Solar drying of food under tropical conditions in Africa

Summary

In many regions of Africa, malnutrition remains a difficult problem that need to be solved. With the establishment of EcoHubs for fish and insect farming and spirulina production, the EU-funded project INNOECOFOOD is tackling this point in Ghana and Kenya. Beside the production activities, post processing of the fish and spirulina is challenging to achieve hygienic and high-quality products with extended shelf live under tropical conditions. Solar-powered drying processes offer sustainable solutions for this. To enable a comparison of technologies, heat for drying is generated using solar thermal energy in Ghana, while in Kenya, heat pumps using propane as refrigerant generate both heat and cold for the drying process. In this article, we will compare the two systems and present the results from the first few months of operation.

Keywords: solar drying, heating and cooling, propane heat pumps, Africa

Field of applications for the findings: Sustainable and solar post-harvest handling technologies for increased shelf live and fight against food spoilage.

Addressed audience: Initiatives and farmers in the global south, Federal Ministry for Economic Cooperation and Development, Federal Ministry of Agriculture, Food and Regional Identity

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1. Abstract

The EU-funded INOECOFOOD project addresses the Farm2Fork approach to local production and marketing of sustainably produced food in Africa. These goals are promoted through the establishment and operation of Living Labs and so-called ECOHUBS.

In the Living Labs, existing fish cage aquaculture facilities are equipped with modern IoT sensor technology and scientifically studied and monitored. The key element of the project, however, is the establishment of four ECOHUBS in Africa: centers dedicated to innovative and modern aquaculture. In addition to fish farming (tilapia and catfish) in innovative recirculating aquaculture systems (RAS) and in-pond raceway systems (IPRS), the ECOHUBS also include the production of the microalgae spirulina and the cultivation of insects (black soldier flies and crickets). The aim is to develop new and innovative products from these resources. A holistic approach is being pursued, with insects and spirulina being used to improve fish feed and waste being used in part as feed for the insects. The eventual goal is to develop high-quality products for human consumption – not only from fish, but also from spirulina and insects. The products are intended to help the local population: high-quality, safe, and affordable food, produced locally. At the same time, ECOHUBS aim to generate profits and enable the local population to benefit from economic growth and employment opportunities. This will be achieved in a sustainable manner through the training of trainers, the certification of food products, and the use of state-of-the-art technologies such as AI sensor technology, IoT, and intensive data analysis. Furthermore, each EcoHub brings together an entire line of food processing in one place and is designed to be powered entirely by solar energy (where possible). This solar-powered approach to food processing can make a positive contribution to reducing overall energy requirements and relieving the load on the grid, while also contributing to stability in the processing operations, especially since the EcoHubs are operated in regions where a stable electricity supply cannot be reliably guaranteed.

This article focuses on the solar-powered drying facility that is being installed in two of the EcoHubs as part of the post-harvest processing. The multi-purpose dryer is designed to ensure a consistently safe and high-quality product with a long shelf life in the tropical conditions of the EcoHubs, as well as minimizing post-harvest losses in the EcoHub. The dryers are being installed at locations in Ghana, on the western side of Africa, and in Kenya, on the eastern side. Both locations are not at the same latitude, but are very similar in relation to the equator and therefore have similar solar radiation conditions. The climatic conditions are also similar: tropical, with high air temperatures, but also with high to very high relative humidity, which poses a challenge for drying. Another challenge facing the dryer is the variety of products, some of which have very different drying requirements. As such, the multi-purpose dryer should be capable of drying fish and spirulina and, ideally, also be suitable for other products at a later stage (e.g., insects for human consumption). In Kenya, the focus will be on drying spirulina, while in Ghana it will be on fish.

The approach chosen for the scenario described would enable valuable scientific and technical insights to be gained while also meeting the drying requirements in the EcoHubs. At both locations, cabinet dryers of similar design and capacities corresponding to the requirements of the EcoHubs are used. Two different approaches were chosen for supplying the dryers with thermal energy, as the two locations with similar irradiation conditions are ideal for comparing the technologies. In Ghana, solar thermal collectors are used to provide hot water. In Kenya, the hot water comes from a heat pump powered by PV electricity. Both systems were simulated with PolySun™ for the design. The size of the PV and solar thermal fields, as well as the heat and electricity storage systems, were designed so that the dryer can be operated all year round and even at night.

In Ghana, a solar thermal system with 80 m² flat plate collectors and 4000 l hot water storage has been set up to provide hot water at about 70°C to cover the overall heat demand of the cabinet dryer with 24 kW. Drain back technology helps to prevent the system from damages from stagnation during no heat demand. The simulation results show that for most of the months the system can effectively meet the monthly heat demand of about 6000 kWh. However, from June to September, there is a slight decrease in the production down to max 5000 kWh per month, which can be attributed to reduced solar irradiation due to the rainy season and increased cloud covers. The maximum electrical requirement of the system is specified as 2,5 kW. In addition to the fans, this also includes the electrical power for all other electrical components such as actuators, control valves, pumps, and the control unit. For a purely solar supply of the electrical components, a separate PV system with 5 kWp and 5 kWh of electrical storage would be sufficient. Alternatively, the dryer is integrated as a consumer in the overall PV system of the EcoHub.

In Kenya, two heat pumps with propane as refrigerant, each with a thermal output of 16 kW, generate both, heat and cold for the drying process to cover the overall heat demand of the cabinet dryer with 32 kW. As in Ghana, a 4000 l hot water tank is connected. The heat pump also produces cold water, which is temporarily stored in a 500 l buffer tank. A purely solar-powered system would require an installed PV capacity of 15 kWp with about 10 kWh electrical storage system. One advantage of the heat pump used is that it allows for two operating modes: operation as air-to-water system using ambient air as heat source to produce hot water up to 75°C or operation as water-to-water system while cooling down a water circuit well below the ambient temperature (7°C).

The availability of cold water opens up two different drying process options for the dryer. The first is convective drying, the most widely used and classic drying technique. Here, food (plant and animal products) is dried using warm air, which heats the material to be dried, causing moisture from inside to move to the surface and then evaporate. Depending on the material to be dried, hot air with a temperature of up to 70 °C can be used. This drying method can be used with both the solar thermal system in Ghana and the heat pump system in Kenya. However, especially when the ambient humidity is high (as is the case in African EcoHubs), relatively high temperatures must be used to dry the products to a water content that ensures a long shelf life. Some products are temperature-sensitive and must be dried more gently at lower temperatures. These include spirulina, which will be a particular focus of drying in Kenya. Convection drying with its high temperatures can inflict damage to proteins and other ingredients if the aim is to dry to low final moisture levels at which spirulina can then be further processed into powder.

For this reason, the second drying method, which is made possible by the heat pump, is particularly interesting. In condensation drying, air at a lower temperature is passed over the product. A temperature of around 35°C or less is sufficient for this, which is also suitable for spirulina. After absorbing water from the product, the air is cooled down in a condenser to such an extent that water can condense and be removed. The air dried in this way is heated up again to achieve lowest relative humidity and passed over the product again, where it can take up more water from the product. In water-to-water mode, the heat pump generates cold water that can be used for this purpose in the condenser. The hot water is used to reheat the dry air. Studies in the experimental setup of a previous project (HORMEE) have shown that convection and condensation drying can be combined extremely well in a heat pump system to achieve gentle, fast, and energy-efficient drying. The setup in the EcoHubs is intended to show how this works in practice – also in comparison to solar thermal solutions. A particular focus is on implementation with solar energy supply. Both systems are fully equipped with sensors to enable accurate evaluation of the respective processes. The data is stored on servers and can be monitored and analysed remotely via IoT protocols.

In this article, we will compare the two solar energy systems for drying in more detail and present the results from the first few months of operation. The set-up of the systems at the two EcoHubs is currently ongoing and operation is expected to start in April and June, respectively.

This project has received funding from the European Union's Horizon Innovation action under Grant Agreement no. 101136739 (INNOECOFOOD) and UKRI under grant agreement no. 10110792. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union, nor the UKRI can be held responsible for them.