Installation and evaluation of autonomous solar dryer for potato drying in Tarma

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Abstract

In this work, an autonomous and automated solar dryer has been developed to dry potatoes in the town of Tarma at an altitude of 3 040 m in July 2019, which has a solar collector with two reflectors, a drying chamber with a capacity of 20 kg, photovoltaic panel and a control system. The thermal behavior of the no-load solar dryer was studied, achieving increases in the temperature in the drying chamber of up to 50.7 $\pm$7 °C with solar radiation of 880 $\pm$144 W m^{-2} h^{-1}. The effect of pretreatment was evaluated with two concentrations of sodium bisulfite (0.02% and 0.03%) and three drying temperatures (50 °C, 55 °C and 60 °C) to evaluate the physical (L*), physical-chemical characteristics (acidity, pH) and chemicals (humidity and ash). The results showed a reduction of 70% of the water having a final humidity between 12.56% to 13.85%. Likewise, no significant difference ($p>$ 0.05) was found between the physical, physicochemical, and chemical characteristics at the different bisulfite concentrations and drying temperatures of the Yungay potato. These potato quality parameters are in accordance with the Peruvian standard NTP 011.119 'potato and its derivatives: potato, definitions and requirements', which offers an efficient alternative to dehydrated agricultural products.

Keywords: automated, autonomous solar dryer, indirect solar drying, potato.

Introduction

Globally, most farmers seek to reduce the moisture content of their harvested crops, this in order to prevent spoilage during storage. Drying is the process of removing moisture through simultaneous heating and mass transfer (El-Sebaii and Shalaby, 2012). Drying is one of the oldest, most classic and commonly used methods to preserve and extend the shelf life of agricultural products such as grains, vegetables, fruits and other products (Chemkhi *et al*., 2004).

In developing countries such as Peru, its application is often restricted to conventional dryers (leaving the product uncontrolled in contact with the sun and pollutants) or industrial processes where enormous amounts of electrical energy are usually consumed (López and Chávez, 2018). Therefore, the use of solar energy as thermal drying where you can have control of variables such as temperature and humidity (to improve the quality of the product) and at the same time reduce the economic and environmental impact would be of great value (Bergues *et al*., 2008).

For example, Rodríguez-Tapia *et al*. (2017), installed, automated, and evaluated a solar dryer, reporting a decrease in drying time (between 30% and 50%), reduction in costs, reduction of losses due to attacks by pests, significant improvements in the quality of the final product, and control and reproducibility of the process. Likewise, Prada *et al*. (2019) reported reduction in the humidity of the coffee bean up to 12.3% in just five days and Quintanar *et al*. (2019) evaluated the economic investment and profitability of a solar greenhouse type dryer for wood, achieving a profitability of up to 240% of their investment.

Perú is the leader in potato production in Latin America (fourteenth in the world) and has more than 3 000 varieties of potatoes, planted on nearly 70 000 ha; however, only 12% is commercialized locally and the rest are often deteriorated in cultivation areas or their distribution (Agraria, 2019). Therefore, an adequate treatment for its conservation is necessary. The quality of fruits and vegetables during drying using a solar dryer has been studied by several researchers. For example, Iglesias *et al*. (2017), tested the quality of the solar drying on the ataulfo mango in Chiapas-Mexico, finding values of 5%, 45 °C and 25 °C referring to the humidity and temperature of the drying chamber and ambient temperature, respectively.

The drying time was 8 hours with 500 W m^{-2} of solar radiation and with a reduction in humidity of 80% (initial) to 8.4% (final). Lati *et al*. (2017) evaluated the effect of the solar dryer on the quality of the potato; through color analysis, reduction of sugar and pH, under a controlled treatment of 50 °C. For their part, Chouicha *et al*. (2013) studied the hybrid solar dryer on sliced potatoes and found a drying time of 3 h and a final moisture content of 0.13%. Likewise, Tefera *et al*. (2013) using a solar dryer found a reduction in weight of 0.9 kg to around 0.19 kg in two days, reducing between 2 h to 3 h compared to a normal sunny day.

Therefore, in this work, as a form of food preservation that meets the technical quality standards NTP.011.110: 2010 (Indecopi, 2010) for the national market of Peru, three objectives have been set: i) design and develop an automated solar dryer to dry agricultural products, which are abundant in the city of Tarma, as a way of preserving these foods; ii) study the thermal behavior of the automated vacuum solar dryer and its temperature control system in the drying chamber;

and iii) evaluate the viability of drying Yungay potatoes in the automated autonomous solar dryer and the effect of drying temperature and sodium bisulfite solution on the quality of potatoes for subsequent marketing.

Materials and methods

Sample preparation

The potato of the Yungay species was purchased from the farmers of Tarma because the solar dryer system was installed within the facilities of the Faculty of Applied Sciences of the National University of Central Peru (UNCP)-affiliate Tarma, which it is located at an altitude of 3 040 masl (latitude of 11° 25' 12" S and longitude of 75° 41'17" W). Its climate is arid and semi-cold with an average wind speed of 1.1 m/s, average annual temperature ranging from 13 °C to 18 °C, and average solar radiation of 5.40 kW h^{-1} m^{-2} day^{-1} as reported by Camayo-Lapa *et al*. (2017).

Potatoes of similar diameter and size were selected, washed and cut into 1 cm x 1.5 cm cubes. The pieces were then scattered inside in a drying room. In total 850 g of weight was used for each experiment. The initial relative humidity measured in the potato samples was 67.0%.

Physical, physicochemical and chemical characterization of the sample

Color was evaluated by means of a colorimeter (Lovibond, RT100, Germany) with illuminant D65 and a 10° standard observer in which the reflection spectra of the samples were determined with the coordinates of the CIE-L*a*b*, where the luminosity (L*), the physicochemical characteristics such as total acidity following the titration method; 942.15 (AOAC, 1996), the result was expressed as a percentage of sulfuric acid. The pH was determined by the potentiometric method, using a pH meter (Schott, PH11, Germany) and the proximal chemical composition with the methods recommended by the Association of Official Agricultural Chemists - AOAC International (AOAC, 2006). In ash (total ash method) and humidity (stove drying method).

Autonomous indirect solar dryer

In Figure 1, the solar collector and its two reflectors are observed, which are flat mirrors and as a whole, it forms the thermal capture system, they are responsible for capturing solar radiation and transforming it into thermal energy (heat) to heat the air that it goes to the drying chamber where the product to be dried is.

In this study, the drying chamber allows up to 20 kg of product to dry and has a built-in ventilation system, humidity and weight sensors, both monitored by means of an electronic display attached to the dryer. Through the display, a system allows the temperature in the drying chamber to be manipulated, according to the required drying temperature, for each product according to technical quality standards. This temperature programming has a range from 20 °C to 70 °C according to the recommendations of (Infoagro, 2020).
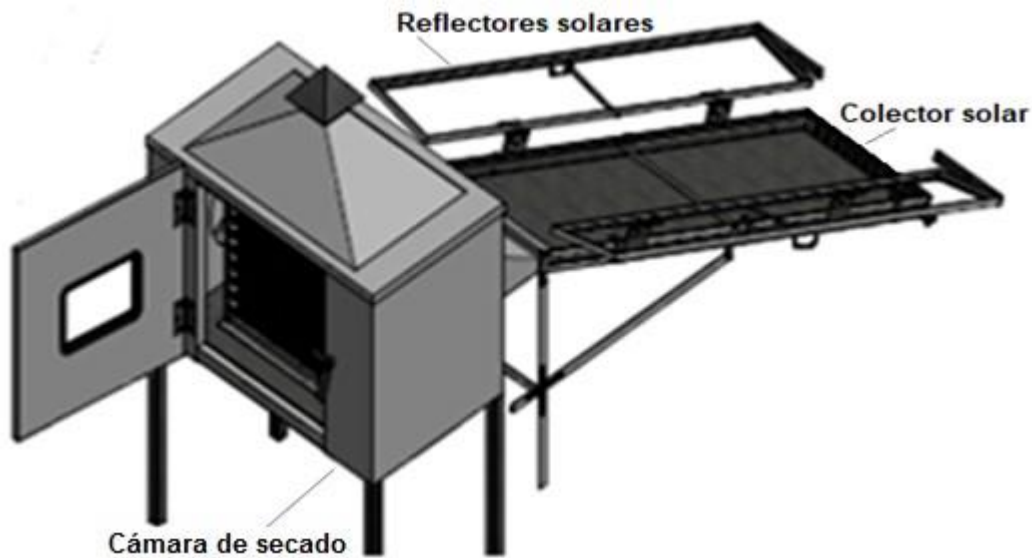
Figure 1. Parts of the autonomous indirect solar dryer.

Installation of the automated solar dryer

The solar collector and its reflectors were oriented to the geographic north, since Tarma is in the southern hemisphere of the earth, thus making better use of incident solar radiation. In addition, the thermal collection system, oriented to the north, was installed with a 22-degree inclination to favor the collection of solar energy during the winter months. The solar collector and the drying chamber were connected through a rectangular profile stainless steel duct, which prevents the leakage and loss of hot air during the passage of hot air into the drying chamber.

Design, simulation and elaboration of the control system

To have control of the system, a control circuit board was designed and implemented using Proteus software (Version 8.9, England). In addition, sensors were installed in the drying cabin, in the chimney and in the solar collector. Measurements of the operating system of the solar dryer were made, for this an algorithm was created with the objective of registering the temperature and humidity on the display in real time. The flow chart of the stages considered in the system to control/manipulate the temperature and humidity is shown in Figure 2.

Context for performance evaluation of the drying process

A few meters away from the solar dryer, a meteorological station was installed where meteorological variables such as ambient temperature (°C), relative humidity (%) and solar radiation ($W/m^2/h$) were measured and recorded, in addition of the internal temperature (°C) of the drying chamber for three consecutive days between 8:00 am to 5:00 pm local time in the city of Tarma (FACAP-UNCP).
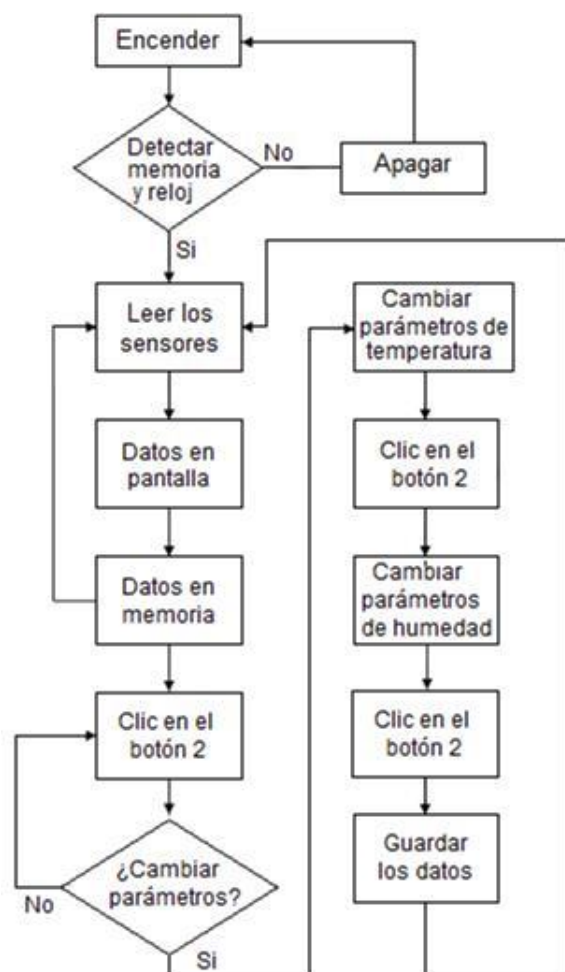
Figure 2. Flow chart of the temperature and humidity control system.

Analysis of data

The data from the physical, physical-chemical and proximal chemical analysis were reported as mean ± standard error, determined in triplicate. Differences between treatments (drying temperature and sulfite concentration) were analyzed by two-way analysis of variance (Anova) and posterior Tukey ($p< 0.05$). Measurements of the behavior of solar radiation, internal and external temperature in the solar dryer were plotted using SPSS Software V.24 and R Project (free software), version 3.3.6 (R Team Core, 2019).

Results and discussion

Automated no-load solar dryer measurements

Preliminary tests without load were carried out with the aim of verifying the operation of the solar dryer. The average results ± standard deviation (DS) of the measurements made (ambient temperature (Ta), solar radiation (RS), relative humidity (HR) and internal temperature of the dryer (Ti)) without load and every hour (8:00 h -17: 00 h) during the three days of tests, in the automated

solar dryer are shown in Table 1. The results showed an ambient temperature range of 7.3 °C to 19 °C (13:00 h), while the internal temperature of the internal dryer varied between 10.7 °C to 50.7 °C (12:00 h).

In turn, solar radiation ranged from 72 W m^{-2} h^{-1} to 880 W m^{-2} h^{-1}. A similar behavior was observed among the three variables (Ta, RS and Ti) previously mentioned, with an increase in their value in the early hours (8:00 am to 1:00 pm) in the morning and a decrease in the evening (2:00 pm to 5:00 pm), reaching its maximum values between 11:00 h and 14:00 h. In contrast, a decrease in relative humidity was observed as the hours passed, being more intense in the hours from 9:00 to 12:00 h. The global radiation and ambient temperature recorded by the Davis meteorological station at the faculty in Tarma are approximately similar to those estimated by Camayo-Lapa *et al*. (2017) of 5.47 kW m^{-2} day average monthly monthly, which makes the use of any equipment for water or air heating very profitable. Seveda and Jhajharia (2012) reported a 75% reduction in humidity, showing results similar to that of this work.

This is in agreement, since the highest solar radiation energy (13:00 hours showed the highest radiation of 880 ±144 W m^{-2} h^{-1}) was captured during this period. This is explained because, if a higher concentration of solar radiation reaches an area or surface, the temperature of this area will be increased (Daut *et al*., 2012). These results showed a higher internal temperature of the chamber (12:00 h showed the highest internal temperature of 50.7 ±7 °C) within this period, thus demonstrating that the installed solar dryer system and photovoltaic panel work perfectly.

Table 1. Average of the ambient temperature, internal temperature of the drying chamber, solar radiation and relative humidity measured on July 15, 16 and 17, 2019.

Hour	Ambient temperature (°C) Mean ± DS	Solar radiation (W m^{-2} h^{-1}) Mean ± DS	Relative humidity (%) Mean ± DS	Internal temperature (°C) Mean ± DS
8:00	7.2 ±2.2	72 ± 26	69 ±8	10.7 ±2.7
9:00	12.1 ±0.8	357 ±111	62 ±12	24.7 ±4.1
10:00	15 ±1.4	678 ±57	42 ±17	36.3 ±5.5
11:00	17 ±1.4	723 ±227	37 ±16	44.7 ±1.2
12:00	18.7 ±0.9	809 ±75	40 ±12	50.7 ±7
13:00	18.9 ±0.9	880 ±144	38 ±7	41 ±7
14:00	18.3 ±0.9	677 ±136	43 ±6	39 ±4.9
15:00	16.7 ±0.9	509 ±150	47 ±8	34 ±5.4
16:00	15.7 ±0.9	281 ±135	50 ±9	20 ±1.7
17:00	14.3 ±0.5	120 ±57	56 ±4	17 ±0.8

DS= standard deviation.

Figure 3 shows the average ambient temperature vs. the average internal temperature of the drying chamber (average of the three days). The internal temperature of the drying chamber showed a notable increase in its temperature up to a maximum of 50.7 ± 7 °C (this observed at the time corresponding to 12:00 h) due to the action of the control system that was configured at this temperature as the maximum. This result corroborates the good operation of the control system,

made up of two fans that come into operation if required. It is noted that the internal temperature of the drying chamber is to provide room temperature and solar radiation since higher chamber temperature, higher temperatures and solar radiation values were recorded.
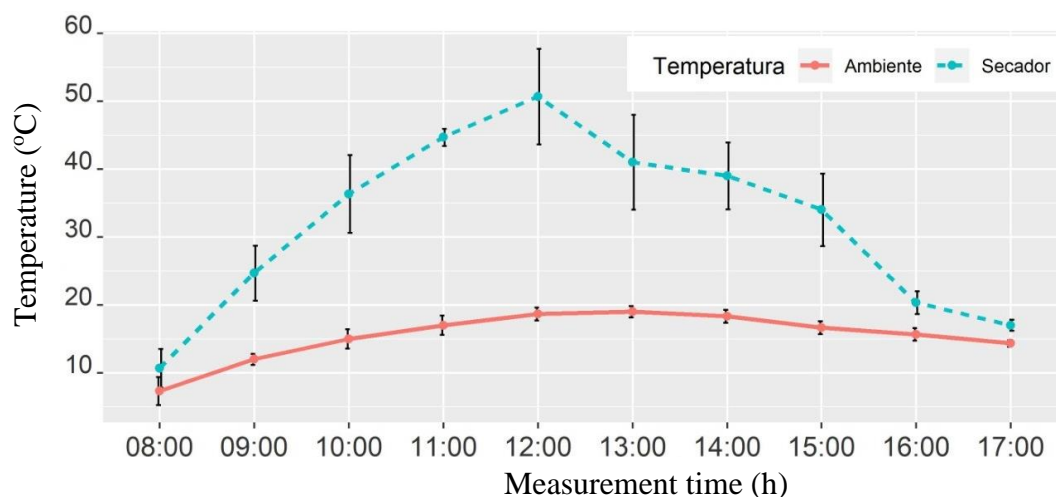

Figure 3. Ambient and internal temperatures of the average dryer, controlled at 55 °C.

Testing of the automated solar dryer with potato Yungay

To evaluate the viability of drying the Yungay potato in the automated solar dryer, the potatoes were first peeled and cut into cubes of 1 cm x 1.5 cm, in total 50 cubes with a weight per sample tested of 850 g. These cubes were immersed for 5 min in blanching using a solution of sodium bisulfite at two different concentrations: 0.02% and 0.03% w/v, once removed they were drained for 5 minutes and they were dried at three temperatures: 50 °C, 55 °C and 60 °C for an approximate time of 72 h, 3 consecutive days, obtaining a 70% reduction (from 850 g to 250 g, from 67% to 13%) in the weight of the sample. Table 2 shows the physicochemical characteristics analyzed after the drying process.

Table 2. Proximal physical, physicochemical and chemical content of dried potato at three drying temperatures.

Drying temperature	Sulfite concentration Mean ±DS	Humidity (%) Mean ±DS	Acidity Mean ±DS	Ash Mean ± DS	pH Mean ±DS	Brightness (L*) Mean ±DS
50 °C	0.02%	13.48 ±0.06 a	0.22 ±0.03 a	2.44 ±0.02 a	6.23 ±0.01 a	58.4 ±0.36 a
	0.03%	13.6 ±0.14 a	0.19 ±0.02 a	2.49 ±0.01 a	6.23 ±0.01 a	58.31 ±0.09 a
55 °C	0.02%	13.44 ±0.05 a	0.17 ±0.01 a	2.31 ±0.11 a	6.27 ±0.01 a	58.63 ±0.15 a
	0.03%	13.45 ±0.03 a	0.15 ±0.02 a	2.32 ±0.05 a	6.29 ±0 a	58.62 ±0.07 a
60 °C	0.02%	12.55 ±0.02 a	0.13 ±0.01 a	2.43 ±0.04 a	6.32 ±0.01 a	58.65 ±0.02 a
	0.03%	12.74 ±0.02 a	0.12 ±0.02 a	2.38 ±0.01 a	6.27 ±0.03 a	58.5 ±0.46 a

Values with different letters within each column denote significant difference ($p < 0.05$), mean values of three repetitions ± standard deviation (DS).

From Table 2, it is noted that when evaluating the interaction of pretreatment with bisulfite and drying temperatures, they did not show a significant difference ($p > 0.05$) in their physical, physical-chemical and proximal chemical characteristics: humidity, acidity, ash, pH and luminosity. Inferring that a temperature of 50 and a concentration of 0.02% of sodium bisulfite would be optimal for obtaining the dried potato. At these drying temperatures the measured quality parameters confirm that the final product is suitable; also, when evaluating the final appearance of the product with respect to the color attribute, all the samples have a light yellow + brown color.

Testing of the automated potato solar dryer

For the validation of the automated solar dryer, pretreatment tests were carried out on the peeled potato (potato cubes) with bisulfite to obtain dry potato as presented in Table 2. In this regard, Ahmed *et al*. (2010) evaluated the effect of peeling, drying at temperatures between 55 °C-65 °C and a pre-treatment of its physicochemical properties and nutritional quality.

They noted that bisulfite inhibits enzymatic browning by causing a reaction between sulfite ions and quinines by inhibiting polyphenoloxidase activity, oxygen depletion, and offering color stability of the final product. They concluded that a better quality product was obtained when the samples are pretreated with sulfite before drying at any temperature. Likewise, drying in the automated dryer helps to preserve the color in its luminance parameter (L^*) and this variable allows to directly evaluate the color degradation of the potato to be dried (Espinoza, 2016).

The NTP 011.119 'potato and its derivatives: potato, definitions and requirements', establishes as quality parameters in dehydrated potato a maximum of maximum 15% humidity and 2.5% ash (Indecopi, 2010). From Table 2, a maximum humidity of 1.89% (0.02% bisulfite concentration) and ash of 2.49% (0.03% bisulfite concentration) are observed. From this it is established that the characteristics (humidity and ash) of the dried Yungay potato obtained in the automated solar dryer is within the quality parameters of the 011.119 standard. It can be affirmed that using the solar dryer and controlling the parameters, a good quality product was obtained and allows us to go on to the development of an industrial automated solar dryer.

Cheftel (2000) pointed out that the availability of water (as a solvent) induces reactions and provides favorable conditions for the development of microorganisms, which could deteriorate the product. In this case, the low percentage of humidity (13.89%) compared to the Peruvian standard (15%) guarantees that our product (Yungay dried potato) will have a longer shelf life, since the probability of propagation of microorganisms is minimal.

Waterschoot *et al*. (2016) point out that the ash content is often related to the presence of minerals such as phosphorus, sodium, potassium, magnesium and calcium. In this work, such minerals were not measured, but we assume the presence of them because the potato is cultivated in soils where their presence exists and that many times they are absorbed through the roots. A report with the content of different minerals in different potato varieties is reported by the Ministry of Health (MINSA, 2017). Peña (2017), for his part, commented that the variability of the ash content basically depends on the maturity of the product and its origin. Ash values in different types of potatoes (for example, bitter, yellow, chuño, white frost, etc.) are in the range of 1.1% to 3.7% (MINSA, 2017).

Obregón and Repo (2013) reported pH values of 6.90, 6.60, 6.30 and 6.70 for the Peruvian potato varieties, yellow runtus, huayro and huamantanga, respectively. These reported values are in agreement with the values obtained in this work (Table 2). The pH has an inversely proportional correlation to the acidity values (Salazar *et al*., 2008). This behavior is shown in Table 2, where at higher pH concentrations, lower acidity concentrations.

This behavior is due to the fact that the organic acid content of the potatoes varies according to their state of maturity. Ojeda *et al*. (2010) evaluated thirteen different potato clones under different environments (areas). Results showed differences in the number of stems, dry matter and leaf area index. Likewise, differences were detected in its physical variables (specific gravity, dry matter, and polar and equatorial diameters) and chemical variables (acidity, pH, starch, and sugars). These results agree with those found in this work.

Conclusions

An autonomous and automated solar dryer for drying agricultural products was designed, which has a solar collector with two reflectors, a drying chamber (indirectly dries the product), a photovoltaic system that allows fans and control systems to operate. temperature and humidity monitored by means of an electronic display. The thermal behavior of the vacuum dryer (without load) was studied, achieving increases in the temperature required in the drying chamber with global solar radiation in saw conditions, and it was also verified that the automated control system allows programming the required temperatures in the drying process of an agricultural product under optimal conditions.

The bisulfite pretreatment and the temperatures established in the drying of the Yungay potato did not show a significant difference ($p > 0.05$) in the physical, physical-chemical and proximal chemical characteristics of drying in the automated solar dryer, thus meeting the quality parameters of the NTP.011.110: 'potato and its derivatives: potato, definitions and requirements', thus demonstrating the viability of potato drying in the autonomous and automated solar dryer, proposing it as an environmentally sustainable alternative for quality and low-cost drying with respect to other conventional alternatives.

Acknowledgments

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