TEMPERATURE CONTROL SYSTEM FOR MINT DEHYDRATION IN DOUBLE-CHAMBER MARQUEE USING LINEAR ACTUATORS
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SISTEMA PARA EL CONTROL DE TEMPERATURA, APLICADO A LA DESHIDRATACIÓN DE MENTA MEDIANTE ACTUADORES LINEALES Y MARQUESINA DE DOBLE

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ABSTRACT

The objective of this research was to determine the thermal performance of a solar dehydration system that allows controlling the temperature for the dehydration of aromatic herbs such as mint. The use of a double chamber marquee allowed obtaining high thermal values, even with low radiation levels. For temperature control, a system of vertical mobile beds was used in order to reach the programmed temperature. This temperature was monitored using an embedded Arduino-type system that allows both monitoring and controlling motors, as well as recording temperature information. It was possible to keep the temperature approximately constant at 40°C, the ideal value for drying aromatic and medicinal herbs.

RESUMEN

El objetivo de este trabajo fue determinar el desempeño térmico de un sistema de deshidratación solar que permita controlar la temperatura para el deshidratado de hierbas aromáticas como la menta. El uso de una marquesina de doble cámara, permitió obtener valores térmicos altos incluso con niveles de radiación baja. Para el control de temperatura se empleó un sistema de camas móviles en la dirección vertical que permita encontrar la temperatura programada. Esta temperatura se monitoreo empleando un sistema embebido tipo Arduino que permite tanto el monitoreo como el control de los motores y el registro de la información de temperatura. la temperatura se pudo mantener aproximadamente constante en 40°C cuyo valor es ideal en el secado de hierbas aromáticas y medicinales.

INTRODUCTION

Due to the increase in the world population, it is necessary to reformulate strategies that could improve agricultural production and, in turn, food security, both for humans and animals. Another factor to take into account is climate change, which does not guarantee harvests on a regular basis with the same precision of both the harvest date and the volume collected. To meet this demand, there must be greater regulation of production, or the food produced must have the ability to be stored after processing. Although continuous production is not possible, it is possible to store food for a certain period when dehydrated *(Singh et al., 2018*).

Although there are mechanical dryers that use fossil fuel-based energy, the cost of drying is relatively high, and access to the combustion source can be difficult for remote areas (*Boroze et al., 2014*) . Additionally, the use of such dryers creates an environmental problem caused by the emission of carbon dioxide. Some researches harness energy that wastes non-renewable sources: part of the energy produced that is wasted is used in another process, thus being a renewable method such as the one used by *(Cacua et al., 2016*), who, from a micro-trigeneration system, used the residual energy of the exhaust gases of a diesel engine for mint drying and cooling.

In general, there are various drying techniques, such as spraying, mechanical, electrical, solar drying, etc. These drying techniques are used worldwide for drying agricultural and non-agricultural products.

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Among these dryers, the solar greenhouse dryer has several advantages over other types that make it a good alternative (*Singh et al., 2018*). These not only reduce the consumption of fossil fuels for drying purposes, but also provide the best quality in organoleptic characteristics (*Patil & Gawande, 2016*).

Kaewkiew et al., (2012) evaluated the drying performance of a parabolic shaped greenhouse dryer in Ubon Ratchthani, Thailand. (*Kulanthaisami et al., 2009*) used an 18 m long and 3.75 m wide tunnel-type solar dryer to dry 5000 coconuts per batch. The plastic sheet was opaque to long-wave radiation. These radiations were trapped inside the dryer and raised the temperature of the tunnel. They used a single layer polyethylene film for the cover of the solar dryer, due to the economy of the material and its easy handling. The dryer wrapped in a polycarbonate sheet had a concrete surface of 160 m^2. 50 W photovoltaic modules were used to power 9 DC fans, provided to maintain the required air circulation. To evaluate the performance of the solar greenhouse dryer, 500 kg of chilies were dried inside. The moisture content was reduced from 74% to 9% in 3 days in a solar greenhouse dryer, compared to the 5 days taken by natural solar drying. Besides, a reduction in the time necessary to complete drying, better flavour and colour were also observed.

Morad et al., (2017) built three identical solar tunnel greenhouse dryers to dry mint with overall dimensions of 2000 mm long, 1000 mm wide and 800 mm tall. The leaves and whole plants were placed in a range of between 6 and 10 cm thick according to the different loads of mint in a wire net, which was installed at the bottom of the lot in a greenhouse. A fixed suction air fan was used, powered by an electric motor of 0.5HP (0.37 kW) at 3000 rpm. The fan was connected to a digital thermostat that was set to operate the fan when the indoor air temperature approached 50°C. The mint load analysed was 2kg/m^2. A drying time of fewer than 12 hours was noted.

On a smaller production scale, researches using solar dehydration through collectors and chimney-type drying chambers are common. The chimney-type drying chamber is commonly used for passive drying (natural convection mode), as shown in Fig. 1 (*Abdulmalek et al., 2018*). Hot updraft air is used to dry the product located in one or more trays arranged vertically at the bottom of the chimney.

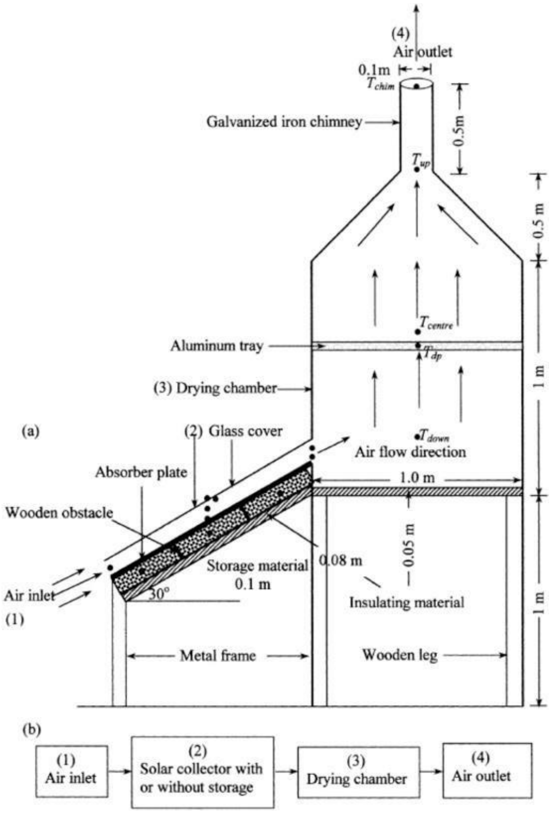

Fig. 1 - Solar dryer of chimney type drying chamber (*Abdulmalek et al., 2018*)

Solar collectors have not only been used for the drying process but also in refrigeration processes. For instance, (*Gil et al., 2017*) developed a solar-powered air conditioning system, also in pool heaters supported by vacuum tubes (*Roldan et al., 2013*). In general, collectors are a technology widely used in research that uses solar energy. A disadvantage could be that the drying volume is more limited than that processed with other technologies.

This is why a combination of technologies was used by *(Aymen et al., 2019*), who used both a collector and a marquee-type system, reaching temperatures close to 50°C in the case of the latter and 55°C in the case of the former, for maximum solar radiation of 800 W/m^2.

The temperature fluctuations that occur due to the rapid variations in radiation can be reduced by using materials with thermal storage. This is what authors (*Natarajan et al., 2017*) did, who analysed storage materials such as rock, sand, and aluminium fillers to identify the thermal performance of a tunnel type dryer and found that the thermal efficiency of the dryer without heat storage was 9.9%; the sand bed, 15.46%; the rock bed, 14.75%; and the aluminium fillers, 13.7%. This allows the sand bed to be identified as a good material for temperature storage. (*Abubakar et al., 2018*) used a black-painted rock bed to improve thermal absorption for a collector-type drying system, taking advantage of its low cost. For the collector dryer, the response of the system when the incident radiation is interrupted has been experimented, observing a first-order response to the dryer *(Deng et al., 2016*).

Solar dehydration systems are mainly used for drying plant material, in order to reduce the moisture content to levels that allow it to be stored for longer times without significantly reducing the active ingredients and the organoleptic characteristics. In the case of *Menta spicata* dehydration, the initial moisture content of 84% was analysed, as well as the final 10% (*Doymaz, 2006*). This study provides an analysis of the drying speed according to temperature.

Despite the fact that solar energy allows the thermal levels required in the dehydration process to be reached, it was necessary to reduce the humidity accumulated both by external filtration and by the number of plants or plant load to be processed. To extract excess moisture for both collector-type dryers just like (*Zaredar et al., 2018*), ventilators were used to produce forced airflow powered by photovoltaic solar panels, the forced ventilation in tunnel-type greenhouse or marquee systems (*Barnwal & Tiwari, 2008*)(Fig. 2), (*Morad et al., 2017*; *Chauhan et al., 2018*).

Fig. 2 - Hybrid photovoltaic-thermal (PV/T) dryer (*Barnwal & Tiwari, 2008*)

The literature consulted showed different methods that use solar energy as the main source of energy with a load capacity that varies depending on the form of heat concentration and that generally seek to be as economical as possible. This research employed some techniques developed in marquee-type dehydrators, modifying heat concentration. A double chamber structure is proposed for the dehydration of aromatic and medicinal plants, which allows to store them in an intermediate chamber embedded within another, thus serving as a thermal mattress, during hours of low radiation flow and which will simultaneously improve thermal levels inside.

The temperatures reached inside the system were recorded, which were above 65°C in the hours of greatest radiation in the upper part of the system, remaining as such at the intermediate level of dehydration, and above 40°C between 8 AM and 5 PM on days with little cloud cover.

Finally, temperature control close to 40°C was achieved for most of the day using a system of mobile beds controlled by linear actuators.

MATERIALS AND METHODS

This research was based on a need to preserve food with a novel methodology that can be transferred through education, ease of use, and that can be replicated in the future, including the ability to choose and adapt it to local conditions, and integrate it into the technology from the region.

This is basically what is known as technology transfer (*Londoño-Gallego et al., 2018*). Currently, this stage of the project corresponds to the second replica of a prototype implemented in another region of the Antioquia department in Colombia.

The analysed system was made of a structure of 2.5 m x 3.0 m x 2.8 m, as shown in Fig. 3 (taken from (*Palacio-Fernández & Cadavid, 2019*). The construction material was PVC for the structure and high-density polyethylene plastics for the inner chamber and the outer chamber, dark and transparent respectively. It sought to capture as much heat as possible between the transparent and dark plastic, taking advantage of the greenhouse effect, and thus to be transferred to the internal chamber gradually, allowing a smooth variation in temperature given sudden changes in radiation.

Fig. 3 - Double-layer polyethylene marquee used

A 60 cm linear stroke actuator was used to control the temperature (see Fig. 4), which allowed the beds to search for the appropriate temperature at the top during low radiation hours, and at the bottom during high radiation hours. The lower forced ventilation system allows excess moisture to be evacuated, since, although the temperature at the bottom is lower than that which occurs at the ceiling level, the current humidity is the opposite, and the excess humidity in the lower part tends to be quite high mainly at the beginning of the dehydration process.

Fig. 4 - Linear actuator for vertical movement of beds

RESULTS

Although the radiation values recorded by the early warning system of the city of Medellín (SIATA, n.d.) were not the best for experimentation on June 21 and 22, 2019, which were the dehydration dates (see Fig. 5), it was possible to achieve thermal values in the beds above 40°C, which allowed maintaining close control at this temperature, as suggested by (*Castro-Restrepo et al., 2013*). Fig. 7 shows the level close to 40°C that was achieved with the linear actuators when temperatures above 40°C were reached inside.

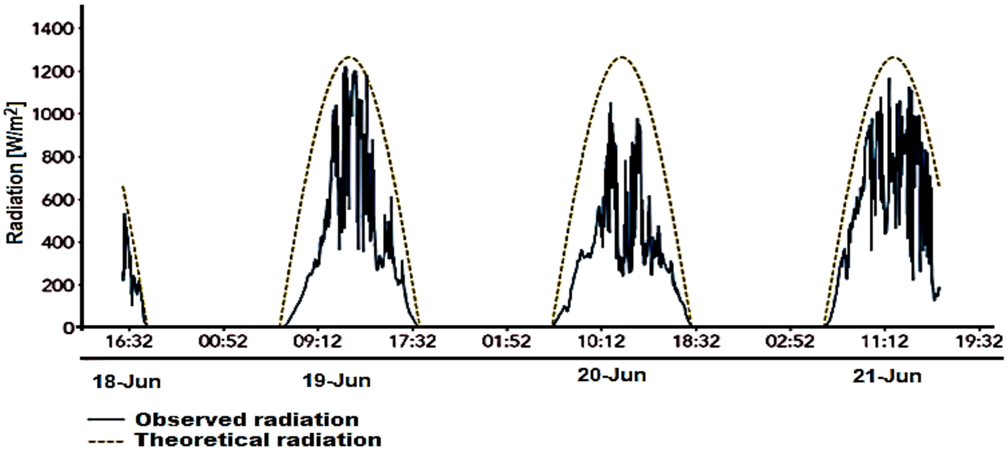

Fig. 5 - Radiation: SIATA tower pyranometer

The data was acquired and the system controlled by shield-type acquisition cards for Arduino Leonardo (see Fig. 6). This allows to control the process (Arduino Leonardo at level 1) and store the information and time of control events through Shield (level 3). Levels 2 and 4 are control cards for vertical linear actuators and for forced ventilation systems, and humidity and temperature sensors built by the authors of this article.

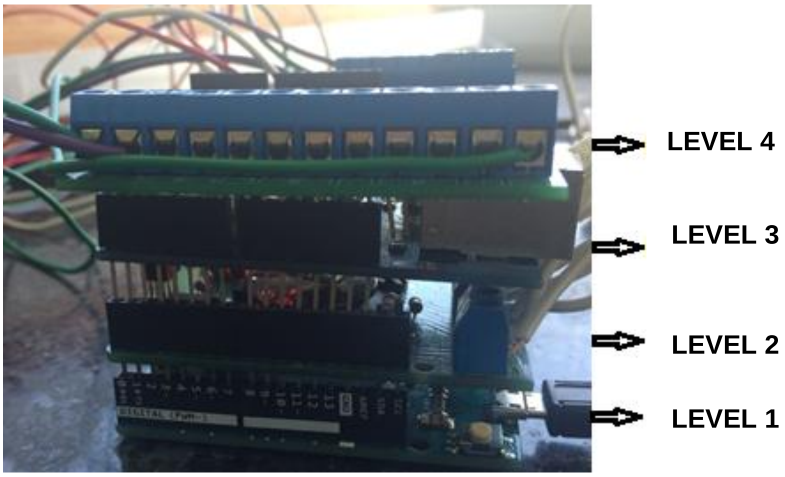

Fig. 6 - Data acquisition system

The data acquired (Fig. 7) show the scope of the constant temperature at 40°C reached during the interval of greatest radiation that allowed thermal levels greater than 40°C inside.

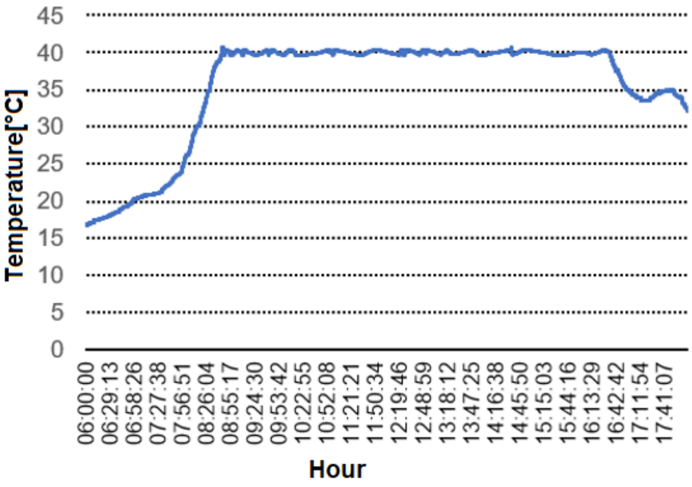

Fig. 7 - Controlled temperature, of approximately 40°C during 8 hours in a day

Fig. 8 shows the state of the fresh (a) and dehydrated (b) plants after the first day of drying for the test material, with the mint –still leaved– in the upper bed. The beds include a real-time weighing system that is recorded together with the environmental variables.


(a) (b)

Fig. 8 - Fresh and dehydrated mint

The mass loss of mint when it is dehydrated with the stem separately, compared to the dehydration with the attached stem, showed a small difference. In Fig. 9, two halves with equal mass were distributed in three beds and two divisions. The mint was placed in one of them with the stems and loose leaves, and in the other, the mint was placed without leafing. The mass of the loose leaves was 1000 g and the mass of the mint without leafing was 1000 g. The mass was analysed on a drying day which registered 389 grams for the mint with stem and 365 for the loose leaves. Mass losses of 65.1% in the former and 63.5% in the latter were achieved.

Fig. 9 - Distribution in each bed, equal mass in each one

When the moisture content decreases, the product changes mass, even though the dry matter remains constant (*García Navarrete, 2014*). The amount of water removed during the drying process was calculated using equation 1.

$$CH_f = 100 - \frac{w_i\left(100 - CH_i\right)}{w_f} \tag{1}$$

Where: w_i : initial mass (g)

w_f : final mass (g)

CH_i : initial moisture content [%]

CH_f final moisture content [%]

At the end of the first day, with an initial mass of 1000 g of loose leaves, a final mass of 365 grams and a final humidity (CHF) of 29.28% were obtained. On the second day, the same material had a final mass of 315 grams and a final humidity (CHF) of 12.11%. The values were average since there were beds in which leaves were placed separated from the stem, and others which included leaves attached to the stem.

CONCLUSIONS

Solar dehydration systems can be economically efficient due to the primary energy that feed them, and they can also be technically efficient if systems with good capacity for capturing and storing energy are built.

The use of mobile beds in a vertical displacement allows performing temperature control, even with sudden changes in radiation.

A little more moisture loss is registered if the mint is defoliated before dehydrating, although the process of removing the dried leaf is faster.

The control was not performed with the possibility that the beds reached the ceiling, due to the length of the actuators. With longer actuators or with another type of system, the temperature control spectrum could be extended during the day.

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