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Solar dryer technologies for agricultural products in Mozambique: An overview

Tecnologias de secadores solares para produtos agrícolas em Moçambique: Uma visão geral

Tecnologías de secadores solares para productos agrícolas en Mozambique: Una descripción general

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Abstract
Mozambique is an agricultural country. However, it faces numerous challenges to feed the population and reduce poverty. Recently, the situation is being worsened by high environmental, social vulnerability and extreme events influenced by climate disruption in the form of cyclones, droughts, and floods. Sustainable use of resources has become an issue in each food supply chain segment. People often suffer from food shortages: some caused by natural disasters, others by excessive post-harvest losses due poor storage facilities. Therefore, reducing post-harvest losses through preservation technologies is an important step toward reaching ending hunger (SDG 2) and ensuring sustainable consumption and production patterns (SDG 12). Thus, practical ways of cheaply and sanitarily preserving foods are needed. The post-harvest losses of agricultural products can be reduced drastically by using renewable energy sources like solar energy. This article presents a review and possibilities of using solar drying, focusing on the technical needs of small farmers in Mozambique. In this study, it was concluded that solar drying is one of the most efficient and cost-effective, renewable, and sustainable technologies to conserve agricultural products. However, solar dryers, being used in Mozambique, are only useful in the presence of solar radiation and useless at night or during cloudy days. To enable off-sun drying, heat storage must be integrated. This way, it can trigger the hopes for alleviation of poverty, opportunity for decent work, economic growth and reduce inequality.
Keywords: Climate change; Environment; Preservations; Solar dryer; Solar energy.

Resumo
Moçambique é um país agrícola. No entanto, enfrenta inúmeros desafios para alimentar a população e reduzir a pobreza. Recentemente, a situação está sendo agravada pela alta vulnerabilidade ambiental, social e eventos extremos influenciados pela perturbação climática na forma de ciclones, secas e inundações. O uso sustentável de recursos tornou-se um problema em cada segmento da cadeia de abastecimento alimentar. As pessoas muitas vezes sofrem com a escassez de alimentos: alguns causados por desastres naturais, outros por perdas excessivas pós-colheita devido a instalações de armazenamento precárias. Portanto, reduzir as perdas pós-colheita por meio de tecnologias de preservação é um passo importante para alcançar o fim da fome (ODS 2) e garantir padrões sustentáveis de consumo e produção (ODS 12). Assim, são necessárias formas práticas de conservar os alimentos de forma barata e higiênica. As perdas pós-colheita de produtos agrícolas podem ser drasticamente reduzidas com o uso de fontes de energia renováveis, como a energia solar. Este artigo apresenta uma revisão e possibilidades de uso da secagem solar, com foco nas necessidades técnicas dos pequenos agricultores em Moçambique. Neste estudo, concluiu-se que a secagem solar é uma das tecnologias mais eficientes e econômicas, renováveis e sustentáveis para conservar produtos agrícolas. No entanto, os secadores solares, usados em Moçambique, só são úteis na presença de radiação solar e inúteis à noite ou em dias nublados. Para permitir a secagem ao sol, o armazenamento de calor deve ser integrado.

Dessa forma, pode desencadear esperanças de alívio da pobreza, oportunidade de trabalho decente, crescimento econômico e redução da desigualdade.
Palavras-chave: Ambiente; Energia solar; Mudanças climáticas; Preservação; Secador solar.

Resumen

Mozambique es un país agrícola. Sin embargo, enfrenta numerosos desafíos para alimentar a la población y reducir la pobreza. Recientemente, la situación está empeorando por la alta vulnerabilidad ambiental y social y los eventos extremos influenciados por la alteración del clima en forma de ciclones, sequías e inundaciones. El uso sostenible de los recursos se ha convertido en un problema en cada segmento de la cadena de suministro de alimentos. Las personas a menudo sufren escasez de alimentos: algunas causadas por desastres naturales, otras por pérdidas excesivas posteriores a la cosecha debido a instalaciones de almacenamiento deficientes. Por lo tanto, reducir las pérdidas poscosecha mediante tecnologías de conservación es un paso importante para acabar con el hambre (ODS 2) y garantizar patrones de consumo y producción sostenibles (ODS 12). Por lo tanto, se necesitan formas prácticas de conservar los alimentos de forma económica e higiénica. Las pérdidas posteriores a la cosecha de productos agrícolas se pueden reducir drásticamente mediante el uso de fuentes de energía renovables como la energía solar. Este artículo presenta una revisión y las posibilidades del uso del secado solar, centrándose en las necesidades técnicas de los pequeños agricultores de Mozambique. En este estudio se concluyó que el secado solar es una de las tecnologías más eficientes y rentables, renovables y sostenibles para conservar productos agrícolas. Sin embargo, los secadores solares, que se utilizan en Mozambique, solo son útiles en presencia de radiación solar e inútiles durante la noche o los días nublados. Para permitir el secado al sol, se debe integrar el almacenamiento de calor. De esta manera, puede desencadenar esperanzas de alivio de la pobreza, oportunidades de trabajo decente, crecimiento económico y reducción de la desigualdad.
Palabras clave: Ambiente; Cambio climático; Conservaciones; Energía solar; Secador solar.

1. Introduction

The first Sustainable Development Goal (UN, 2015) ensures the need to eradicate poverty in all ways, combating hunger is one of the biggest challenges in the world, especially in a country like Mozambique. The country has an arable land cover above half of the national territory; the economic development base is agriculture occupying about 80% of the active population (LBPTC, 2010). Paradoxically, achieving food security in Mozambique is critical, since 80% of the population cannot afford an adequate diet and 42.3% of children under the age of 5 are stunted (Matavel et al., 2022).

As the agricultural products are seasonal, the harvest period is annual. With this, there are period of abundance and other of scarcity that is caused, on one hand by the seasonality of some crops, but in another, by the weather conditions. In the period of abundance, there are a lot of food waste and spoiled, in most cases, due to the weak capacity of infrastructures for the rapid flow to consumption points; the other reason is the weak conservation capacity of perishable products.

The conservation of products has been a major problem for the farmers, from the era of human civilization up todays (FAO 2022); this probably the main reason of the shortage of farm products along a part of the year. The irregularity of availability of the products, contribute for high price of the food on the market and risk for innutrition.

Fruits and vegetables are of great importance all over the world, regarding social, economic and food aspects. The fruits and vegetables are sources of vitamins, minerals, carbohydrates (glucose, fructose, sucrose, starch) and fibers crucial to human health. These foods contain low protein and fat values and are mostly composed of water. To preserve the quality of the product and its storage life (conservation of nutrients and vitamins contained in), it has necessary to reduce the moisture content to a level that is safe for storage. Drying is, therefore, a key process for managing the product moisture (FAO, 2022; Indiarto, et al., 2021).

Currently, the country faces many challenges with regard to access and quality of energy and chronic food insecurity. About 67% of population live and work in rural areas, but only 6% of the population has access to electricity. Mechanical process dryer require energy, which is limited in rural areas. Sustainable solutions that do not require electricity for food processing are already available.

Mozambique has great potential for the use of solar energy throughout the national territory. This energy constitutes an advantageous option in the viability of projects that could promote development in various sectors such as fruit drying, water heating for industrial and domestic use, and in the conversion of solar energy into electricity for places where the electricity grid of energy is hard to reach. Small farmers use solar energy to dry their produce after harvest as an attempt to ensure safe storage of food until the next harvest. However, the use of traditional open solar drying to dry agricultural produce results in significant losses such as contamination from dust, rain, spoilage, insects, and other pests (Matavel et al., 2021). Thus, the purpose of this paper is to review different technique of drying and various modes of solar drying, focusing on the technical needs of small farmers in Mozambique.

2. Drying Technologies Evolution

Drying food is the oldest methods of food preservation; it involves changing the form of the water in the food to gas, by removing it from the food by evaporation, the food becomes dehydrated (Indiarto, et al. 2021). The rest of water content of properly dried food varies from 5 to 25 percent depending on the food (DiPersio, et al. 2007). Any agriproduct, types of seeds, fruits or vegetable can undergo the process of dehydration. Therefore, the technologies used is the key to successful dehydration.

The process of food dehydration involves simultaneous transfer of mass and latent heat within the food. Adequate technology must supply enough heat to draw out moisture, without cooking the food, dry air to absorb the released moisture, and adequate air circulation to carry off the moisture. Therefore, in drying process are involved energy resource, human labour, and dried product quality.

In Africa, especially in Mozambique, great quantities of food, to feed the market and the rest of population in towns and around, come directly from agriculture fields. Due to weak number of process agriculture industries, those farms and agriculture field the majority are in rural without electrically grid. Hence, the main source of heat to dry agriculture products is the solar radiation. Thus, it is important to describe solar drying methods and its function principles.

2.1 Sunshine drying

Sunshine drying is the first ever food preserving method used by man. In this traditional method, the solar radiation heats directly to agriproducts laying on the floor by atmospheric temperature (Burade, et al., 2017). Along the time, this was the solution of drying food. As solar radiation is free and abundant, this method has the advantage of saving costs and energy. Nevertheless, it is highly dependent on weather changes. Solar drying method is suitable for tropical areas, like Mozambique, with at least 6 hours of sunlight received per day (Burade, et al. 2017; Nijegorodov, et al. 2003).

Mozambique has excellent solar conditions with an average of 7–9 h of sunshine per day throughout the country; the average annual radiation is about 1700 to 2200 kWh/m2 (Chichango and Cristóvão, 2021). However, this method takes the following drawbacks: It is very dependent on the weather, inapplicable when the climatic conditions are rainy, windy, moist and dusty; has very slow drying rate. In addition, the solar radiation is uncontrollable, too high temperature for drying can be achieved.

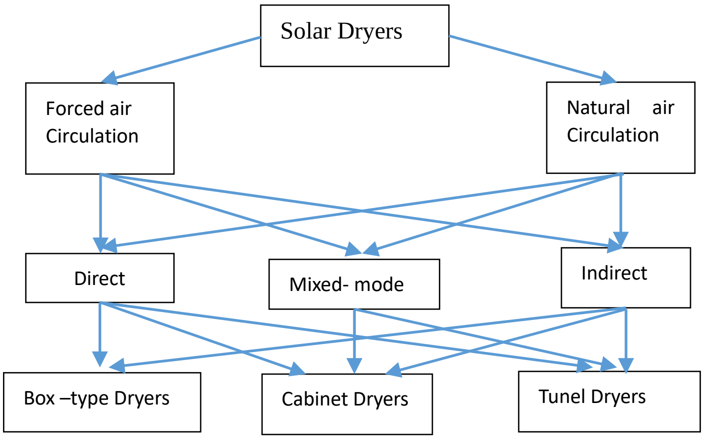
Food products, especially fruits and vegetables require hot air in the temperature range of 45–60 0C for safe drying (BAL, Satya and Naik 2010). In most of case, there are loss of produce to birds, insects and rodents, etc. The process also requires large area for drying takes time and highly labour intensive (Indiarto, et al. 2021).

2.2 Solar dryer

Seeking for high efficiency and capacity of drying, to attend, especially in adverse weather conditions. The drawbacks of the sun-drying method led researchers to present new drying method. Solar dryers are types of specific devices used to control the drying process and protect post-harvest products from damage by insect pests, dust and rain (Cekirge and Elhassan, 2015). The technology of solar dryer, in comparison to natural atmospheric temperature dryers (sun-drying), generate higher temperatures, lower relative humidity, and lower product moisture content and reduced spoilage during the drying process (Indiarto, et al. 2021).

According to the Phadke, et al. (2015), solar dryers can be classified depending upon the mode of air circulation, they can be natural or forced circulation dryers. Based on type of drying, like, direct, indirect solar drying and mixed-mode solar drying, depending upon the construction of the drying section, Figure 1.

Figure 1 - Classification of solar dryers. Source: adapted from DiPersio, et al. (2007).

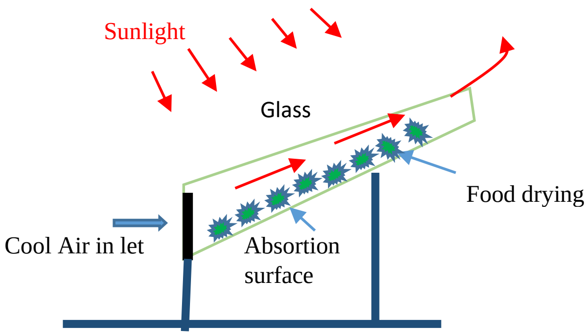


Source: Authors.

2.2.1 Box–type dryer

In direct solar dryer, the sun's rays directly affect the product to dry through glass, plastic or other pellicles (Figure 2) present the box–type dryer and its elements using natural air convection.

Figure 2 - Direct solar dryer (box- type).



Source: Authors.

In indirect dryers, the drying occurs in the dryer cabinet by the hot air. The solar collectors first collect the sun's heat by heating the air passing through the collector. The air enters to the drying chamber through the process of natural convection or through an external source like fan, pump, suction device, etc., in natural air convection the hot air flow up naturally drying

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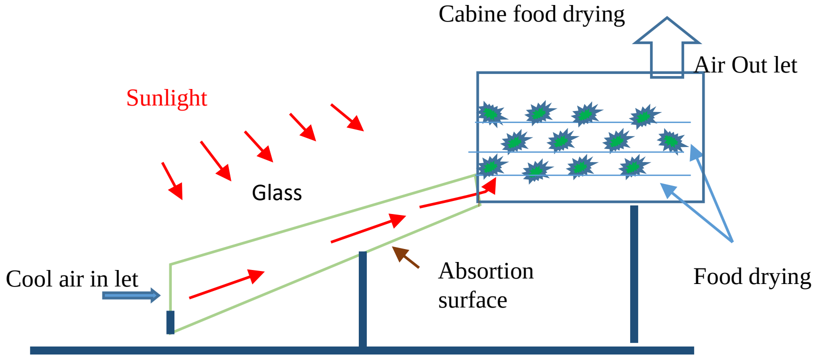
the produce on the plates. According to Burade, et al. (2017), this type of solar dryer is low cost, simple to maintain and to operate.

2.2.2 Cabinet dryer

Due to large area needed to dry, integrated solar dryers were introduced: In this type, the solar energy collection and drying takes place in a single unit (cabinet). Some of the examples for this category includes step type dryers, cabinet dryers, rack dryers, tunnel dryers, greenhouse dryers, and multi-rack dryers, Figure 3.

Figure 3 - Indirect Solar Dryer (cabinet – dryer). Source: meatsandsausages.com.



Source: Authors.

Later, mixed Mode-dryer were introduced: In this type, the solar energy collection takes place at both the flat plate air heater as well as a drying chamber and the drying takes place only at the drying chamber. The outer part of the dryer will also get solar energy; this helps to remove the moisture quickly.

The revolution of natural convection air dryer was forced convection solar drier (called active mode solar dryer) in it, a forced convection solar dryer the additional energy is needed to operate the fans to convey the heated air within the solar tube towards the food tray. The forced circulation air helps to dehumidify the food in less time. However, this dryer has disadvantages for many people in rural areas, they have no electricity grid, incur high costs to generate the electricity used to run this type of dryer. Therefore, these types of dryers are widely applicable with solar panel PV to generate electricity to run the blower (Burade, et al. 2017).

2.2.3 Thermal storage in solar dryer

The new step for evolution of solar drying technologies is thermal storage systems to ensue continuously drying products even without solar energy supply. Intermittent solar energy supplying is drawback of existing solar drying technologies. As the sunshine is available only during the day, there is a gap between energy supply and energy demand (Sharma, et al. 2009).

Thermal energy storage has been an active area of research at present. It can be stored in well insulated fluids or solids as a change in internal energy of a material as sensible heat, latent heat and thermo-chemical or combination of these. Krishnan and Sivaraman (2017) affirm that selection of thermal storage system for an application depends on factors such as storage duration, economics, temperature supply and utilization requirements, storage capacity, heat losses and space availability.

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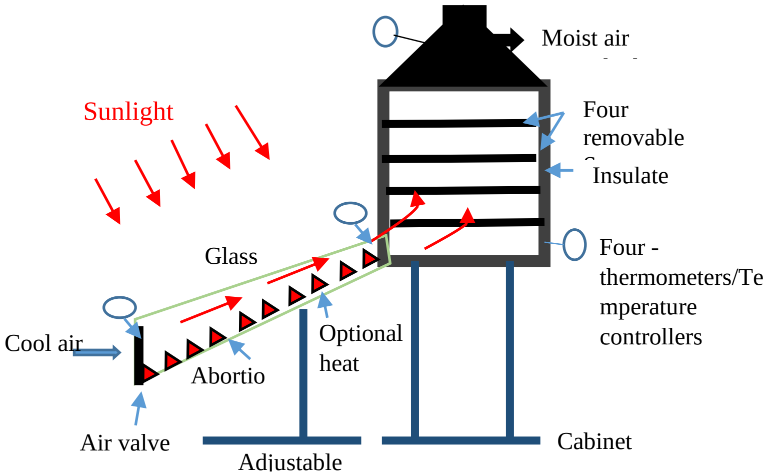
In the recent past, various designs of small-scale solar dryers, having thermal energy storage have been developed for drying agricultural food products, Figure 4. Badland Naik (2010), in their paper summarized the past and current research in the field of thermal energy storage technology in materials as sensible and latent heat in solar dryers.

Figure 4 - Dryer with thermal storage.



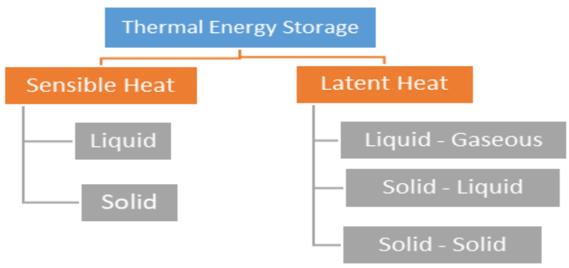
Source: Authors.

Paraffin is one of the most preferred thermal storage materials. It can absorb large amounts of heat during charging phase without increasing temperature significantly. When the ambient temperature drops below the phase change temperature, it solidifies, releasing stored heat. The drawback of paraffin is the low thermal conductivity. Baland Naik (2010) presents more details of material proprieties in review of solar dryer with thermal storage.

2.2.4 Thermal energy storage material for solar dryer

According to the Bal et al. (2010), the thermal energy can be stored in well-insulated fluids or solids as a change in internal energy of material as sensible heat, latent heat and thermo-chemical. The Figure 5 shows the techniques of storage of solar thermal energy.

Figure 5 - Technique of storage of solar thermal energy. Source: Baylin (1979).



Source: Authors.

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid, utilizing the heat capacity and change in temperature of the material during the process of charging and discharging. While in Latent heat storage (LHS) technique, the heat is absorbed or released when a storage material undergoes a change of phase from solid to liquid or liquid to gas or vice versa at constant temperature. Both techniques have advantages and disadvantages related, like

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the availability of material and the high energy storage required. The storage capacity amount of heat stored in SHS and the LHS system with a phase change material (PCM) medium are given by:

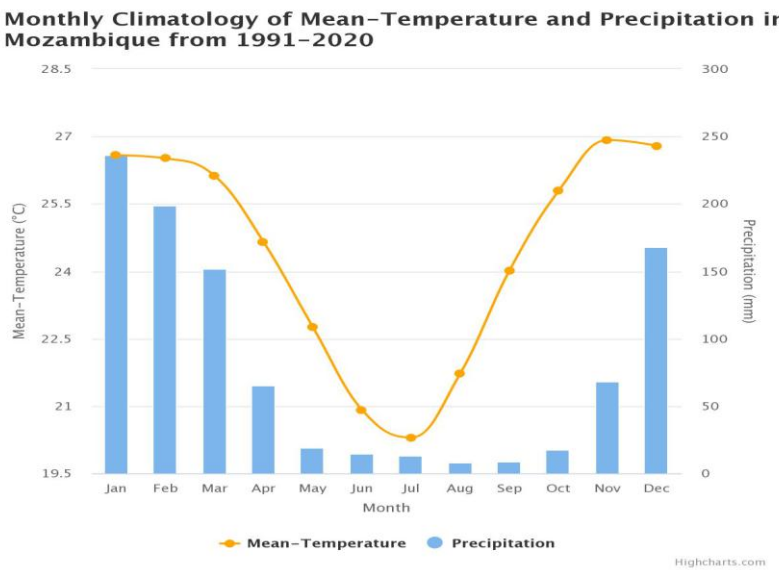
$Q_{SHS} = \int mC_p dt = mC_p(T_f - T_i) Q_{SHS} = \int mC_p dt = mC_p(T_f - T_i)$ and
$Q_{LHS} = \int_{Ti}^{Tm} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{Tf} mC_p dT Q_{LHS} = \int_{Ti}^{Tm} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{Tf} mC_p dT$

From the formulars above, the amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material. Thermal energy storage using Phase Change Material (PCM) in solar dryer application are lately being investigated by several researchers. Some results shared by Krishnan and Sivaraman (2017) shows that Latent heat storage systems using phase change materials have high thermal storage capacity when compared with that of sensible heat storage materials.

3. Suitable Drying Technology for Mozambique Climate

Mozambique faces two major energy challenges: inadequate access to energy and climate change. About 67% of population live and work in rural areas and 80% of the energy used in the country is in the form of traditional biomass (Chichango and Cristovão, 2021). In another hand, according to the climate and annual mean temperature, Mozambique has solar radiation in almost during all the year. The average annual temperature is above 25^{0-}C, whit high temperature and precipitation, see Figure 6. The grid on population is less than 40%, while 80% of people living in rural areas have the agriculture as the principal activity.

Figure 6 - Temperature and precipitation for Mozambique.



Source: Authors.

The lack of electricity from the grid in rural area should be the reason of weakness of agriculture processing industries, therefore; the preservation of postharvest products is one of the big challenges of rural people. The drying technology to meet the assumptions made before, the solar dryer technology using indirect drying, natural convection with storage heat is suitable for Mozambique on-farms and rural area in general, See Figure 4. The appropriate storage technique for

Mozambique can be Sensible Heat Storage (SHS) with solid and liquid material, such as rock bed. Waked (1986) also reported some advantages related with these issues. The reason for choosing this technology is among, available and affordable material; Low labour required; Low cost of drying device; no electric energy required.

4. Final Considerations

Mozambique, an agricultural country, is endowed with abundant solar energy, but the country is poor in its capability to exploit and use. There are significant post-harvest losses of agricultural products due to the lack of the use of proper preservation. In addition, almost non-existent installation/manufacturing sites, distribution, installation, and maintenance of solar dryer technologies in the country. This makes the country rely on more expensive imported systems and, consequently, low market penetration levels due to weak purchasing power. Small-scale, community-based solar dryer systems, along with trainings on their use, can help bolster family incomes as processing increases the market value of agricultural products. Small farmers need cheap, clean, and simple energy technologies to conserve biomass and preserve the environment. Thus, the most appropriate technologies for Mozambique are solar dryer integrated with natural rocks as energy storage for drying fruits and vegetables. But lack of adequate financing schemes and subsidies to start the spread of solar dryer technologies will be barrier to build the systems.

The research project will continue to work on the project based on our results from this review and build a solar dryer integrated with natural rocks as energy storage for drying fruits and vegetables to give to the farmers in rural Mozambique, while also keeping in mind the social acceptance by the farmers.

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