Responsive Dehydration: Sensor-driven Optimisation of Production Cycles in a Solar Dehydrator

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Abstract

Drying is an effective method for preserving food. Compared to freezing, it consumes less energy and produces equivalent results. Solar heat is a great way for small farmers to create sustainable and affordable goods since it costs no energy. This article describes and explains how to operate equipment developed to address this issue. The equipment is currently undergoing experimental validation, and real-time monitoring and user notification systems have been installed to improve the production experience and the post-harvest conservation of food products. Additionally, the installed tracking system allows farmers to keep track of their products from the farm to the factory. This article demonstrates how integrated monitoring and tracking systems can enhance small farmer production by optimizing the drying process of acorns.

Keywords
Solar drying, food drying, production management

1. Introduction

Drying is one of the best methods for food preservation. Alternative to freezing, it consumes less energy with equivalent results. Moisture removal has high heat costs; for example, a ton of coffee requires 21.10 GJ to be spray-dried [1]. Consumption is nearly half of a standard European household's heat yearly [2]. These high energy costs are added to the equipment cost of industrial machinery. Elevated capital and operational costs make it unattainable for small farms to compete

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in the drying food market, generally with biological production. Until 100 kg a day of produce, small producers are left without modern technical solutions. At the same time, industrial farming operations invade the market with large quantities of dried goods that recur intensively to fossil fuels. One conceived a new solar dryer to level the plane field by recovering ancient techniques [3]. Solar heat has zero energy cost, making it an excellent way for smaller-scale farmers.

This article presents a description and operation method of equipment at the state of experimental validation developed to address the problem. It relies on a monitoring system that can keep track of the drying process in real time via Global-System Mobile Communications Internet Protocol. This system allows the product to reach optimal dryness by avoiding over-drying, a common feature in artisanal moisture removal techniques.

The drying can be achieved by high temperatures that expand the air, reduce relative humidity, enhancing the air capacity to extract moisture from the food. However, high-temperature processes tend to degrade the organoleptic proprieties of the food, lowering its nutritional and commercial value. However, another type of drying is low-temperature drying with increased flow. The airflow is promoted around the food surface, forcing the internal moisture to diffuse towards the outside and subsequently be blown away [4]. The thermosyphon mechanism can create the air flux. The sun generates the thermal gradient to promote this natural convection.

This article will present how a proper set of measurement and communication instruments can aid the control of a natural drying process, thus merging traditional food processing techniques with current automation equipment. The solution becomes competitive because the operational costs remain substantially lower than those of fossil fuel solutions. Additionally, one presents in this article the incorporation of simple product control and tracking the fruits from the tree to the factory.

2. The Equipment

The equipment is a mobile solar food dehydrator. The food is placed inside air-permeable bags and hung inside the drying chamber. The volume of each bag was limited to a maximum capacity of 10 kg. Two bags can be suspended, one on top of the other, by the eyelets at the bottom. Each set can dry a maximum of 20 kg. The overall chamber capacity is 20 sets of 20 kg, totalling 400 kg.

The dryer structure is made from aluminium and is covered by a tarp surrounding it like a tent, separating the hot interior from the cold exterior. It has three parts: solar collector, chamber, and chimney. A self-adjustable wind wheel chimney hood was installed at its top to ensure the wind maintained negative pressure in the chimney. The lower external part of the solar collector has thermal insulation to provide high heat absorption and retention efficiency.

The dryer can be disassembled and folded for transportation in a simple tow. When assembled, the chamber and chimney have approximately 1.0 x 2.2 x 4.0 m. The collector has almost 14 m² of area, seven times larger than conventional models for the ratio food/surface [3].

2.1. Operation

The device was designed to be transported to the drying site, close to the high-yield trees, and operate autonomously. The equipment is easily assembled in the field, Figure 1.

Figure 1: Assembled Dryer on test site.

When the assembly is concluded, the product is inserted into the bags and hung inside the chamber [3]. The food will stay there until reaching the desired level of moisture. When the product is dried, the operator will replace the bags with dry products with new ones.

Figure 2: Bags hung inside the drying chamber.

2.2. Thermosiphon mechanism

A thermosiphon is a highly effective and straightforward method for transferring heat from one location to another through the natural convection principle [5]. In this case, an open loop system is employed. The heat is applied to the solar collector to initiate the heating process. A sketch of the events sequence of this mechanism is in Figure 3.

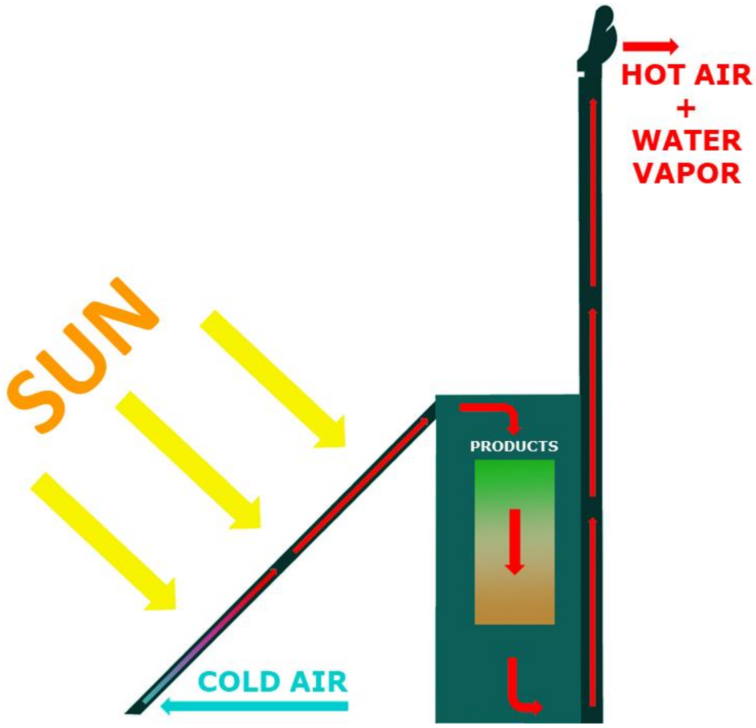

Figure 3: Thermosiphon mechanism.

The collector has an opening at its bottom chamber-faced wall. Since the collector is heated by sunlight, the air inside will expand and rise. New ambient air will enter the cavity by the differential pressure created to generate airflow.

The chamber has one opening on its top front wall where the air from the collector will enter. As the air flows inside, it will pass through the bags, carrying out the moisture as the water vapour leaves the food, the air temperature cools, increasing density. The colder air will flow to the bottom and be expelled through one opening at the bottom of the back wall.

The chimney has an opening at the bottom of its front wall, where the air from the chamber will enter. Its top part changes from a squared section to a triangular one, decreasing the area and increasing the airflow velocity. As the section area falls and the top black part is heated by sunlight, the hot air is expelled through the self-adjustable wind wheel chimney hood. This process continues as long as there is a temperature difference between the heat source and its surroundings, driving the natural convection flow.

2.3. Field tests

The first field tests to verify functionality were carried out on a local farm, Figure 1.

During these tests, a few possibilities for construction improvement were noticed. After the testing period ended, the device was returned to the workshop for structural upgrading and sensor installations. The insulation was also installed during this workshop time, as well as a net in the collector entry, to reduce heat losses and create a bug-free environment.

Within the test period, the dehydrator survived with damages, as did the storms Aline and Bernard hit. It was reinforced before being installed on a farm in Arraiolos, Portugal, weathering four other storms: Celine, Domingos, Elisa, and Frederico [6].

3. Data processing and synthesis of results

The conditions inside the chimney and drying chamber and the weight loss measured throughout the drying process allow us to confirm that the equipment operates as designed.

The drying process of this prototype resides in 2 phenomena: (1) the increase in temperature, which in turn dries the air; (2) regular air circulation, generated by the hot air produced in the collector, which goes to the drying chamber and subsequently to the chimney. The results of the first phenomenon are in Figure 4. This graph simultaneously shows the evolution, throughout a typical November day, of solar irradiation (G) and temperatures inside the drying chamber (T2) and in the chimney (T1). The radiation scale is represented on the left ordinate, and the temperature scale on the right ordinate.

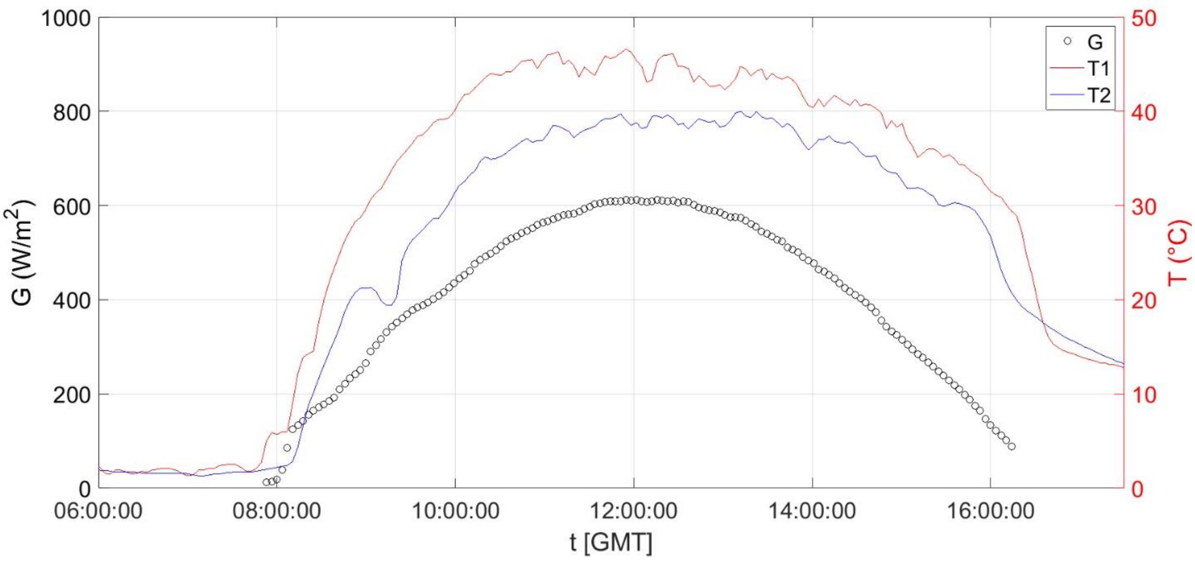

Figure 4: Temperature diagram.

The day was sunny, with sunrise around 8:00 am and sunset at 4:45 pm. The irradiation value is null outside these times. There is an increase in irradiation throughout the morning until reaching the zenith at noon, with a maximum value of 600 W/m^2. At the same time as the radiation increases, we have an increase in the temperature inside the chamber, from 2°C at 8:00 am to 22°C in just 1 hour. The increase in temperature is even more pronounced in the chimney, rising from 2°C to 30°C in the same period. This temperature difference is responsible for air circulation between the bags filled with acorns, promoting their drying. This drying is more delicate as it is done at a low temperature, which does not exceed 40°C throughout the day. Note that the temperatures in the drying chamber remain high throughout the day, even with lower irradiation values.

Figure 5 shows the expected result over three days of drying. As the acorn bags lose water, they begin to become lighter. The product weighed 22 kg in the graph, indicating that the bags were too full. Drying proceeded usually, although at a slower rate than initially forecasted due to the desiccation characteristics of this type of acorn.

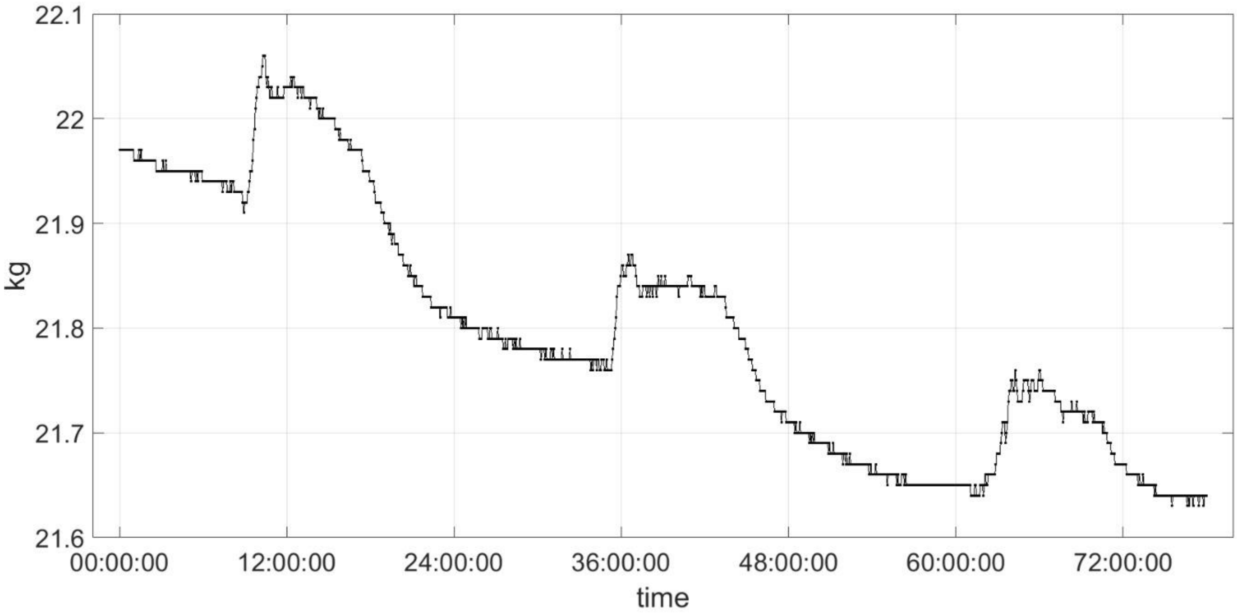

Figure 5: Weight loss from two bags of acorns over two days.

4. Measurement and monitoring devices

The equipment was instrumented with sensors to measure temperature, humidity, radiation, and load. The radiation sensor is located on the chamber's roof, away from the chimney, to avoid shading problems. The instruments that allowed the proof-of-concept validation are powered by a battery charged by a photovoltaic panel (PV panel), Figure 6.

The PV panel ensured that the system never had a power failure, reducing the probability of data communication failure to almost zero. The data is stored and transmitted via a GPRS modem. The installed instrumentation is described in Table 1, and the distribution of temperature and humidity sensors is in Figure 7, where each red cube represents a pair.

Figure 6: Front view of the equipment on the farm.

Table 1
Instrumentation used in the tests

Measure	Reference	Quantity
Temperature/Humidity	AM2302	17
Radiation	RS-TBQ	1
Weight 300 Kg	101BH	1
Solar Panel 50/200W		1
GPRS modem		1
Monitoring System		1

Figure 7: Temperature and humidity sensor positioning diagram.

The first samples placed for drying are displayed in Figure 8. One can observe the boxes for processing the electronic signals of the measurements and communication on the right side of the featured photo.

Figure 8: Boxes for processing the electronic signals.

4.1. Communication

The data can be monitored in real time by a custom-made application. In Figure 9 the main interface is displayed. At the main screen, it is possible to verify each sensor's temperature and humidity, as well as the product's total weight, at 22.06 kg and sun radiation of 390 W/m^2. With this information, the operator will know when to collect the product based on the difference in mass notified by the program via smartphone, smartwatch, or personal computer.

Different values for temperature are displayed. Such a difference happens because the collector and chimney are receiving sun radiation, while the drying chamber gets cooled down by evaporative cooling. In Figure 9 the highest temperature is from the sensor at the top of the wind wheel chimney hood, and the lowest is from the middle inner of the chamber. The three charts at the centre display some of the sensor's daily values.

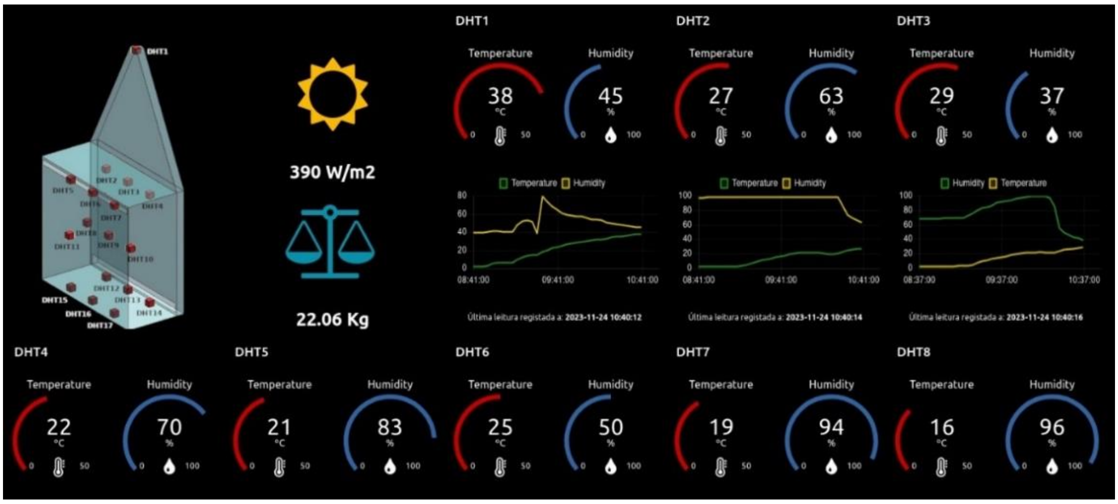

Figure 9: Application interface.

5. Production cycle optimisation

This section will demonstrate how optimising the drying process with minimum instruments supported by data monitoring and communication systems is possible.

The sensors were installed to optimise production. They are connected to a data acquisition and sharing system, which aims to notify the operator about the right time to collect the food and change the bags for new produce. The main goal is to avoid any unnecessary waste of time and resources.

By avoiding collecting the food too early, before reaching the desired dryness level, the system guarantees a sustainable way of constantly supplying the same product quality and mitigating wasted time and resources. Alternatively, it also avoids the late arrival of the operator, guaranteeing the product is not overdried. The extra drying time can then be used for a new batch of products.

5.1. Production control

Aside from the communication resource, a production control system was also implemented. It provides production control through barcodes on each bag, allowing control from drying to the factory. The bags leave the dehydrator and are transported to the factory, enabling trackability with the producer, the species and tree coordinates, delivered mass, drying percentage, and harvest date. The barcode can be seen in the upper part, Figure 10.

Every time a bag is hung, its barcode should be scanned to enter the information into the system. Through this logistics, one obtains better production control, accelerating the in-factory identification processing process by simply checking the bag.

Figure 10: Bag with the barcode at the top.

5.2. Minimal requirements for production cycle optimisation

The temperature, humidity, and radiation sensors help monitor the environmental conditions and the temperature threshold for the organoleptic properties of the food. However, the minimum required for the system is the load sensor and communication interface. Dryness is a function of mass loss; therefore, the load sensor is fundamental for each dryer. Moreover, the communication system enables the system to flag when the drying process is complete.

6. Conclusion

Implementing monitoring systems in low-tech solar equipment can be a powerful combination. The simplicity, low capital, and operational costs make this an excellent way for smaller producers to compete in the food industry. Of course, just like any new technological development, improvements are needed.

The drying rate did not reach the initially forecasted because of minor problems in the dryer related to the bags' overloading and the acorns' desiccant properties. Moreover, the telemetry was a success. The data could be consulted in real time via the Internet. The system allows for flagging when the pre-determined dryness level is reached. Also, the barcode mechanism promises to improve the whole value chain of the product as production grows.

6.1. Future work

Future work should mainly address the feedback of the sensors to the user. Data collection and storage should be optimised, avoiding wasting time and computational resources when reading and breaking down data. The design of an interactive application for reading data, graphs, and reminders for the operator will be one of the main objectives in the future, thus facilitating the drying process for the operator.

At the same time, one will improve the assembly and disassembly method, optimising the manning of the dehydrator.

Acknowledgements

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