to obtain the required moisture content of various products. Each crop is weighed using a sensor before the drying process, and the dryer is adjusted according to the crops’ drying requirements. Once the preservation process is done and the necessary moisture content is acquired, the solar dryer will ring an alarm to indicate it is done. Fan speed was also simulated and evaluated by [75] to optimize energy efficiency caused by temperature and solar radiation changes. Air temperature in three locations: collector inlet and outlet and drying chamber outlet was determined to use in mathematical relations. The dryer productivities are computed using the controlled system. Thus, the findings revealed that the computer-generated simulation and statistical analysis could control the fan speed and highly improved the dryer efficiency, getting a 1% probability level throughout its operation.

6.2 Instrumentation in the solar dryer for agricultural products

The instrument used to monitor and determine the input and output parameters is also crucial to optimize the drying condition of a solar dryer. Any change in the dependent variable in a study that results from changes in the measuring instrument used is influenced by instrumentation. Thus, to have a basis on what instrument to use, the data below shows some of the devices used in previous studies to measure different parameters. [76] presents the control of ideal environments requirements for fluidized bed paddy dehydration in drying rice.

Table 8 below summarizes the instrument used by previous studies

Table 8. Instrumentation

Ref.	Temp. and Humidity Sensor	Solar Irradiance	Wind Speed	µcontroller	Monitor
[59]	12b20	-	-	Arduino Mega 2560	LCD TFT_HX8357.h
[74]	DHT22	-	-	89C51	LCD LM018L
[77]	PT 100	Pyranometer	Anemometer	-	-
[55]	K-type thermocouples and thermometer	Pyranometer	Vane-type anemometer	-	-
[58]	T-type thermocouples	Pyranometer	Anemometer	-	-

6.3 Parameters needed in the solar dryer for agricultural products

The solar drying frequency differs on outside factors that cannot be controlled, like relative humidity, radiation, ambient temperature of the air, and wind speed [78]. Therefore, it is crucial to maintain the inlet parameters like humidity and temperature, which significantly affect the solar dryer's drying performance. Simultaneously, the initial moisture content and physical properties of the dried products contribute to the overall drying implementation of a solar dryer [79].

7. CONCLUSION

Solar energy has yielded remarkable results, particularly in drying agricultural products. This work provided an inflatable solar dryer with photovoltaic panels and a solar air heater by reviewing low-cost plans and performance optimization of the various materials for various agricultural commodities. The construction materials availability, the energy sources, the type of drying chamber, the energy management, and the control system are all factors needed to consider when designing an efficient and low-cost dryer. In this paper, hybrid energy sources such as photovoltaic panels and solar air heaters aid in the continual drying of agricultural products even in low radiation and off-grid applications. Additionally, a comprehensive assessment of the materials used in constructing solar air heaters is shown. SAH with and without thermal energy storage are reviewed. It has been discovered that water is the most cost-effective and efficient thermal energy storage at temperatures spanning from 0 to 100°C of all the previously investigated thermal energy storage methods.

Moreover, materials to optimize the performance of the absorber collector were also investigated. Many studies use a flat absorber plate, even though a v-groove plate was more effective. Galvanized iron painted black and glass glazing were more commonly used as absorber materials and glazing.

In terms of the drying chamber, the researcher chose to employ an inflatable solar dryer because it has already been demonstrated to be efficient and cost-effective in drying agricultural products in numerous experiments. This document depicts the utilization of an inflatable solar dryer in several settings and the materials used to construct the chamber.

Energy management and algorithm are also reviewed, and several ways to manage and control the input and output parameters required in drying were highlighted. Excellent performance of the solar dryer will be achieved by having an efficient flow of energy and a quality product by selecting the optimum instrument for the dryer and determining the input and output parameters.

Overall, all the principles discussed in this article will be beneficial to farmers, academicians, and researchers involved in the construction, design, and optimization of solar dryers.

8. FUTURE SCOPE

This paper concentrates on searching for cost-effective materials and optimization techniques to be able to use by local farmers even in the absence of solar radiation. A hybrid solar dryer powered by photovoltaic panels and an integrated solar air heater are recommended as an energy source to dry agricultural products. The combination of two energy sources with storage will prolong off-grid applications. However, investigation for all-night application and continuous low radiation season in the solar dryer was not yet given attention. At the same time, for energy storage, consolidated articles suggested that liquid sensible storage such as water is the best storage medium due to its cost-effectiveness and high specific heat characteristic [30]. Yet, there are still limitations on how long the water can keep the thermal energy even with thermal insulations. Future research should focus on integrating batteries for the solar PV's and keeping specific heat in the water for continuous application of the dryer all night long and even in continuous low radiation season.

In terms of absorber plate materials, the highest performance for solar air heaters was determined to be v-groove painted with black [48], but it is also the most expensive. As a result, in the field of SAH, the search for cost-effective materials will be beneficial. Because there are no records of recycled tin cans as absorber plates in current publications, further research into their performance and usefulness is recommended. Tin cans, which are commonly and inexpensively available due to their prevalence in the beverage industry, can be used as a double pass air heater in SAH.

The inflatable solar dryer concept is still suggested for drying chambers since it has been demonstrated to be effective and low-cost when compared to other forms of drying chambers. However, instead of using a roller bar made of iron pipe to mix the crops inside the chamber, this paper recommends using a much cheaper roller bar made locally available like woods.

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