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Evaluation of a cocoa dryer prototype using LabVIEW software and Arduino hardware

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Abstract

In a country like Colombia, food drying plays an important role in the extension of technology so that farmers improve the quality of their productivity. The objective of this work is to develop a system for acquiring thermodynamic variables, to establish the energy efficiency of a product drying oven, specifically for cocoa beans using Arduino hardware and LabView software. This research begins by establishing the variables to be measured and recorded by the DHT11 sensors, such as temperature and humidity. These sensors are connected to an Arduino Uno board that has an Atmel microcontroller, which captures the information from each of these. An algorithm was also developed that captures the temperature and humidity data and sends it through the serial port to the LabView software, in which the visualization on the front panel and programming in the block diagram have been developed, being viewed from the HMI (Human Machine Interface). For the experimental tests, 3,309 grams of fermented cocoa beans were taken, and dried for 36 hours, removing a total mass of water of 1,650 grams. The results show an energy efficiency of 10.62%, concluding that the drying oven that takes advantage of the residual heat of an 18000 BTU condenser integrated with the proposed variable system is suitable for drying cocoa beans. Despite this efficiency being low, it meets the objective of removing moisture from them.

Keywords: Convective dryer, Cocoa beans, Heat and mass transfer, Energy efficiency, Temperature, Humidity, Condenser

1. Introduction

Cacao is the ripe fruit of the cocoa tree, which grows in the tropical regions of Africa and South America. Raw cocoa is one of the most nutritious foods in the world and has been shown to protect the body from free radicals, reduce stress and depression, and protect against heart disease and many types of cancer [1]–[4]. This health benefit of cocoa beans is often granted thanks to the presence of polyphenols. Polyphenols are present in cocoa beans around 12-18% of the dry weight of the entire cocoa bean [5]–[7]. The main composition of polyphenols found in cocoa beans are simple phenols, benzoquinones, phenolic acids, flavonoids, etc. [8]–[11].

Additionally, cocoa beans are a great source of nutrients (lipids, proteins, carbohydrates, minerals, and vitamins). However, cocoa is eaten especially after a few processing techniques [12]–[14]. The steps before cocoa processing are harvesting, crushing, fermentation, and drying, which are necessary to ensure the quality of the cocoa beans. It is important to keep in mind that the flavors of cocoa develop during fermentation and the toast. Most commercial cocoa products are made from roasted beans [15]–[19].

During roasting, the flavor pioneers made during fermentation interact with each other to work on the desired chocolate flavor, which develops between amino acids and sugars through the Maillard reaction. Cocoa that is not roasted has a bitter, sour, astringent, and nutty flavor. Because, by roasting cocoa beans, the acidity is reduced by decreasing the concentration of volatile acids. However, processing also causes chemical changes that reduce the nutritional value and antioxidant properties of cocoa beans. Which would cause negative harm to the possible health benefits of consumption [20]–[23].

For example, high temperatures in processing favor lipid oxidation and non-enzymatic browning, resulting in the loss of fatty acids, essential amino acids, and digestible carbohydrates, reducing the nutritional value of foods. Likewise, they lead to the destruction of vitamins and reduce digestibility. In addition to affecting the nutritional and organoleptic properties of grains and final products, they also produce toxic compounds that are harmful to consumers [24]–[27].

Several studies report on the effects of temperature and processing time on the nutritional value and phenolic content of edible seeds. The quantity and quality of cocoa bean polyphenols depend on the method and conditions implemented during roasting. As polyphenols tend to have a bitter taste and the compound is modified due to heat treatments such as roasting, treating them with high temperature and duration is reported to have marked fluctuations in taste, aroma, and variation in total polyphenol content [28]–[30]. Therefore, in this research work, a food product drying oven is integrated with a thermodynamic variable acquisition system using the Arduino Uno board and the LabView software, to establish its energy efficiency [31], [32].

2. Research method

This article aims to integrate a system for the acquisition of thermodynamic variables with a drying oven for food products with trays, appropriate for a context where condensers are available and the possible use of the residual heat that they emit into the environment, through a compact prototype. It is integrated into the refrigeration system and this energy can be used in drying food. In this case, the tests are carried out with cocoa beans.

2.1. Materials

Figure 1 shows the use of high residual heat that a condenser discards into the environment in an 18000 Btu refrigeration system. To do this, a drying oven is designed with a cubic geometry and four trays inside, the walls are covered with sheets of a special wood that maintains the flavor and aroma of the cocoa beans to be dried; the trays are made of a wooden frame and with 304 stainless steel mesh (Figure 2). Additionally, in the lower part there is a diffuser through which forced air flow enters for drying (it will enter with higher pressure and low speed, optimizing drying and turbulence inside). Also, on the lower base of the equipment, there is an electronic digital scale, where the loss of mass and humidity of the cocoa beans can be displayed every 15 minutes.

The equipment has a data acquisition system using sensors that capture temperature and humidity (DHT11) at strategic points in the oven, coupled with an Arduino Uno card that collects data in real time and sends the information to a computer using a USB cable. There is an application in LabVIEW Software (previously designed and programmed), that visualizes and monitors the thermodynamic variables of the process [33]–[35]. In addition, there is a photovoltaic panel that powers a 12V battery and, in turn, provides energy to the hardware and the electronic acquisition equipment (Figures 2 and 3).

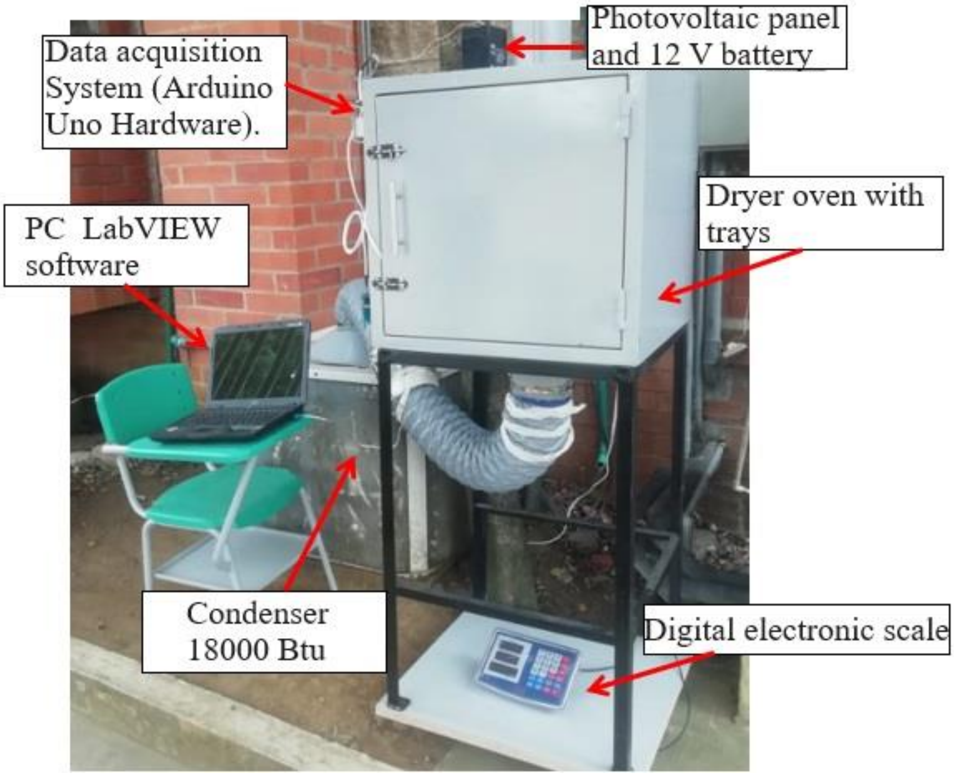

Figure 1. Drying oven with trays coupled to an 18000 BTU condenser

Figure 2. Tray of cocoa beans to dry (3,309 kg)

Regarding the data acquisition system, the following materials are necessary:

- Arduino UNO board: easy-to-use microcontroller
- 3 DHT11 sensors: they will be responsible for measuring humidity and temperature variables
- 12V battery connected to a solar panel: due to the use of the three sensors and the Arduino Uno board, a power source is necessary
- Electronic digital scale (kg)
- Computer for installing the LabView software

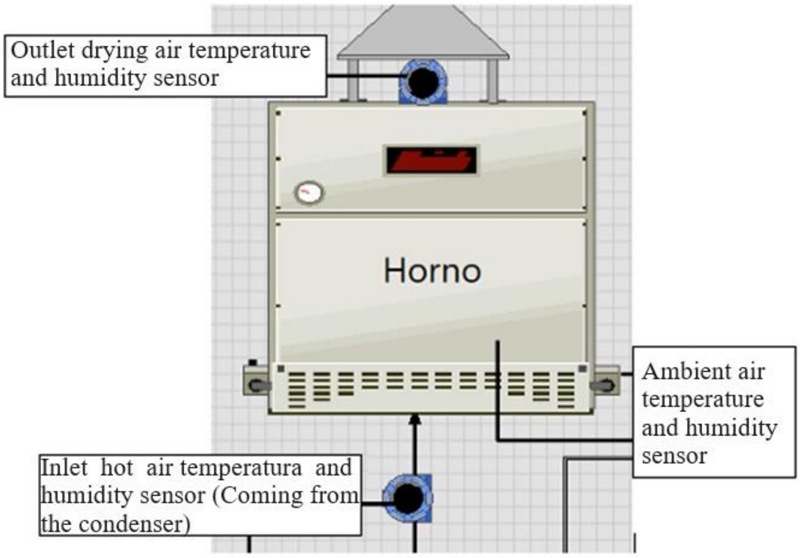

Figure 3. Location of the DHT11 sensors in the drying oven

2.1.1. Sample preparation

The cocoa beans were collected from a farm located in Playón in the department of Santander, Colombia. Before drying, fresh cocoa beans were fermented in Styrofoam boxes for five days. The cocoa beans for one drying batch were 3.309 kg with an initial moisture content of X_h = 0.58 (58%) (Figure 2).

To begin, the variables that will be registered in the system must be identified. These variables were selected based on a review carried out in previous studies.

Within these variables were found:

- Temperature (ºC): The optimal temperature provides the optimal conditions for the evaporation and drying process of the cocoa beans.
- Time (h): The normal drying time for cocoa beans in the sun is six hours a day for seven days, totaling 42 hours of drying with varied temperature ranges.
- Humidity (%): Humidity is a physical variable that expresses the amount of water dissolved or absorbed by a solid or gas and this content can be expressed through Equation 1 (moisture content in a solid).

$$X_h = \frac{M_a}{M_a + M_s} \quad (1)$$

Where:

M_a: Mass of the wet solid

M_s: Mass of the dry solid.

From this analysis, it is then possible to find what the amount of water in a solid will be by knowing the total weight of the wet solid and the total weight of the dry solid as indicated by Equation 2 (humidity at each instant).

$$X_t = \frac{W - W_s}{W_s} \quad (2)$$

Where:

W: Total weight of the wet solid.

W_s: Total weight of the dry solid.

On the other hand, determining the efficiency of the drying oven is done by applying Equation 3 (humidity at each instant).

$$Efficiency(\%) = \frac{T_{ae} - T_{as}}{T_{ae} - T_{aa}} \quad (3)$$

Where:

T_{ae}: Inlet air temperature

T_{as}: Exit air temperature

T_{aa}: Ambient temperature

As mentioned above, two DHT11 sensors were used to measure the temperature and humidity at the inlet and outlet of the drying oven, and one to measure the ambient air variables, as presented in Figure 3.
The data collected from the sensors is read by the Arduino Uno board and transferred to the LabVIEW data logging software. Table 1 mentions the pin connection made of the DHT11 sensors with the Arduino Uno board and Figure 4 shows its graphic representation. It is important to mention that humidity and temperature data are delivered through the same pin using serial communication.

Table 1. Connection of the DHT11 pins with Arduino Uno

Uno Arduino pin	Function
2	Receive information on weather conditions
3	Receive information on furnace inlet conditions
4	Receive information on oven exit conditions

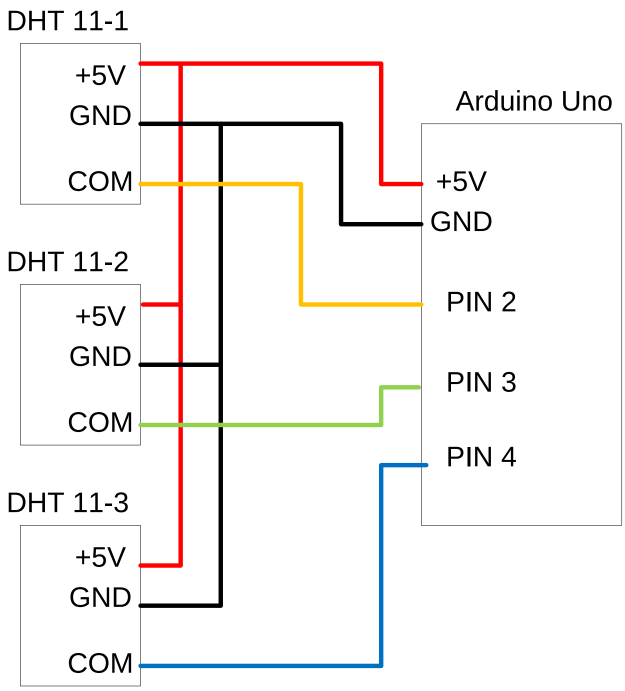

Figure 4. Connecting DHT11 sensors with Arduino Uno

Figure 5 illustrates the step-by-step actions executed by the microcontroller of the Arduino Uno board, where the humidity and temperature values of each of the sensors are read sequentially and subsequently sent through serial communication at a speed of 9,600 baud.

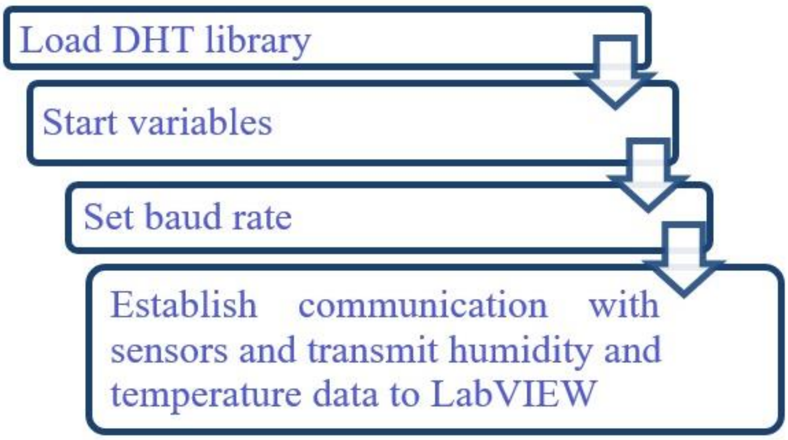

Figure 5. Step by step of the programmed workflow in Arduino Uno

Once the data acquisition system has been developed, Figure 6 shows the HMI interface where the communication test between the acquisition system and LabVIEW was carried out. This figure shows the thermodynamic variables such as temperature and relative humidity, automatically calculates the efficiency of the drying oven, and determines the moisture content of the solid or cocoa. The drying process is divided into four stages:

- Exit conditions
- Entry conditions
- Environmental conditions
- System efficiency and data entry

In this way, the data acquisition system and the drying oven are ready to start the tests.

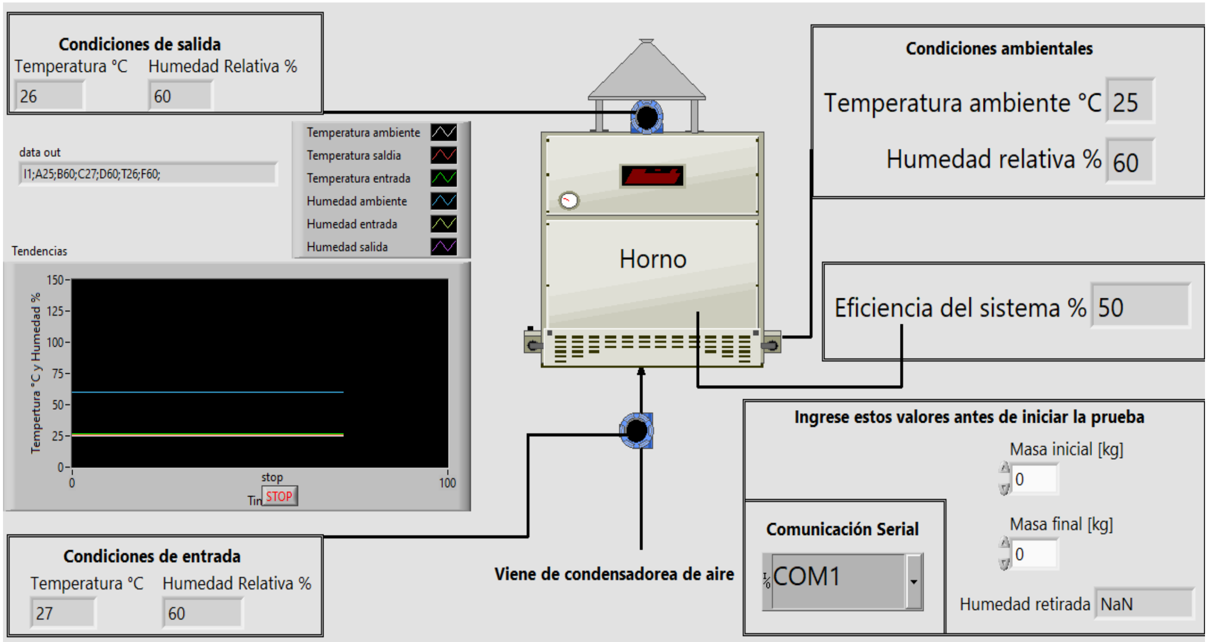

Figure 6. HMI interface developed in LabVIEW

3. Results and discussion

To begin, a sample of 3,309 grams of fermented cocoa is taken with an internal humidity of 58%. Subsequently, the cocoa almonds were loaded into four trays, distributing the weight evenly, and introducing them into the drying oven.

3.1. Drying tests

The tests begin at 06:00 hours on day 1, at which time they turn on the cooling system (18000 BTU) of an office of the Technological Units of Santander; therefore, the high heat that is discarded in the condenser which is used in the forced drying process that is being studied, maintaining this continuous process for 36 hours in a row, that is, until 6:00 p.m. on day 2. The drying oven is located next to the condenser and, using a designed and simulated nozzle is attached to its outlet, directing the forced air it expels and entering this hot flow at the bottom of the oven.

The flow of forced hot air enters through the lower part of the equipment and, through a turbulent flow, is saturated with the moisture removed from the grains, leaving through the upper part of the equipment. To do this, the temperatures and humidity of the ambient air, the hot air at the inlet, and the saturated air at the outlet (chimney located at the top) are monitored and displayed. Figure 7 shows the water loss of cocoa with respect to drying time, the final mass of this test was 1,659 g in a time of 36 hours. The total mass of the water removed was 1,650g, with these values we obtain X_h y X_f.

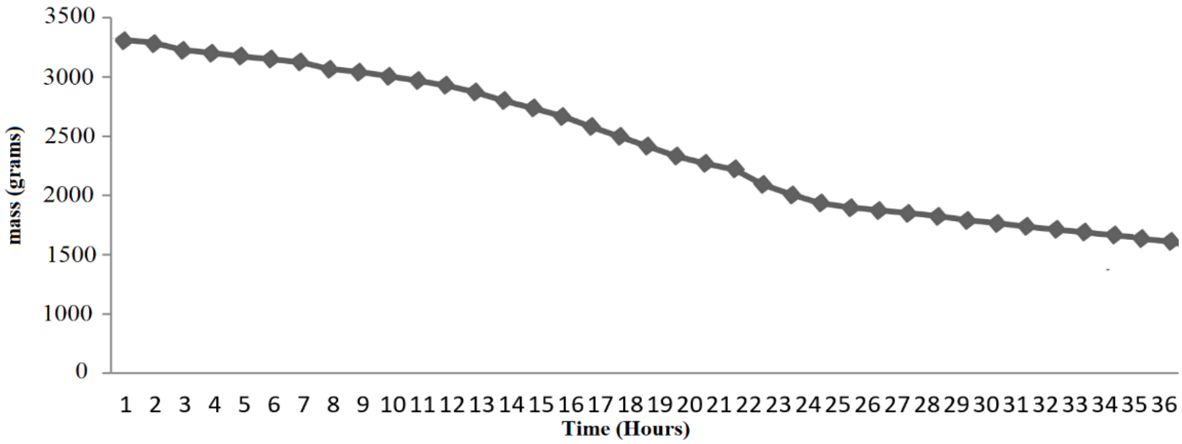

Figure 7. Variation of mass moisture loss in grains during drying time

3.2. Energy efficiency

From the temperature variations at the entrance and exit of the oven and according to the ambient temperature, the efficiency of the oven is obtained, as indicated in Figure 8. The average of this value is an efficiency of 10.62%.

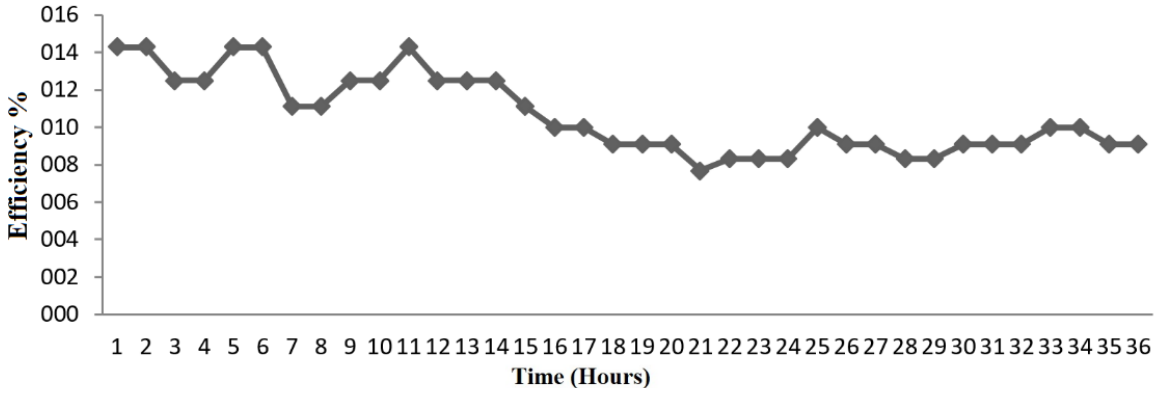

Figure 8. Energy efficiency

3.3. Drying speed

To determine the drying speed, Equation 4 is used where A is the contact area of the cocoa ($0.25m^2$) and M is the mass of the cocoa for the different moments. The experimental drying speed curve is presented in Figure 9, it can be seen that it does not remain constant, therefore, the dehydration of the solid is carried out with decreasing speed, which implies that moisture losses decrease over time. To reduce the drying time, it is important to mention that if the permeate velocity curve were constant in the first stage, a constant moisture loss would be guaranteed in a shorter time interval (Equation 4).

$$R = \frac{M}{A}\frac{d_x}{d_t} \tag{4}$$

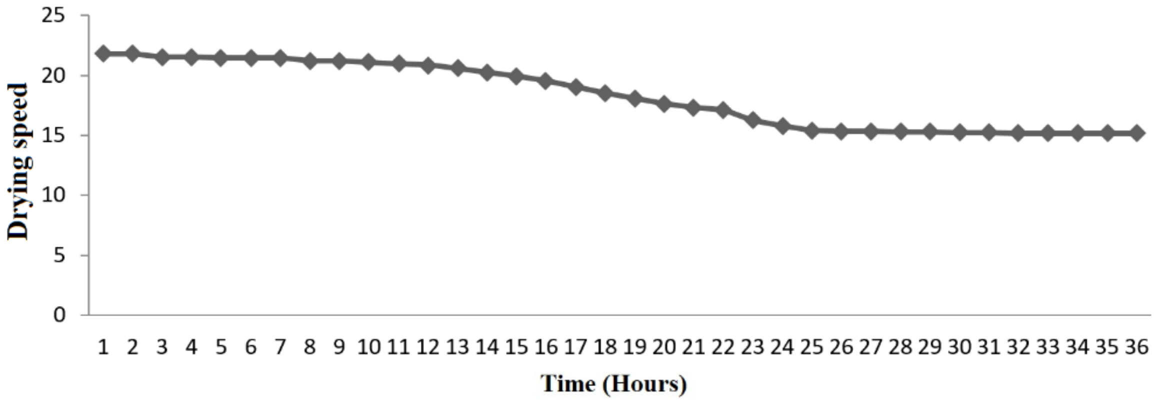

Figure 9. Drying speed

3.4. Relative humidity content at inlet and outlet

As seen in Figure 10, the relative input humidity remains at an average value of 50%. However, as expected, the output humidity increases as the cocoa dries, and part of the water that it contains begins to evaporate, which generates the increase observed in Figure 11, reaching a maximum value of 61%.

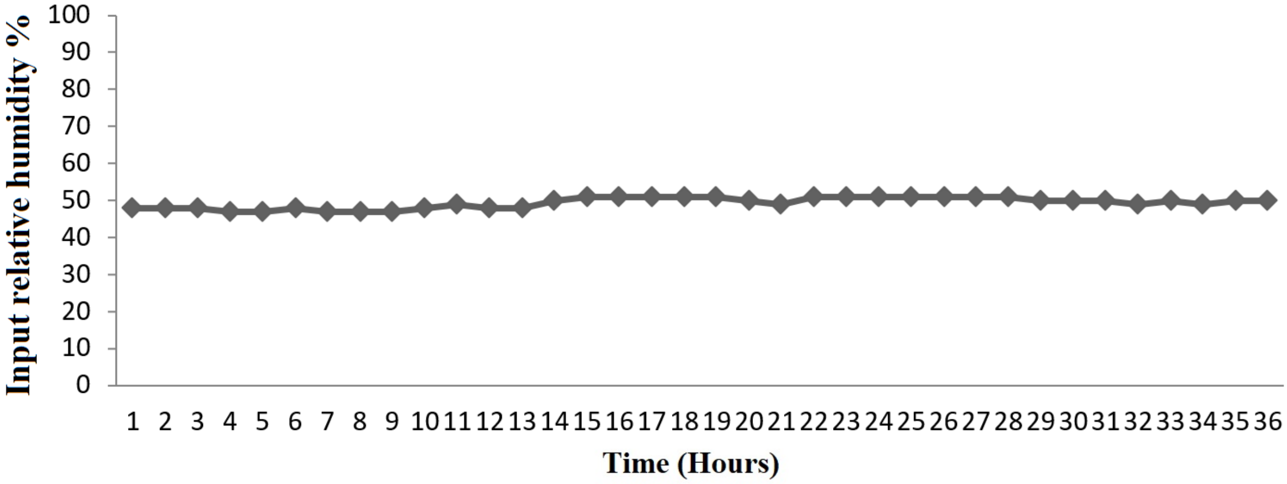

Figure 10. Inlet relative humidity trend

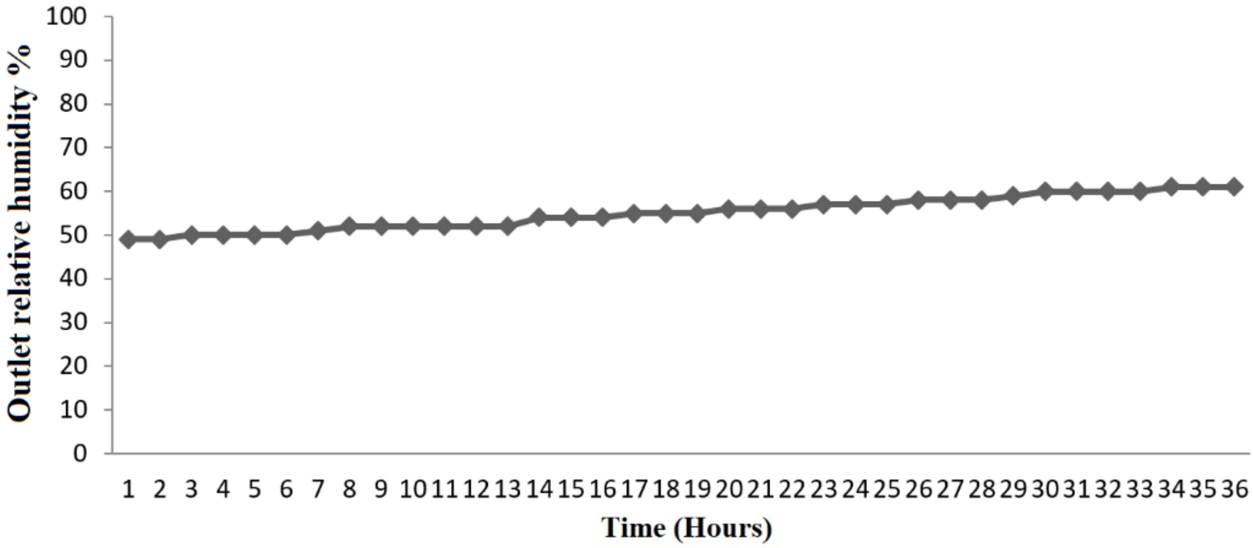

Figure 11. Outlet relative humidity trend

4. Conclusions

The research presents the evaluation of the energy efficiency of a drying oven, specifically for cocoa beans integrated into a system of thermodynamic variables with commercial data collection software LabVIEW combined with a developed HMI interface. As part of the design of the data acquisition system, the DHT11 temperature and relative humidity sensor and the Arduino UNO board were selected to measure the thermodynamic variables of the oven and process the information respectively, for which Holmes matrices were used. Using the Arduino IDE software, programming was carried out that follows a series of steps such as initialization of variables, use of the DHT.h library, configuration of transmission speed, and initialization of sensors. Through the LabVIEW software on the front panel, a series of indicators were implemented to record the thermodynamic variables of the oven such as temperature, and relative humidity. In addition to this, the initial and final weight of the test, and in the block diagram, a series of VIs was used to record the information sent through the serial communication port from the Arduino Uno and separate it according to the encoding that was established.

After implementing the acquisition system, the tests of 36 hours began using a cocoa sample, removing a total mass of water of 1,650 grams from an initial sample of 3,309 grams of fermented almonds, until obtaining 1,659 grams of dry cocoa beans. With an internal humidity of 7%, sufficient for subsequent processing and obtaining chocolate products, the temperature variations at the entrance and exit of the oven, and the ambient temperature, it is possible to obtain an oven efficiency of 10.62%. From the results, it can be concluded that the drying oven with an 18000 BTU condenser integrated with the proposed variable system is suitable for drying of cocoa beans, taking advantage of the residual heat of a condenser used in the refrigeration system of an office.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

The contribution to the paper is as follows: A. D. Rincon-Quintero, L. A. Del Portillo-Valdes and C. L. Sandoval-Rodriguez: study conception and design; A. D. Rincon-Quintero, L. A. Del Portillo-Valdes and C. L. Sandoval-Rodriguez: data collection; A. D. Rincon-Quintero, L. A. Del Portillo-Valdes: analysis and interpretation of results; A. D. Rincon-Quintero, L. A. Del Portillo-Valdes and C. L. Sandoval-Rodriguez: draft preparation. All authors approved the final version of the manuscript.

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