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Development and Performance Assessment of a Solar-Assisted Desiccant Dryer for Banana, Camote, and Taro Chips

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The demand for efficient and sustainable food preservation methods has driven interest in solar drying technology. This study focuses on the design, fabrication, and performance evaluation of a laboratory-scale solar dryer integrated with calcium chloride as a desiccant for drying banana, camote, and taro chips. The fabricated solar dryer (FSD) consists of a solar collector that heats incoming air, which is then circulated into the drying chamber by an exhaust fan. The drying efficiency of the FSD with and without a desiccant was assessed, alongside moisture content reduction and drying kinetics under three different conditions: FSD with desiccant, FSD without desiccant, and traditional sun drying. Results indicate that the FSD with desiccant demonstrated superior performance, achieving drying efficiencies of 30.27 %, 32.08 %, and 31.39 % for banana, camote, and taro, respectively. The drying time to reach the desired moisture content was significantly reduced to 24 h for bananas and 28 h for camote and taro, representing a 50–80 % reduction compared to the traditional sun-drying method, which typically requires 48–120 h. Additionally, the FSD with desiccant exhibited the best falling-rate drying behaviour, and a more rapid moisture reduction compared to the other methods. These findings suggest that the FSD with desiccant offers an effective, energy-efficient, and hygienic alternative for drying food products.

1. Introduction

Awareness of the significant role of renewable energy in providing technology for the agricultural sector especially in emerging nations like the Philippines to upscale and improve production is timely (Mamuad et al., 2022). Philippine families have the lowest vegetable and fruit consumption in Asia, averaging less than 30 kg per person annually, much less than the required annual intake recommended by the World Health Organization (WHO) (Applestein et al., 2021). Because of this, many farm products are wasted because of poor after-harvest management and the absence of processing. The effect of this condition is a big discrepancy in the amount of food produced and available food for consumption. Decreasing the loss of harvest is important in improving the quantity of available food from existing production. Even in the ancient period, moisture removal of plants and meat material for consumption was used as a preservation method. Microbes that will spoil and destroy food will not tribe and multiply if it is free from moisture. Many catalysts such as enzymes in food and other biological materials are inactive without moisture. Microorganisms are inactive when the moisture content of biological materials is below 10 wt. %. It is advisable to maintain a moisture content of less than 5 wt. % in foods to retain its flavor and nutrition (Alp and Bulantekin, 2021). Drying harvest is an important technique in agriculture to store and preserved crops. Drying is done either by utilizing fossil fuels to power mechanized drying process or by solar drying of crops directly under the sun. Using fossil fuels is very expensive and has detrimental effect on humans and the surroundings. Direct exposure to the sun also destroys the vitamins and minerals contained in the food.

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Direct solar drying is widely used in tropical regions like the Philippines due to its low cost and simplicity. It is considered economical but it poses several challenges, including poor control over drying conditions, leading to substandard product quality, high labor requirements, and susceptibility to weather and biological contaminants. These limitations reduce process efficiency and highlight the need for improved, more reliable drying technologies.

To address the limitations of open sun drying and provide baseline data for future solar dryer development, this study focuses on the design, fabrication, and testing of a solar dryer integrated with calcium chloride ($CaCl_2$) desiccant. The aim is to reduce energy consumption and improve the drying performance for taro, banana, and camote. The study specifically evaluates the performance of the FSD with and without desiccant by comparing moisture content, drying time, and drying efficiency against conventional sun drying. The findings are expected to benefit local farmers by offering a more hygienic and cost-effective drying method for root crops and fruit products.

2. Materials and Methods

A laboratory-scale solar dryer is designed, fabricated, and tested in this study. Developmental method procedures are used on the design and fabrication of the solar dryer equipment while experimental method was used in testing the performance of the fabricated equipment. The design and testing of the equipment have been conducted at the Unit Operations Laboratory of the Chemical Engineering Department at the Mariano Marcos State University, City Batac, Ilocos Norte Fabrication has been done at Brgy. 6 San Agustin, Laoag City Ilocos Norte.

2.1 Design and Fabrication of the Solar Dryer

The method considered in designing the FSD is the recorded weather data in the location of study from PAGASA. Other important data was analyzed and computed base from the design specification set for the equipment. A schematic diagram of the FSD is presented in Figure 1.

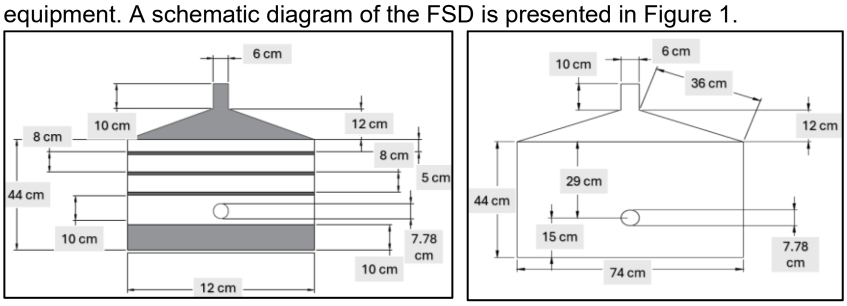

Figure 1: Schematic diagram of the FSD

2.1.1 Determination of the collector area and drying chamber

Using one-year hourly meteorological data on solar irradiance (It), ambient temperature (T_a), relative humidity (RH), and wind speed (v) from the City of Batac, Philippines PAGASA station, the FSD solar collector was designed by solving the steady-state energy-balance equation given in Eq(1).

Drying trials used three replicates with 3 kg per batch of banana, camote, and taro chips. RH were not controlled and varied naturally throughout the drying period and solar flux was assumed to be 1,400 W/m^2. The collector is where the air enters and is heated by solar radiation. It has three major components: transparent cover, absorber plate, and insulation. The area and volume of the tray in the dryer chamber are designed to hold 3 kg per sample of banana, taro, and camote and to contain the CaCl2 desiccant. In determining the collector area, equation (1) was used (Akter et al., 2022).

$$Q = MCpdT \tag{1}$$

2.1.2 Determination of the Angle Tilt of Solar Collector and the Amount of Dessicant

The angle of Tilt (β) of the Solar Collector is dependent on the latitude of location and must be positioned well to receive the greatest amount of solar radiation. It is determined using Eq(2) (Eltawil et al., 2018). The amount of desiccant will be based on the guidelines provided by the supplier.

$$\beta = (latitude\ of\ location\ x\ 0.9) + 29 \tag{2}$$

2.1.3 Design Considerations and Fabrication

The frame is designed to hold the absorber while containing enough heat and air to meet the energy demands of the drying chamber. The solar absorber used is a corrugated galvanized sheet, which collects solar irradiation from the sun. Flat black paint is applied because it enhances absorption. Glazing, made of regular window glass, is utilized to capture heat from the sun and trap it inside, resulting in higher temperatures within the collector.

2.2 Testing and Experimental Procedure

The solar temperature was measured using a pyrometer. Temperature was monitored using a thermometer for every crop variety. Drying time was conducted from 9 am to 5 pm. The mass of the banana, camote, and taro is monitored using a digital analytical balance. Experimental methods conducted were all replicated to confirm the reliability of the results gathered. Preliminary testing was conducted to check the functionality of all the parts of the equipment. The banana, camote, and taro were cut with thicknesses ranging from 3.5 mm to 5 mm, the best thickness condition for drying. The Solar Dryer warmed up for 1 h to reach 50 °C prior to its operation. The temperature was monitored using a temperature controller, which was set to maintain temperatures between 50 °C to 60 °C. The amount of water loss was determined by weighing the samples every 2 h. Dried samples were packed in a secured plastic bag.

2.2.1 Determination of the Moisture Content and Drying Rate

The formula to be used in getting the total amount of moisture evaporated is presented in Eq(3). Determination of drying rate of banana, taro, and camote is to be obtained by Eq(4).

$$MC = \frac{weight\ of\ moisture}{weight\ of\ moisture\ +\ weight\ of\ dry\ solid} \tag{3}$$

$$DR = \frac{initial\ weight\ -\ final\ weight}{drying\ time} \tag{4}$$

2.2.2 Determination of the Drying Efficiency of the Fabricated Solar Dryer

Eq(5) was utilized to compute the drying efficiency of banana, taro, and camote where m is the mass of the moisture evaporated, L_{ev} is the Latent heat of evaporation of water, m_{cn} is the weight of the solid, Cp_a is the specific heat capacity of the product, ΔT is the change in temperature, and A is the Aperture area, G is the intensity of the solar irradiation, and t is the time in drying the product.

$$\eta ds = \frac{m.Lev\ +\ mcCpa\Delta T}{AGt} \tag{5}$$

3. Results and Discussion

The designed and fabricated laboratory scale solar dryer is made of materials found in the locality. The equipment was tested to compare its performance to a direct solar drying system both theoretically and experimentally were conducted.

3.1 Design of the Fabricated Solar Dryer

The main parts of the fabricated solar dryer are the drying chamber and solar collector. The specifications utilized in the design and fabrication of the solar dryer are shown in Table 1. The drying chamber is fabricated from galvanized iron (GI) sheet and has dimensions of 49 cm in height, 74 cm in width, and 74 cm in length, providing a structurally stable enclosure for drying operations. An internal tray, measuring 74 cm in width, is constructed from aluminum, chosen for its lightweight properties and high thermal conductivity, which aids in uniform heat distribution across the drying surface. The chimney is also constructed from galvanized iron sheet and is designed with dimensions of 15.24 cm in height, 12.7 cm in width, and 12.7 cm in length. These dimensions support adequate air draft and moisture removal from the drying chamber, facilitating efficient convective drying. To minimize heat loss, the system incorporates a dual-layer insulating material made from polyethylene foam, with thicknesses of 0.10 cm and 0.05 cm. This material is selected for its low thermal conductivity and high moisture resistance, contributing to improved thermal efficiency of the drying unit.

3.1.1 Determination of the Drying Chamber and Collector Area and its Dimensions

The fabricated solar dryer is composed of a 3-layer drying chamber, a chimney, 3 trays, a polyethylene foam insulator, and a desiccant container. The drying chamber is made from 0.9 mm GI Sheet. It is insulated with 10 mm insulation foam. It consists of 3 x 74 x 74 cm trays made of aluminum and GI casing. A separating sheet made of GI and polyethylene foam separates the chamber from the adsorbent container. The chimney is 12.7 x 12.7 x 15.24 cm, made from GI sheet. The material used for the air inlet is also GI sheet, with a 77.8 mm diameter. The solar collector component of the solar dryer is constructed using marine plywood, selected for its durability and resistance to moisture, making it suitable for outdoor thermal applications. The collector has a height of 15 cm, a width of 73 cm, and a length of 120 cm, providing sufficient surface area for effective solar energy absorption and heat transfer. It is incorporated with a 73 x 100 cm corrugated galvanized sheet and painted black for better heat absorption. It is enclosed with 1.27 cm glass as its glazing to trap the heat, and an exhaust fan to transport the heat to the drying chamber. A temperature controller was used to maintain the temperature from 50 ^{o}C to 60 ^{o}C. The system is insulated with polyethylene foam to enhance thermal retention and minimize energy loss. The insulation is applied in dual layers with thicknesses of 10 mm and 5 mm, contributing to overall system efficiency by maintaining internal temperatures and reducing conductive heat losses. An exhaust fan powered by a 12-volt supply is integrated into the system. This fan facilitates controlled air movement within the drying chamber, improving convective heat transfer and aiding in the efficient removal of moisture-laden air during the drying process.

3.1.2 Determination of the Tilt Angle of the Solar Collector and the Amount of Desiccant

The effectiveness of the solar system is strongly affected by the inclination angle of the collector to the sun, aside from the outcome of the solar collector. The highest efficiency is obtained when the solar collector is mostly oriented at right angle to the sun. The angle of inclination of the air collector was determined to maximize the intensity of the sun all throughout the day. By multiplying location latitude by 0.9 and then adding 29, the perfect tilt angle of solar collector was determined (Kokate et al., 2022). The tilt angle based on equation 3 is 35° due south. Desiccant is needed to avoid remoisturization of the sample during nighttime. Calcium chloride ($CaCl2$) was used as desiccant since it is highly hygroscopic, non-toxic in normal amount and can be used in foods (Malan et al., 2017). The amount of desiccant to be placed in the solar dryer is based on the volume of the drying chamber, based on the guidelines provided by the supplier. The desiccant utilized was based from the guidelines given by the supplier sorbentsystems.com that for the volume of the FSD drying chamber that is 0.268324 m^3, 0.2925 kg of desiccant is needed. This is base from standard RH of drying chambers that is 30.1±3.4 %.

3.1.3 Design Considerations and Fabrication

The fabricated solar dryer (FSD) constructed is made of locally available materials. The specifications are listed in Table 1 and the photo of the actual equipment is presented in Figure 2. An indirect FSD was considered since it is more hygienic, the color and nutrient content of the sample is also preserved (Etim et al., 2020). FSD comes with a thermostat temperature control system and a fan powered by a battery with 1 Ampere current to ensure that the temperature inside the chamber is maintained and uniform.

Figure 2: Actual Photo of the FSD

3.2 Testing and Experimental Procedure

The designed and fabricated solar dryer is considered low cost since it is made from locally available materials. Testing and experimentation were conducted to compare its performance to direct sun drying both theoretically and experimentally. The solar dryer was placed in an area where it can be penetrated by sunlight all throughout the day. Under ambient temperature conditions ranging from 28 °C to 35 °C, the internal temperature of the drying chamber was consistently maintained within the range of 50 °C to 60 °C. This indicates that the solar dryer effectively amplifies and retains thermal energy, achieving a temperature elevation of approximately 20–25 °C above the surrounding environment. The observed thermal performance can be attributed to the combined effect of solar energy capture, insulation efficiency, and greenhouse effect within the chamber. This temperature elevation is primarily facilitated by the use of a transparent glass cover, which allows solar radiation to enter while minimizing heat loss through convection and radiation. The polyethylene foam as insulation reduces conductive heat loss, and the absorber plate enhances heat accumulation, resulting in sustained internal temperatures suitable for drying agricultural products.

Table 1: Specification of the Fabricated Solar Dryer

Description	Specification	Units
FSD overall length	2.06	m
FSD overall height	1.4	m
Dimension of absorber plate	1 x 0.73	m
Thickness of glass cover	0.005	m
Total thickness of Insulation	0.010	m
Space of absorber and plate	0.05	m
Space of absorber and insulation	0.05	m
Amount of trays	3	
Space between trays	0.15 m	m
Collector tilt angle	35° due south	

3.2.1 Determination of the Moisture Content and Drying Time.

The average moisture content and drying time of banana, camote, and taro using the three drying methods, which are using the FSD with desiccant, FSD without desiccant, and direct sun drying, are presented in Tables 2 and 3, respectively. The three drying methods considered in drying the banana chips achieved the optimum moisture content for storage and chipping, which is 5 % to 15 % moisture content while for camote and taro only the FSD with desiccant obtained the standard moisture content for storage and chipping, which is 5 % to 10 %. The lowest moisture content obtained for camote using FSD without desiccant is 11.50 % and 10.80 % through direct sun drying. For taro, the lowest moisture content obtained using FSD without desiccant is 10.48 % and 10.88 % for direct sun drying. Figure 3 presents the moisture content reduction over time for banana, camote, and taro under three drying conditions: FSD with desiccant, FSD without desiccant, and sun drying. Across all crops, the FSD with desiccant consistently achieved the most rapid and significant moisture reduction, demonstrating its superior drying efficiency. The stepped decline pattern observed in camote and taro suggests intermittent drying kinetics likely due to internal moisture migration and variable drying front resistance. Traditional sun drying exhibited the slowest drying rates and the highest final moisture contents, indicating limited moisture removal capability and greater susceptibility to environmental fluctuations. The use of desiccants enhanced moisture gradient driving forces, especially in the early drying stages, leading to faster drying times and potentially better product quality preservation. These findings affirm the effectiveness of integrating desiccants into FSD systems to improve drying performance, particularly for high-moisture root crops (Ramli et al., 2021).

Table 2: Average Moisture Content

	Banana	Camote	Taro
FSD with Desiccant	11.13±1.715	9.67±0.689	7.48±2.498
FSD without Desiccant	13.95±0.699	10.31±0.314	10.48±1.971
Sun Drying	14.42±1.309	10.80±1.01	10.88±1.658

Table 3: Average Drying Time (h)

	Banana	Camote	Taro
FSD with Desiccant	24±0.353	28±0.150	28±0.283
FSD without Desiccant	50±0.490	50±0.247	50±0.370
Sun Drying	78±0.226	74±0.453	76±0.339

For the drying time, banana obtained the desired moisture after 24 h in the drying chamber for FSD with desiccant, while 50 h for FSD without desiccant, as shown in Table 4. Direct sun drying of banana chips obtained its desired moisture after 78 h. The result is like the study of Gunatelake et al., (2021), where it contains 29.08 % moisture after 16 h of drying the banana chips in FSD. For camote and taro same result was obtained for drying using FSD with desiccant and without desiccant. For direct sun drying, camote obtained its lowest moisture content after 74 h, while 76 h for taro. The results of the three methods of drying the three commodities considered show that drying through FSD with desiccant is most effective, since all three samples obtained the standard moisture content for storage and chipping at the shortest time.

Table 4: Drying Efficiency of the FSD (%)

	Banana	Camote	Taro
FSD with Desiccant	30.65±0.408	32.08±0.451	31.39±0.639
FSD without Desiccant	14.82±0.240	17.89±0.189	17.18±0.335

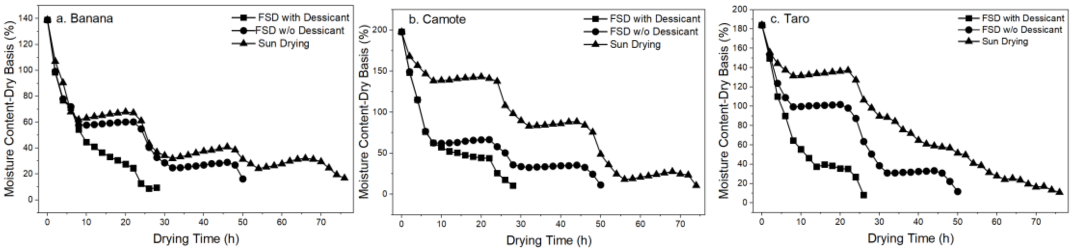

Figure 3: Moisture Content vs. Dryingt time of (a) banana, (b) camote, and (c) taro

4. Conclusions

FSD has been successfully designed, fabricated, and tested. It was found out that the average temperature within the drying chamber varied from 25 °C to 32 °C above the ambient temperature. The maximum temperature within the drying chamber varied from 50 °C to 60 °C. These temperature ranges are very effective for drying banana, camote, and taro. The addition of desiccant in FSD increases the efficiency of the equipment. Data shows that the traditional direct sun drying lats up to 78 h for banana, 74 h for camote and 76 h for taro of intermittent drying to achieve its lowest moisture content. This drying time was reduced to 24 h for banana (69 % reduction), 28 h (62 % reduction) for camote and 28 h (64 % reduction) for taro if FSD with desiccant is utilized. Two falling rate periods can be observed when drying the samples through FSD with or without desiccant while three falling rate periods when drying the samples through direct sun. Results indicate that utilizing FSD in drying banana, camote and taro for storage and chipping is highly recommended since the method displayed high efficiency of drying, lower drying time rate and it also indicates a more hygienic method of drying compared to direct solar drying. Applying FSD to preserve the excess production for future utilization is effective to solve post-harvest management problems and even increase the income of farmers since loss due to spoilage is avoided. To further validate and expand the application of FSD, future studies should assess the economic feasibility of adopting FSD at the household and cooperative levels, including cost analysis and return on investment. Scaling up the system for small farming communities should be explored, focusing on locally available materials, ease of operation, and maintenance needs.

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