



Convective Solar Drying of Spinach Leaves (*Spinacia oleracea*)

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ABSTRACT

The drying on of the means is usually used which allows the conservation of the food products by lowering of the activity of water. This paper presents the results of an experimental spinach (*Spinacia oleracea*) drying study in a new solar dryer. It is an indirect solar dryer with forced convection was developed and improved at the Food Science laboratory. Drying spinach leaves to a final moisture content of 2% from 93.2% (wet basis), with an air-drying speed equal to 1 m/s.

This study made it possible to determine the drying kinetics of spinach leaves, the evolution of the temperature profile and the influence of drying air recycling (0, 50 and 90%) on drying time. The curves of drying obtained show that the drying rate increased marginally with the increase in fraction of air recycled. It is reduced 3 to 4 hours, by increasing the fraction air recycled from 50 to 90% respectively, with a significant profit of thermal energy. The drying temperature is higher and stable in the drying chamber of the order of 55 to 65°C (90% air recycled).

Keywords: Cervical disc replacement; Motion preservation; Cervical disc disease

INTRODUCTION

Solar energy is an important alternative source of energy. It is relatively preferred to other sources because it is free, abundant, and inexhaustible and non-pollutant in nature compared with higher prices and shortage of fossil fuels. Solar energy is very abundant in Algeria, in particular in the south of this country.

As an alternative to open sun drying, the solar drying system is one of the most attractive and promising applications of solar energy systems. It is a renewable and environmentally friendly technology that is also economically viable in most developing countries.

Drying is one of an important post handling process of agricultural production. It can extend shelf life of harvested products, improves the quality and reduces post-harvest losses. Solar crop drying has been demonstrated, to be cost effective and could be an effective alternative to traditional and mechanical drying systems, especially in-locations with good sunshine during the harvest season [1]. The purpose of this process is to remove moisture from a product to achieve the desired moisture content. The amount of heat supplied to the product by air heated with natural or artificial means causes the movement of moisture from inside the product to the surface [2].

The temperature of the drying air must be kept below the recommended values for the intended use of the product, as the excessive temperature of the drying air can cause physical and chemical changes and deterioration of the product quality. To maintain the quality of the product and avoid damaging its constituents, especially essential oils and vitamins that are sensitive to heat, it must be dried at a low temperature.

The problem of drying at low temperature is that it takes a lot of time. Many studies have led to a mastery of the solar drying process, and the design of dryers thus reducing drying times, improving the quality of dried products, and

eliminating losses due to poor drying of products. This work was also carried out both at the kiln [3-6] and at the level of the drying process [7-13]. However, it is clear that the practice of drying has remained strongly traditional.

In this work, we are interested in improving the performance of an indirect forced convection solar dryer. To reduce the drying time and preserve the organoleptic quality of

MATERIAL AND METHODS

Drying system

The indirect solar dryer with forced convection (**Figure 1**) is used in this study. It designed and realized by the LESEI laboratory [14]. **Figure 2** shows a photograph of this solar dryer. It consists of mainly a solar air heater, a centrifugal blower and drying chamber.

- Solar air heater (2 x 1 m), with single pass and single glass cover was developed to preheat the air. It consists of a galvanized absorber (0.5 mm thick, painted dull black), glass wool insulation (50 mm thick) and a wooden (15 mm thick) outer cover box. The south-facing solar flat plate collector was installed at an angle of 30° with horizontal.
- Drying unit, a vertical drying chamber (0.5 m³, inside) was provided for keeping the sample holding trays through which the hot air passed from the bottom tray to the top tray. Six drying trays were stacked evenly at a vertical spacing of 120 mm to each other in the drying chamber. A door (800 x 600 mm) was provided with locking arrangement on one side (front side) of the drying chamber for loading and unloading of trays.
- A centrifugal blower having 8.0 m³/min capacities was used to circulate the air through the solar dryer. The blower was operated with the help of a single-phase, 1 hp, and 2800 rpm electric motor.
- A extractor blower placed at the top of the chamber to evacuate the air used to the outside.

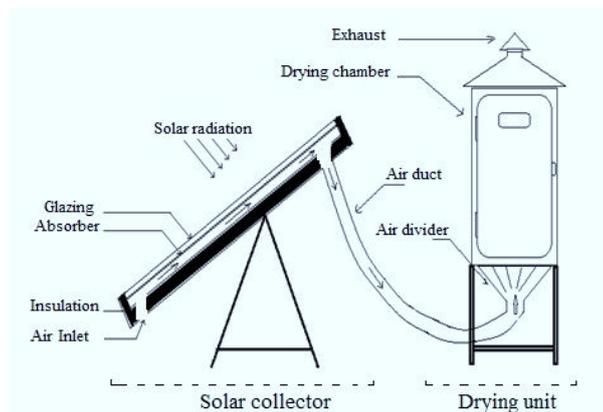


Figure 1: Indirect solar drier with forced convection



Figure 2: Photograph of solar forced convection dryer

Measurement instruments and equipment

The following measurement instruments were used:

- Pyranometer to determine global sunlight received.
- Thermocouples of the type K accuracy $\pm 0.5^{\circ}\text{C}$, to measure the temperature.
- Thermo-hygrometers accuracy $\pm 1^{\circ}\text{C}$ for temperature, $\pm 3\%$ for relative humidity, placed inside the drying chamber to measure temperature and relative humidity.
- Anemometer of uncertainty ± 0.1 m/s to measure the airflow rate.
- Precision balance ± 0.1 g, to determine the moisture loss of the products to be dried.

Vegetal product

Spinach is an herbaceous plant, vegetables grown for the consumption of their leaves, used first as a medicinal plant. It is very recognizable by its long green leaves, curly or flat depending on the variety [15]. The spinach leaves used in this *Spinacia oleracea* variety study, were collected in the area of Batna in June 2015.

Experimental methods

The drying experiments, were carried out in a solar drier with forced convection for the periods (May-July, 2015), under the climatic conditions of the Batna's city. Each experiment starts at 9 am to 5 pm. The leaves of spinach to be dried of initial moisture content is approximately 93.2%, drying occurs until a final moisture of 2%; by taking the loss of moisture using a balance starting from an initial mass of 500 g/tray, each thirty minute.

During this process, the air velocity setting in the drying chamber was fixed at 1 m/s. Air temperature (ambient temperature and the air temperature at the inlet, middle, and outlet of the collector), solar radiation, and wind velocity were measured. The temperatures of air inlet, inside and outside the drying chamber, were also measured each thirty minute. Relative humidity sensors were installed in the middle of the drying chamber. Air temperature was measured by a K-type thermocouple, and the intensity of solar radiation was measured by a pyranometer. The solar dryer improvement involves the addition of a drying air recycling system, connecting the drying chamber outlet with the solar collector inlet.

The study of the influence of the different fractions of recycled air (0, 50 and 90%) on the kinetics of drying and the effect of drying on the quality of product to dry was carried out.

During the drying operation, there is a double transfer: thermal and mass. To illustrate these transfer movements, there are several characteristic curves called "drying curves"[16]. To know:

- The water content as a function of time: $X = f(t_s)$;
- The drying rate as a function of the water content: $dX / dt = f(X)$.

RESULTS

Experimental conditions

Drying tests of spinach in the forced convection indirect solar dryer were carried out during the period of May-July 2015. **Figure 3** shows the variation of ambient conditions with time of day during the experimental drying. This period is characterized by sunny days.

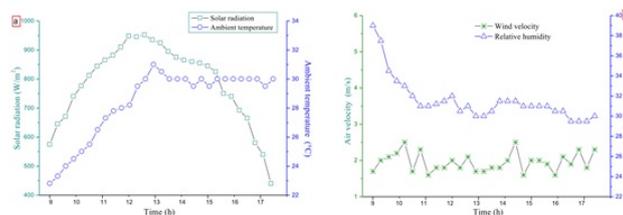


Figure 3: Variation of ambient conditions during the experiments drying

Figure 3a presents the change in global solar radiation for the day considered. It varied between 843 and 950 W/m^2 , the intensity of solar radiation reached its maximum around noon hours. The variation in sunshine during drying

implies a variation in the ambient air temperature of 23.0 and 31.9°C. In addition, the relative humidity varied between 17.5 and 43.6% and the maximum wind velocity is 3.6 m/s is shown in **Figure 3b**.

Study of drying kinetics

The spinach leaves were dried to a final moisture content of 2% from 93.2% (wet basis) in 6 hours with an air-drying speed equal to 1 m/s. The drying curves of spinach are decreasing (**Figure 4**). They admit the same pace in the three experiments, but with a time gain of 3 to 4 hours of the drying time for the second and third experiments respectively, when increasing the fraction of recirculated air by 50 to 90%.

It is obviously observed from the **Figure 4**, that the moisture content is decreased faster at the initial stages of drying and thereafter became slower as drying proceeds. It is seen from the **Figure 5** that the drying rate increased marginally with the increase in fraction of air recycled. The results agree with those of Bayouhd and Sghaier [17].

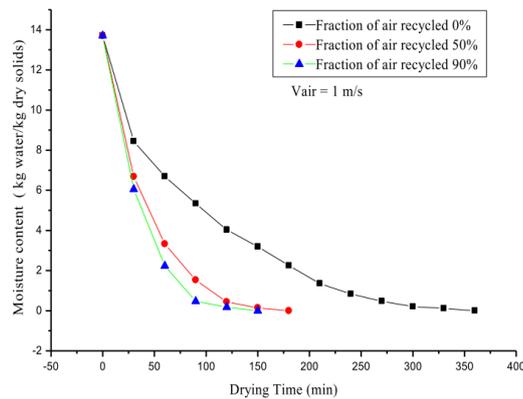


Figure 4: Variation of mean moisture content with drying time at different fractions of air recycled

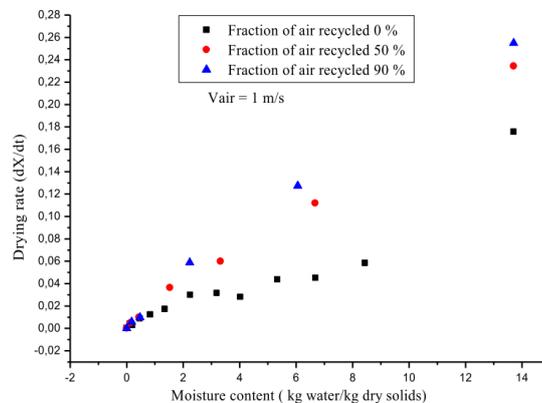


Figure 5: Drying rate at different fractions of air recycled

There is a significant difference between the value of the ambient temperature and the temperature at the output of the solar collector (**Figure 6**), this temperature difference varies from 10 to 33.9°C during the day of the experiment. Knowing that the ambient temperature is between 24 and 32°C for the day considered. The difference is due to the influence of solar radiation on the absorber and to the greenhouse effect, which has results among the absorber and the glass cover, playing an important role in the heating of the air flowing through the air inside the solar collector.

The drying temperature is higher and stable in the drying chamber of the order of 55 to 65 °C, under the effect of recycle exhaust air (90% air recycled). However, in the drying recirculation of exhaust air, it is more disturbed and variable of the order 26 to 43 °C (0% air recycled) are shown in **Figure 7**. This is the simultaneous action of reheating the exhaust air recycled, causing the temperature stability in the drying chamber, and then a significant decrease in drying time.

An essential factor in the drying process is the air relative humidity; the variation of the exhaust air relative humidity with drying time at different fractions of air recycled (up to 90%), is shown in Figure 7. It is seen from the figure that the relative humidity of the exhaust air is higher in the beginning of drying and decreased with drying time as drying proceeds and became constant in the final stage of drying. This is because the higher drying rate of the spinach leaves during initial stage of drying results in release of more moisture in the drying air. It is also observed from the figure that the relative humidity of the exhaust air increased, with the increase in fraction of air recycled. The results of this study are in agreement with those of Bayouhd and Sghaier [17].

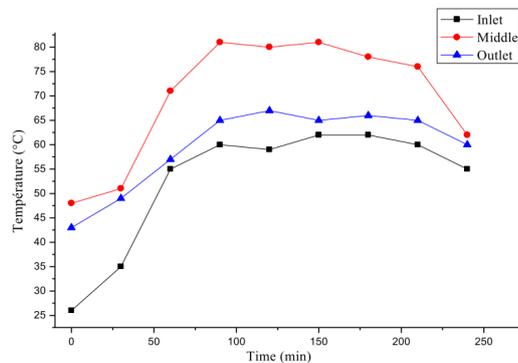


Figure 6: Evolution of the air temperature at the solar collector

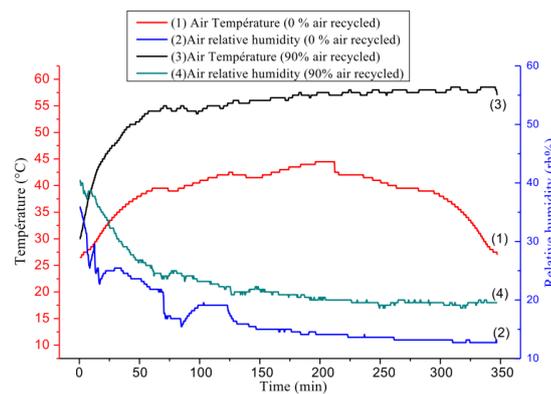


Figure 7: Evolution of temperature and relative humidity in the drying chamber

CONCLUSION

The solar forced convection dryer operated well for dehydration of spinach leaves for the controlled conditions of drying air temperature, relative humidity and drying air velocity. The dryer is also facilitated with recirculation of exhaust air.

The spinach leaves were dried to a final moisture content of 2% from 93.2% (wet basis) in 6 hours with an air-drying speed equal to 1 m/s. The drying curves of spinach are decreasing. They admit the same pace in all experiments. The drying rate increased marginally (3 to 4 hours) with the increase in fraction of air recycled (50 to 90%). with a significant profit of thermal energy.

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