Investigation note

# Efficiency of tunnel type solar dryer with cocoa (*Theobroma Cacao* L.) in Tabasco

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## Abstract

The drying of cocoa in the region of Chontalpa, Tabasco, Mexico carried out by the farmers is mainly done outdoors in a cement yard or in dryers built with wood. With this type of drying there may be contamination with dust, fungi and animals that affect the safety of the dry grain. The beneficiaries of the region use gas as an input for artificial drying, which increases the cost and the ecological footprint of the product obtained. During the dry season the drying process requires up to 3.5 days and in the rainy season few producers carry it out. The present work had as objective to know the efficiency of the drying time of cocoa bean with a polycarbonate tunnel type solar dryer, during the canicular period and the satisfaction of the participant producer, in the region of Chontalpa, Tabasco. A test was conducted in august 2017, with measurement of the atmospheric variables: temperature and relative humidity, in a farm located between the coordinates 18° 0’ 36’’ north latitude and 93° 18’ 18’’ west longitude. The results obtained indicate that in 24 h it is possible to comply with the percentage of moisture in the grain required by the NMX-F-352-S-1980 standard and the satisfaction of the participating producer related to the characteristics of internal and external color, odor, sound, final weight, separation of the husk and presence of fungi of the dry cocoa bean.

**Keywords:** greenhouse, harmlessness, *Theobroma Cacao* L.

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# Introduction

Cocoa is a crop with a long tradition in our country. It is considered that its primary center of origin according to the experts was Central America, from where it is estimated was dispersed to different regions of America, most likely through the various indigenous groups that populated this continent (ASERCA, 1995). Cocoa is a culturally and economically important crop in Tabasco, as it´s a traditional agroecosystem and is the first producer nationwide with 68% of the surface and 61% of production (SIAP, 2018). The drying of cocoa in the region of Chontalpa, Tabasco, Mexico carried out by the farmers is carried out mainly by solar drying in the open air, in concrete yards; in some cases dryers constructed with wood are used.

With this type of drying there can be contamination with dust, fungi and animals that affect the safety of the dry grain.). The beneficiaries of the region use gas as an input for artificial drying, which increases the cost and the ecological footprint of the product obtained. During the dry season (March-May) the drying process requires up to 3.5 days and in rainy or northerly season (November-February), few producers carry it out. The NMX-F-352-S-1980 standard establishes that the maximum moisture content should be 7.5% wb, which allows to conserve the safety of the grain during storage and decreases the risk of the appearance of fungi (Normas, 1980). The drying process consists of reducing the moisture content of the product to reduce its deterioration in a period of time called "safe period of storage" (Ekechukwu, 1997).

The decrease of humidity in agricultural products is carried out through the evaporation that entails the transfer of mass and heat (Ekechukwu and Norton, 1999). The decrease in moisture in a product can be achieved naturally or by forced convection. The natural way is when the hot air circulates naturally through the product due to the temperature difference and in the forced convection, the hot air is circulated through a blower or fan.

The use of solar energy in countries near the equator has great potential, however the development of technologies based on this energy is still limited (Eggers-Lura, 1979). Obtaining electricity through the use of solar cells has become popular as a sustainable alternative (Labouret and Villoz, 2010). There are different types of dryers that take advantage of solar radiation, which have been designed or adapted to the conditions of the tropics and that take advantage of the materials of the region to reduce costs (Ekechukwu and Norton, 1999). Solar radiation can be used more effectively for the drying of products by controlling the parameters of air temperature, humidity, rate of drying, moisture content and air flow rate (Garg, 1987).

In this regard, Hii *et al*. (2006) designed and evaluated a solar dryer type greenhouse, with capacity of 20 kg and polyethylene cover with ultraviolet protection, which allows to isolate the grain from the contaminants with a minimum drying time of 4 days. Dina *et al*. (2015) used an indirect solar dryer prototype with a capacity of 1 kg and recorded a drying time of 2 days when using molecular sieve 13x ($Na86((AlO_2)86*(SiO_2)106)*264H_2O$) and $CaCl_2$, as desiccants Barnwal and Tiwari (2008) tested a greenhouse dryer, with plastic cover and extractors activated by solar cells, in order to obtain evaporated moisture predictions, with multilinear expressions in forced convection mode. Arjoo *et al*. (2017) performed the evaluation of a tunnel-type solar dryer, with a capacity of 400 kg and covered with polyethylene with UV stabilizer, for the drying of garlic whose initial humidity was 66% (wb) and final of 9% (wb) in a period of 9 days.

The objective of this work was to test the efficiency in the drying time of a polycarbonate tunnel-type solar dryer, by forced convection, in cocoa bean during the canicular period in the Chontalpa, Tabasco region and the satisfaction of the participating producer.

## Materials and methods

**Polycarbonate tunnel type solar dryer**

The polycarbonate tunnel type solar dryer used is based on a Thai design (Figure 1) proposed by Janjai (2012), developed for the use of food drying by small scale industries. This dryer consists of a parabolic roof covered with polycarbonate sheets, galvanized steel structure and concrete floor. The dimensions of this dryer are 8 m wide, 20 m long and 3.5 m high, with a loading capacity of 1 000 kg of fruits or vegetables. The main modifications made to the original design were the integration of fans in the ceiling to homogenize the internal temperature and accelerate the drying process, activated by a solar cell, and the use of aluminum in its structure to make it lighter, more durable and portable.

**Figure 1. Greenhouse solar dryer designed by Janjai (2012) for small-scale industries.**

The dimensions of the solar dryer used are: 1.20 m wide by 2.40 m long and 0.6 m high, with maximum drying capacity of 21 kg of cocoa in a single layer. The Makrolon Bayer brand unicellular polycarbonate cover used has a thickness of 6 mm, has UV protection and is mounted on an aluminum structure and galvanized steel base. Inside the cover, installed on the roof, there are four 4-inch 12 V fans to homogenize the internal heat and in the back there are three 4-inch 12 V fans for air extraction. The fans work with energy generated by a solar panel type SE-156 * 26-25P-36 of 25 W and 21.7 V with dimension of 55 x 36 x 2.5 cm, manufactured by Solarever. On the front part there are two air intakes of 15 x 5 cm each, with movable windows to regulate the air intake.

Three double trays made of aluminum, with a height of 10 cm from the ground, are placed in line on the ground, with a separation of 10 cm between them. Six trays, constructed in aluminum and teflon mesh of 50 x 60 cm, with a capacity of 3.5 kg each, are placed on the tray holders, Figure 2.

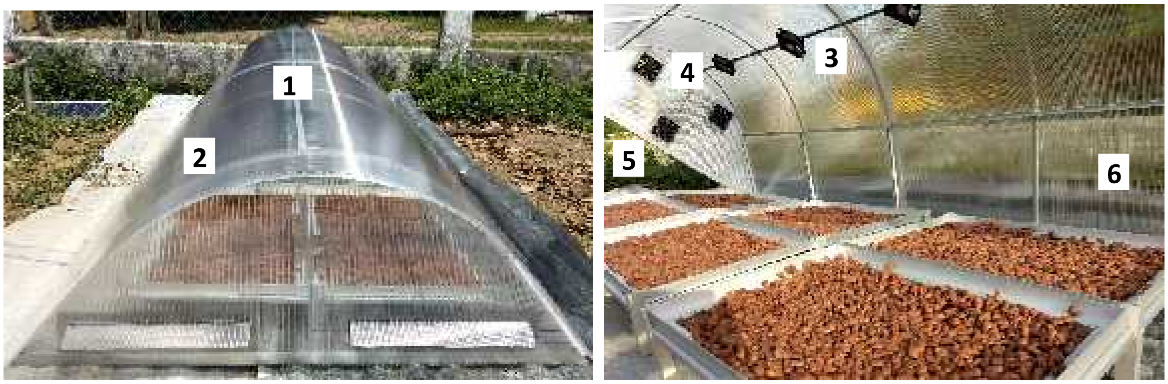


**Figure 2. Main parts of the polycarbonate tunnel type solar dryer. 1) polycarbonate cover with UV protection; 2) windows that allow air to enter; 3) fans to homogenize the internal heat; 4) exhaust fans; 5) carriage holder; and 6 trays.**

## Drying test

A drying test was carried out for two days on the farm of a collaborating producer located in the Ranchería Miahuatlán 2nd section, of the municipality of Cunduacán, Tabasco (18° 0’ 36’’ latitude north latitude and 93° 18’ 18’’ west longitude length). Fermented cocoa of the Trinitaria variety harvested on august 19, 2017 was used. The fermentation process was carried out during 5 previous days, starting on august 20, 2017, with the use of Macuili wood boxes (*Tabebubia rosea*), with a first rotation of the grain at 24 h and eight subsequent rotations every 12 h to favor aeration.

The drying test was carried out on the 25th and 26th of the month of august 2017, from 8:30 am to 7:30 pm. A load of 12.94 kg of fermented cocoa distributed in the six trays was placed, without moving it or mixing it, forming two layers of grains. The determination of moisture content was determined gravimetrically using the oven method, at 105 °C for 24 h Park and Brod (2002). Park and Brod (2002). The drying data were taken every hour from 8:30 am on the first day and from 7:30 am on the second day. The six trays were listed to carry the weighing log. Each tray was taken out of the dryer and placed on the scale for weight recording.

## Physical properties

## Moisture content

The moisture content ($\theta_m$, %) was determined by mass by the following formula:

$$\theta_m = \frac{m_w}{m_m} . 100\% \quad (1)$$

Where = $m_w$ (Kg) is the mass of water and $m_{material}$ (Kg) the mass of dry material.

Considering that moisture in the material originates, in general, from three sources: external water, internal liquid water and water vapor present in the environment, the use of gravimetric determination was considered to determine the average moisture content, starting from of the weight of the samples before and after drying (Erich and Pel, 2011).

The determination of the absolute moisture content was calculated by establishing the difference between wet and dry samples ($\theta_m, k\ / k$).

$$\theta_m = \frac{m_w - m_d}{m_d} \tag{2}$$

Where: _$m_{wet}$ (Kg) is the mass of wet material and $m_{dry}$ (Kg) the mass of dry material.

**Calculation of the humidity ratio**

Data obtained at different drying temperatures were transformed to the moisture content ratio (MR, without dimension) and is expressed as:

$$M = \frac{M - M_e}{M_0 - M_e} \tag{3}$$

Where =*M*, w.b. decimal, M0, wb decimal and Me, wb decimal are the moisture content at any instant of time, the initial moisture content and the moisture content at equilibrium, respectively.

**Moisture content in equilibrium**

The equilibrium moisture content of cocoa beans is obtained when it has remained constant for a certain time, at a certain temperature and relative humidity. The moisture content ($m_i$) of the grains was determined using the dry weight of the cocoa beans using equation 4.

$$m_i = \left(1 + \frac{FM}{IM_i \times \left(\frac{FMC}{100} - 1\right)}\right) \times 100\% \tag{4}$$

Where= the terms $IM_i$ (g) and FM (g) refers to the initial mass and the final dry mass, respectively FMC (%, wb) refers to the final moisture content.

The initial and final weight of the cocoa beans were recorded using a digital scale (BAPO-01 Rhino brand with a reading error of 1 g.

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**Producer satisfaction**

The peasant satisfaction with respect to the dry cocoa beans obtained with the polycarbonate tunnel-type solar dryer was carried out by the participating producer and contrasted with that of a table-type wood dryer, used by the same producer. The satisfaction criteria considered, established by the producer based on his knowledge and experience, were: presence of fungi, external and internal color, smell, texture, separation of the scale and sound when dry. Satisfaction was assessed using a rating scale of 1 to 10. The score of 1-5 was considered unsatisfactory, the lower the score awarded, the higher the level of dissatisfaction. The score of 6-10 was considered satisfactory, the higher the value awarded, the higher the level of satisfaction.

**Measurement equipment**

**Temperature and relative humidity:** two HOBO UX100-003 Data Loggers were used to measure temperature and relative humidity with an error range of 3.5%. One was placed inside the dryer and the second was placed at a height of 2 m from the ground, 14 m away from the dryer to read the conditions of the external environment.

**Solar radiation:** the data were taken from the automatic meteorological stations belonging to the national meteorological service of Mexico. http://smn.cna.gob.mx/tools/GUI/EMAS.php.

## Results and discussion

In this section, the conditions under which the cocoa bean drying test was carried out using the tunnel type solar dryer with polycarbonate cover are presented. The parameters of temperature and relative humidity inside the dryer, as well as the solar radiation, moisture content and humidity ratio in the cocoa bean are discussed.

The drying process required two days and one night, a total of 35 h. Figure 3 shows the records made of the ambient and interior temperatures of the polycarbonate tunnel-type solar dryer. The difference between the ambient and internal temperature at 10:30 h was 8.7 °C. The maximum temperature difference is observed at 15:30 h with a difference of 25.7 °C.


**Figure 3. Comparison of ambient temperature with the interior temperature of the polycarbonate tunnel-type solar dryer in the Ranchería Miahuatlán, Cunduacán, Tabasco, Mexico using data Logger HOBO UX100-003.**

The Figure 4 shows the solar radiation for the region of Chontalpa, Tabasco during the days in which the test was performed. It is observed that the maximum value is 900 $W/m^2$, coincides with the maximum temperature of 59 °C recorded inside the solar dryer type tunnel polycarbonate. According to the results of Jinap *et al*. (1994), with 60 °C of temperature, dry cocoa beans are obtained with a high concentration of volatile fatty acids (VFA) that intensifies the flavor of the chocolate produced with said cocoa. It is considered that the polycarbonate tunnel type solar dryer achieves similar conditions in the quality of the dry cocoa bean recorded by Jinap *et al*. (1994).


**Figure 4. Solar radiation in the region near Cunduacán, Tabasco, Mexico.** http://smn.cna.gob.mx/tools/GUI/EMAS.php.

It should be noted that the variations in solar radiation observed (Figure 4) are due to the presence of cloudiness during the day, which seems to be directly related to the temperature inside the dryer (Figure 3).

The Figure 5 shows the records of environmental relative humidity and inside the polycarbonate tunnel- type solar dryer. It is observed that the relative humidity values inside the solar dryer are kept below the values of relative humidity in the two days of the test, which confirms the efficiency of the dryer used for the drying process of the grain of cocoa and the improvement of the original design with the integration of the fans in the inner part of the solar dryer that favors the homogeneous drying in spite of the double layer of grains (Figure 6). The latter eliminates the need for the constant turning of the cocoa beans that is carried out with the drying methods used by the region's producers.


**Figure 5. Comparison of the relative humidity (%) with the interior of the polycarbonate tunnel- type solar dryer in Miahuatlán, Cunduacán.** Measurements taken every hour.

**Figure 6. Aspect of the cocoa dried in two layers with the tunnel-type solar dryer of polycarbonate.**

The Figure 7a shows the decrease in moisture content, from 56.40% (wb) to 6.2% (wb) in cocoa bean. The final value obtained was lower than the maximum value established by the Mexican standard NMX-F-129-S-1979. The Figure 7b shows the time in which the drying process was carried out until reaching a period without loss or humidity gain that goes from 7:30 p.m. on the first day to 8:30 p.m. on the second day, despite the presence of rain at night and dew in the morning during the trial period. To obtain cocoa beans with a final moisture content of 6.26% (wb), two days of drying (24 h) were required. The drying time obtained is 6 hours less than the time obtained with the integrated solar dryer with desiccant thermal energy storage and the use of desiccant type adsorbent, and 5 hours more compared to the use of desiccant type absorbent Dina *et al*. (2015).

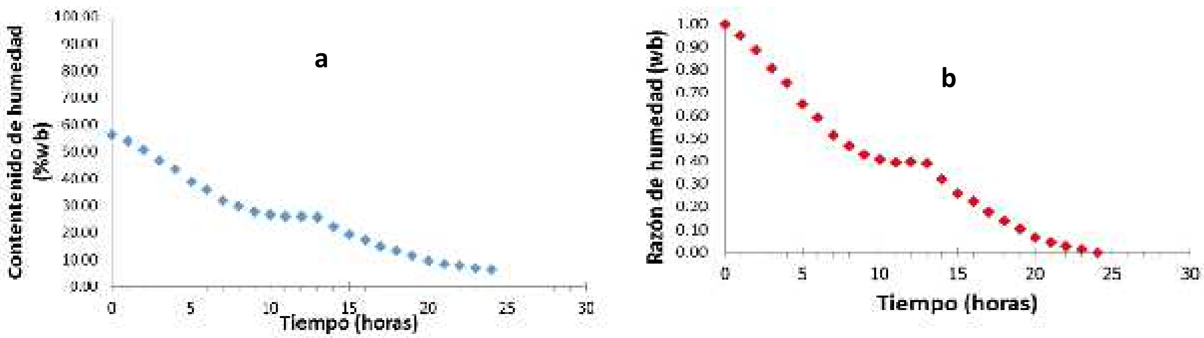


**Figure 7. a) Moisture content in percentage of wet bulb (% wb) with respect to time; and b) ratio of humidity loss measured in wet bulb (wb) to the drying time.**

## Producer satisfaction

The producer related an adequate drying of the grain with an external color between cinnamon and chocolate. A whitish color in the grain indicates that it was not properly dried. The internal color must be of a homogeneous color chocolate (brown), a black or purple color indicates a grain that has not been properly fermented or the grain was not ripe at the time of cutting. Another aspect considered was the sound of the dry grain, which was verified by moving and causing the cocoa beans to collide with each other, when the sound is 'thick' or severe, it indicates that it requires more drying time, and when the sound is 'light' or sharp, proper drying has been achieved. In the case of the husk, a brittle consistency that favors easy separation of the grain is sought, otherwise it is designated as pellejuda when stuck to the grain.

The satisfaction of the producer with respect to the dry grain obtained with the tunnel- type solar dryer of polycarbonate, had a difference of 4 to 6 points in the scale of measurement defined, related to the presence of fungi in the grain, external color of the dry grain, odor, separation of the scale and sound of the grains, in relation to the table-type wood dryer. The satisfaction of the producer improved from 2 to 3 points with the tunnel-type solar dryer of polycarbonate, in relation to the reduction of the weight of the grain, time and drying capacity per load. The satisfaction with respect to the internal color of the grain improved only in one point, since some dry grains with violet color were observed inside, however, the producer related this characteristic to the grains harvested prematurely. In general, all the criteria evaluated showed greater satisfaction with the solar tunnel dryer of polycarbonate tested in relation to the wood dryer used by the producer (Table 1).

**Table 1. Qualitative evaluation of the dry and harmless process of the dry grain in table-type wood dryer and the polycarbonate tunnel-type solar dryer, carried out by the producer.**

| Satisfaction criteria | Satisfaction with table-type wood dryer (scale from 1 to 10). | Satisfaction with the polycarbonate tunnel type solar dryer (scale from 1 to 10). |
|---|---|---|
| Drying time | 7 (3.5 days) | 10 (2 days) |
| Capacity (kg) per load | 7 | 9 |
| Presence of dry grain fungi | 4 (2%) | 10 (0%) |

| | | |
|---|---|---|
| External color of the grain | 5 (whitish coffee) | 10 (reddish) |
| Internal color of the grain | 7 (dark coffee) | 8 (dark coffee and some violet) |
| Odor | 6 | 10 |
| Weight loss when drying | 7 | 9 |
| Separation of the husk | 5 (carved, glued to the grain) | 9 (crunchy, crisp) |
| Sound of the grains | 5 (opaque) | 9 (good sound) |

## Conclusions

The drying of 12.94 kg of fermented cocoa of the Trinitaria variety was carried out with the polycarbonate tunnel- type solar dryer. As a result, drying was obtained in less time than sun drying in the open air carried out by the producers of the region. The final weight was 6.19 kg (47.82% with respect to the initial weight) with a loss of 52.18% of water. A marked difference was registered between the ambient temperature with respect to the interior temperature of the greenhouse, as well as the relative humidity, which indicates the efficiency of the dryer used. The humidity of the grain remained with a gain almost null during the night despite the presence of rain at night and dew in the morning.

The final moisture content test on a wet basis indicates a percentage of 6.6% (wb) achieved in two days of experiment, which is less than that established by the Mexican norm, which is a maximum of 7.5% (wb). The satisfaction of the producer of the drying process of the cocoa bean with the polycarbonate tunnel-type solar dryer was greater than 4 to 6 points than with the table-type wood dryer.

## Acknowledgments

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