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ORIGINAL ARTICLE

Effect of Black Painted Granite as Thermal Storage Material on Solar Drying of Banana

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Abstract

Objective: To experimentally study the performance of a solar tower dryer equipped with black painted granites as an energy storage system. **Methods:** This study therefore focused on the impact of a storage system with black painted granite on the drying of bananas in a solar tower dryer. To achieve this, black painted granites were placed in the dryer sensor and bananas were subjected to drying. Drying took place during the day and night with and without the granites in the dryer. **Findings:** In the dryer without granite the yield was 17% and drying was achieved in 9 hours (over two days), while the dryer equipped with granite had a yield of 48% and drying was achived in 4 hours (in one day). The study showed that drying occurs faster with the integrated storage system. Also, storage of heat allowed drying to continue overnight, when the was no sunlight. Storage with black-painted granites greatly increased the performance of the dryer. **Novelty:** This work showed that black painted granites are effective in drying of agricultural products all round the clock.

Keywords: Solar tower dryer; Black painted granite; Storage; Banana; Yield

1 Introduction

Burkina Faso is a very sunny country. Clean and renewable energy sources have gained momentum over the past decade due to the energy crisis and environmental damage caused by the overexploitation of fossil fuels [(1)]. Solar energy stands out as a promising source of clean and renewable energy [(2)]. Its exploitation is therefore necessary and profitable. Technology has advanced to an extent that electricity and heat could be applied at high and low temperatures. According to the International Energy Agency (IEA), thermal energy accounts for 50% of total energy consumption worldwide, far exceeding electricity (20%) and transportation (30%) [(3)]. Solar power also contributes to the production of thermal energy. Among the applications of low temperature solar thermal, we have drying.

Drying is one of the oldest processing methods for preserving agricultural products. This process is energy intensive, and its consumption can represent up to 20% of the total energy consumption of the industrial sector. It can represent up to 90% of treatment costs [4]. The traditional sun drying process for food preservation has quite a few disadvantages such as drying time and deterioration in the organoleptic quality of the product. It is recommended that food should be dried in a controlled environment for best results. Solar dryers are systems or devices that can provide solutions to the problems encountered during direct drying in the sun. These solar powered dryers have been designed in different forms and a large part of the fossil fuel consumption can be reduced through these [5]. All these design variations of solar dryers share the same mechanism of evaporation of water molecules present inside the products. The mode of heat transfer from the product depends on the configuration and can be achieved by conduction, convection or radiation [6]. Many researchers have already developed and tested different types of solar dryers for efficiency. Solar dryers can be classified based on the movement of heated air, their design and the incidence of solar radiation. The main solar dryers include direct type, indirect type, mixed, solar dryers with heat storage systems, passive mode and active mode solar dryers [7]. A large number of studies have been carried out to improve the performance of solar dryers. Mourad et al. [8] studied the effect of racks in an indirect dryer and successfully demonstrated that mesh racks are better. Boureima et al. [9] showed that regulating the temperature and air velocity in an indirect dryer improves its performance. Mohammed et al. [10] designed and studied a solar dryer with a perforated collector and an inverted absorber using forced convection. The device exhibited drying efficiencies ranging from 20.37% to 34.01%. Nitin et al. [11] demonstrated the importance of supplemental heating in a solar dryer. They showed that the use of supplemental heating increases efficiency from 11.94% to 25.16%. Suherman et al. [12] experimentally evaluated the efficiency of a dryer powered by photovoltaic energy. They show that the product dries better in the dryer than in the open air but has a low yield. Authors [9], [12], [13], [14] obtained returns of 17%, 18.8%, 22.38% and 28.4% respectively during their operations. However, none of these authors presented results obtained during the night. The instability and intermittency of solar energy cause system performance to decline during periods of high energy demand [15].

The integration of energy storage systems into solar dryers compensate for inefficiency as energy (heat) stored in excess during sunny days is deployed for use when there is low illumination. An increase in the volume fraction of phase change material increases charge and discharge times and reduces heat transfer from sensible thermal energy storage [16]. A compound such as CB550-OC has broad application prospects in the field of thermal energy storage [17]. A material like concrete is important for storing thermal energy due to its efficient energy management. We can therefore say that storage is the creation of an energy reserve from energy flows to be available later if necessary [18].

There are several methods of thermal storage: Thermal storage by thermochemical method, storage of thermal energy by latent heat and storage of sensible heat. Storage by sensible heat consists of the increase in the enthalpy of a solid or liquid material during the storage phase, the heat being released during the removal phase. Indeed, the quantity of energy stored in sensible heat storage depends on the mass, the specific heat of the storage medium and the temperature difference of the storage medium between its initial and final states [19]. The stored energy is not only used to heat a fluid, but also to maintain the temperature of the fluid [20].

The study was concerned with the analysing the advantages of using black painted granite as a heat back up system for efficient drying of banana and prevention of minimum heat losses. The study consists of determining the performance of the dryer without and with the storage system in order to examine the efficiency of both systems.

2 Methodology

2.1 The "solar tower" dryer

The solar tower dryer was made of a square collector with a side of 2m topped by a chimney whose height varied between 1m and 3m. The chimney with 20cm diameter was made of 1.5mm thick mild steel and insulated with TRAPALU-40 which is a weather resistant insulator. The racks were inserted along the chimney making it a drying chamber. The tower collector consisted of a glass roof covering an absorber. The roof of the collector was made up of four "lime-soda" glass panes with a square meter of surface area and 5 mm thickness each, forming an angle of 4° between the collector inlet and that of the chimney.

The absorber plate was aluminum zinc sheet of 0.35mm thickness, painted matt black and insulated by 20 cm of polystyrene on its underside.

Figure 1 shows the solar tower dryer used.

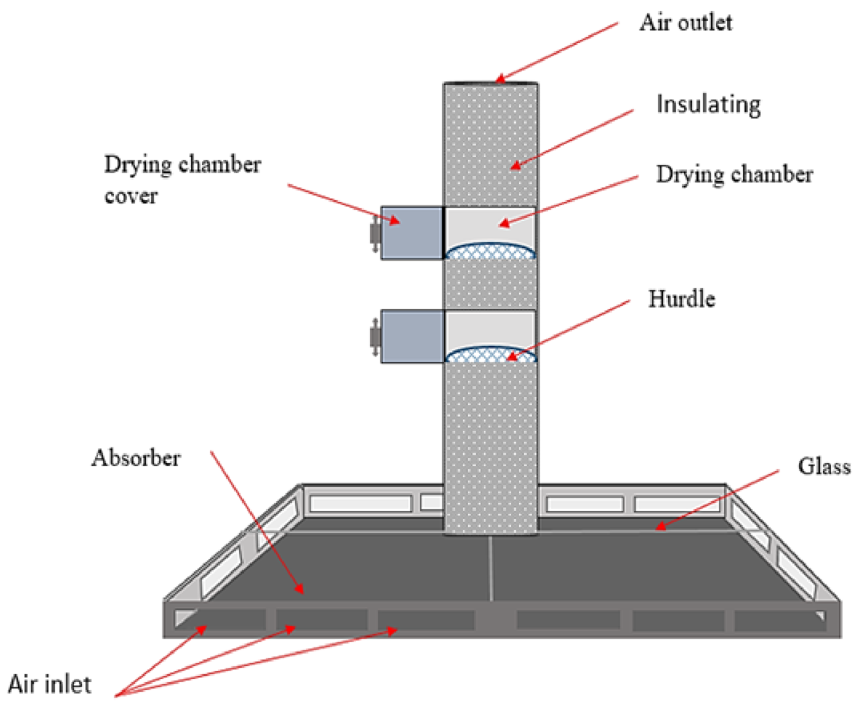

Fig 1. Tower dryer schema

2.2 Storage materials

For the study, granite was used a storage material because of its viable heat retention ability and other specific features.

Table 1 presents some physical properties of granite.

Table 1. Some physical properties of granite

Properties/Material	Density (kg/m^3)	Specific Heat (J/kg K)	Heat Capacity $\rho c \times 10^{-6}$ (J/m^3 K)	Thermal Conductivity (W/m K)
Granite	2640	820	2,1648	1,73 -3,89

To increase the absorption coefficient, the granites were painted with black colour.

Figure 2 shows the granites at natural state and also when painted with black colour.

2.3 Measuring devices

Temperatures were recorded using K-type thermocouples connected to a GL200A datalogger. For temperatures between -100°C and 1370°C the margin of error is $\pm$ 0.05% + 1.0°C of the reading.

The masses were weighed with a PCE-Bs brand balance. The solar flux was recorded with an SR03 type pyranometer. It has an uncertainty of $\pm$ 1.8%, a sensitivity of 15 x 10-6 V/(W/m^2). The temperature range for its normal operation is between -40°C and +80°C.

2.4 Method

2.4.1. Experimental protocol:

Banana was used as experimental material. Products were obtained from a local market in Quagadougou. They were sorted, washed, spelled cut into thin slices ($\approx$2mm), drained, weighed and put in the dryer. The temperatures at the level of the absorber, the drying chamber, the air inlet, the window, the air between the window and the absorber were recorded.

Fig 2. Granites (left: natural and right painted black)

Tests without the storage system and tests with the storage system, which is black painted granite, were carried out over several days (day and night) at the Ouagadougou site.

2.4.2. Mathematical expressions

The initial Moisture content X_0 was determined by **equation (1)** [21]:

$$X_0 = \frac{m_o - m_s}{m_s} \tag{1}$$

With,

m_o**:** The initial mass(kg);

m_s: Dry mass (kg)

The moisture content at each time X(t) was determined by **equation (2)**:

$$X(t) = \frac{m(t) - m_s}{m_s} \tag{2}$$

With,

$m(t)$: the mass at time t (kg)

m_s: dry mass (kg)

The dryer efficiency was calculated by **equation (3)**:

$$\eta = \frac{m_{ev}.L_v}{\phi St} \tag{3}$$

With,

mev the mass of evaporated water (kg),

Lv latent heat of vaporization of water (J/kg)

Φ the solar flux (W/m^2), the collection surface (m^2) and the drying time (s)

3 Results and Discussion

3.1 Temperature profiles

Figure 3 shows the temperature profiles at different parts of the dryer without the storage elements.

The curve of the variation of the different temperatures shows that they evolve in the same direction as the curve of solar flux. The temperature of the absorber and that of the air confined between the glass and the absorber have the highest temperatures.

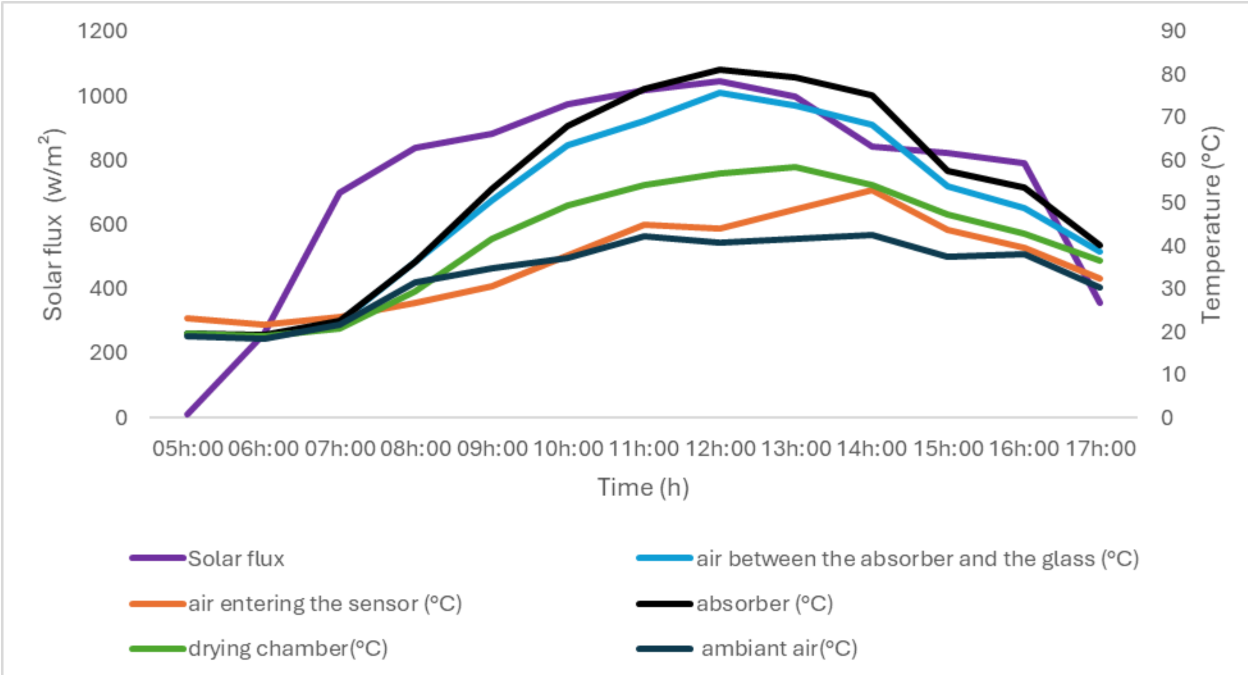

Fig 3. Variation curves of the different temperatures of the dryer and the solar flux

Their maximum values were 80.6°C and 78.1°C respectively. In fact, the black-painted absorber absorbed a large quantity of solar radiation but also emitted enough heat towards the air which heats up. The maximum temperature reached at the level of the drying chamber was around 60°C. The temperature of the air at the sensor inlet and that of the ambient environment had maximums around 48°C and 42°C respectively. The air begun to heat at the sensor inlet to the chimney inlet. These relatively high temperature values were due to the strong solar flux observed. In fact, the fairly homogeneous solar flux curves indicated a clear sky with a maximum value of around 1045W/m^2.

Figure 4 shows the temperature profiles at different parts of the dryer with the storage elements (black painted granite) inserted between the absorber and the glass.

The solar flux evolved quite normally, that is to say an increase until around 1 p.m. then a decrease. The temperatures of all the curves also have the same appearance. An increase until around 1 p.m. followed by a decrease.

Temperature was observed to rose highest (91.4 °C) at about 1pm in the system that had granite painted black. This temperature rise was due to the strong solar flux and also thanks to the black paint on the granites which increased its absorption coefficient. The temperature of the air confined between the absorber and the glass and that of the absorber are similar. Their maximum values are respectively 82.8°C and 81.4°C (around 1 p.m.). The drying chamber reaches a maximum temperature of 67.5°C. These high temperature values are due to the contribution of the granites.

3.2 Evolution of moisture content

Figure 5 shows the evolution of the moisture content in the dryer without the storage system

The curve of the variation of the moisture content is decreased throughout the period of drying. The moisture content of the banana decreased by approximately 2.5 kgw/kgdm on the first day. On the second day the moisture content continued to decrease but slowly until no significant changes in weight of the product was observed, marking the end of drying.

However, we note that from the evening (5 p.m.) until the morning (9 a.m.) the moisture content of the product has decreased very slightly. That is a reduction of 0.11 kgw/kgdm. The drying therefore did not really continue overnight. Several authors have made the same observation [21], [22].

Figure 6 presents the kinetics of banana drying with granite storage in the dryer.

The moisture content curve presents a single phase, namely the decreasing phase. The decrease is very rapid in the first hour of drying then slows down until the end of drying. Unlike the test without storage, drying took place in one day and better in four hours. Its results are due to the influence of granites which behave like an absorber.

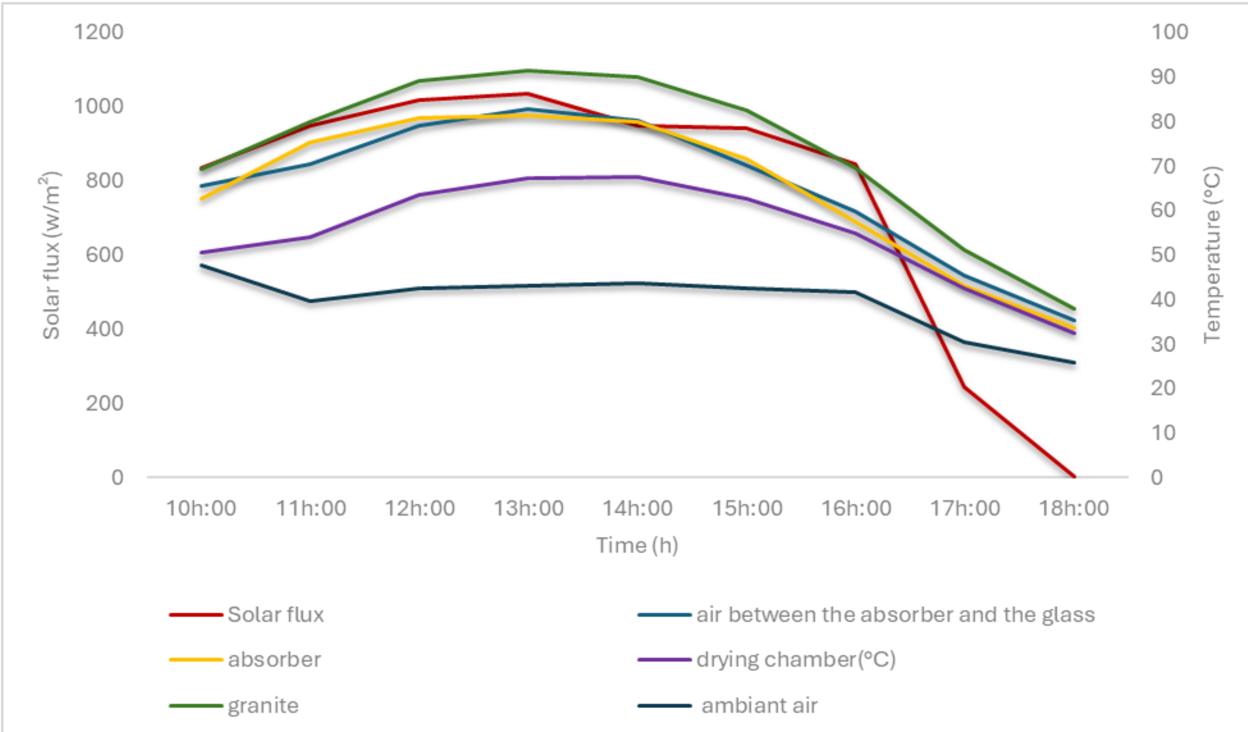

Fig 4. Curves of different temperatures in the dryer with storage (granite)

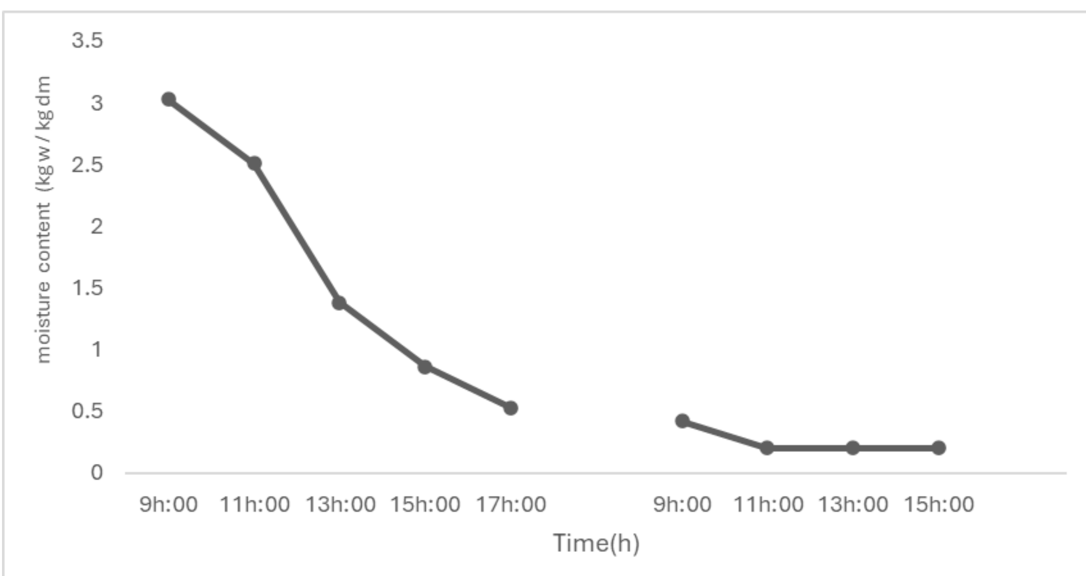

Fig 5. moisture content variation curve

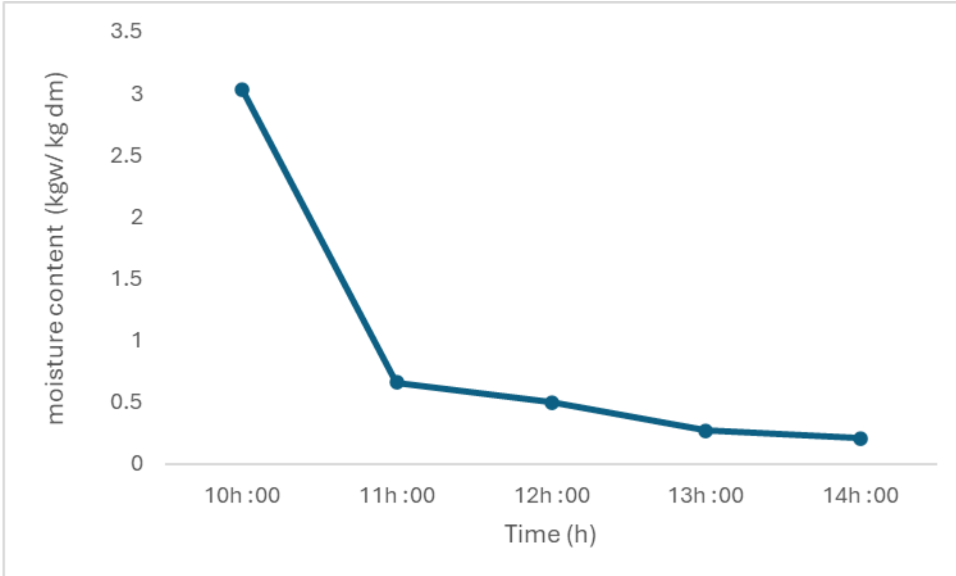

Fig 6. moisture content curve with the influence of granites

In order to determine the influence of storage on drying overnight we carried out a night drying test. A small quantity, 78g of banana, was dried from 5 p.m. The tests are carried out in the month of November when solar radiation is almost zero at 5 p.m.

Figure 7 shows the nocturnal influence of storage on the nighttime drying of banana.

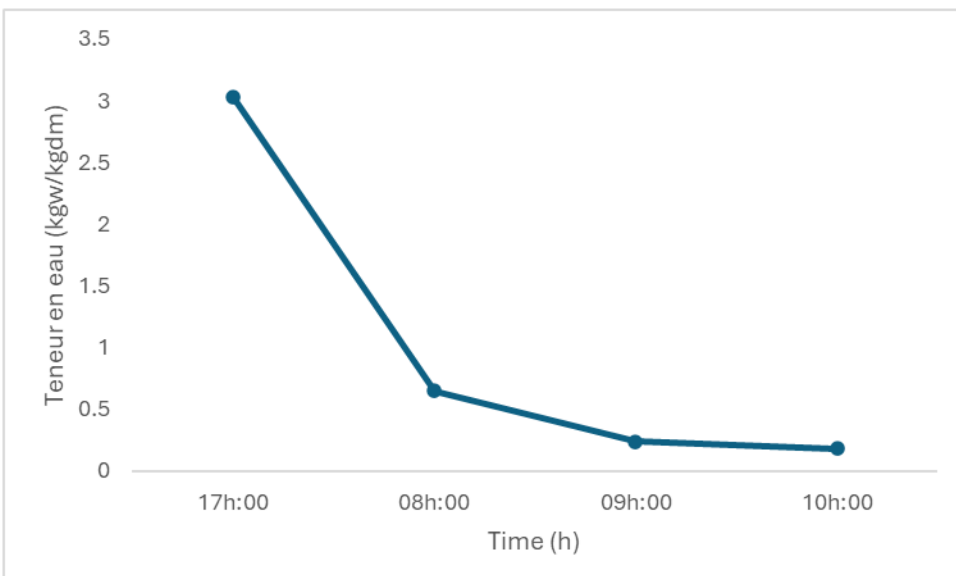

Fig 7. Curve of the variation of the moisture content during night drying

The curve of the variation of the moisture content shows a strong decrease in the curve from 5 p.m. until the next day at 8 a.m. During the night when there is no sunlight, the banana still lost approximately 73.71% of its total mass of water. Drying continued thanks to the energy released by the granites (storage system). In fact, during the day, the granites store energy which they release when the heat source is no longer, that is to say at night. This result is consistent with the results of the literature. Indeed, Fatih Selimefendigil et al. also showed in their study that drying time is reduced by about 36.6% using a latent heat thermal energy storage unit integrated with natural dolomite powder and an air-to-air heat recovery system[23].

Dounia Chaatouf et al. showed that with a solar dryer equipped with PCM tubes, efficiency increases by approximately 3.12% at night[24]. Gopinath Govindan Radhakrishnan et al. also showed that paraffin as a heat storage element in a solar dryer reduces drying time[?].

Table 2 summarizes the banana drying results.

Table 2. Summary of banana drying results with and without storage system

Without storage	**Initial**		**final**		**Drying time (h)**	**With storage**	**Initial**		**final**		**Drying time (h)**
	Moisture content (kgw/kgdm)	**Mass (g)**	**Moisture content (kgw/kgdm)**	**Mass (g)**			**Moisture content (kgw/kgdm)**	**Mass (g)**	**Moisture Content (kgw/kgdm)**	**Mass (g)**	
	3.03	110g	0.2	33g	9h		3.03	126g	0.21	36g	4h

3.3 Yield

The study showed that the dryer without the storage system had a yield of 17 % but recorded a yield of 48 % when the storage system was embedded. These results clearly show that the storage system considerably improve drying efficiency. The result is an improvment to previous studies done on the same subject. Bacha et al.[?], used granite pieces on the racks, achieved a drying efficiency of 13.67% and an overall efficiency of 6.39%. Lingayat et al.[?] found that the thermal efficiency of solar dryers was improved by nearly 50% with n-docosane paraffin and kerosene mixed in a ratio of 2:1.

4 Conclusion

Our solar tower dryer is tested for drying bananas day and night firstly without an energy storage system and secondly with energy storage elements which are black painted granites. The same quantity of banana was dried in 9 hours (in two days) in the dryer in the absence of storage elements and in only 4 hours when storage elements are added. The calculated efficiencies were obtained as 17% and 48% respectively for the dryer without energy storage and the dryer with energy storage. Drying was also continuous at night in spite of the non-availability of sunlight. This was a distinct feature of the solar system embedded with a heat storage system. The use of black painted granites as heat storage material in solar dryers is recommended for optimal result.

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