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Development of an Indirect Forced Flow Greenhouse Solar Dryer for Barberry Drying

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ABSTRACT

Barberry (Berberis vulgaris L.) is an important horticultural plant mostly cultivated in Iran. Since fresh barberry fruit has a high moisture content its shelf life is very short. Therefore, product drying after harvesting is necessary. On the other hand, because the moisture of barberry fruit is capsulated in the skin, its drying is very energy-consuming process. So, the present study proposed an indirect forced flow solar greenhouse dryer, to evaluate the dryer, a prototype was constructed, and its performance was experimentally investigated. In this way, the tests were carried out at different drying temperatures (30, 40, and 55ºC) and drying air velocities (0.5, 1, and 1.5m/s). The results indicated that raising the temperature from 30 to 55ºC decreased drying time by 8%. Similarly, drying time decreased by around 24% when the air velocity increased from 0.5 to 1.5m/s. The obtained specific energy consumption (SEC) values were between 0.11 and 1.1 kWh/kg. The lowest SEC was achieved at the lowest temperature with the highest velocity. Finally, it was found that the higher drying rates, the puffier products.

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INTRODUCTION

Barberry fruit is a food additive mostly used for its medicinal benefits. Iran is the largest barberry producer throughout the world, producing more than 4500 tons annually. Iranian seedless barberry, the locally so-called "zereshk", which is widely cultivated in the south Khorasan province is an important horticultural product in this semiarid area and plays an inevitable role in the economy of rural families. Fresh barberry fruit is commonly used for juice, jam, and fresh eating. However, because of the high moisture content of barberry fruit its conservation for a long time is impossible and needs huge refrigerators/freezers (Aghbashlo et al., 2009). Therefore, most barberry producers prefer to dry the product after harvest, But, since the moisture of barberry fruit is capsulated in a non-perforable skin, its drying is very complicated and time- and -energy-consuming. on the other hands, the harvesting time of barberry, in the south Khorasan province, usually coincidences with the beginning of the cold season, when the reduction of the and the cloudy sky make the open sun drying of the product so difficult and long, which eventually, results in a significant degradation and loss of the product. So, to prevent the loss, many producers have to wholesale their products, in-garden, before harvesting. In this way, some researchers have investigated industrial dryers for barberry fruit drying. Although industrial dryers reduce drying time, results of a study showed that the quality of the dried barberries in these dryers was lower than those dried by traditional shade drying method. the other drawback of industrial dryers is that they are commonly hot-air dryers, which respect to the low thermal conductivity of the agricultural products consume a lot of energy such that it is estimated that the highest energy of producing agricultural products is belongs to the drying stage (Alavi & Mazloumzadeh, 2012).

The high energy consumption of industrial dryers, in one hand and reduction of fossil fuel resources besides the environmental concerns of their consumption, on the other hand, have caused a growing motivation for solar dryers (Mustayen et al., 2014).

The low and intermittency of the solar light intensity is the major problem of all solar-powered systems. For this reason, solar dryers usually have low capacities and need a long time to dry the products (Fudholi et al., 2010; Phadke et al., 2015).

A method proposed to minimize the effect of solar intensity fluctuations on dryer temperature during the day is the use of thermal storage (Bal et al., 2010; Baysal et al., 2015).

Although solar greenhouse dryers, in term of the internal space volume, are comparable with industrial dryers, their low temperature results in a low drying capacity. To increase the temperature and enhance the dryer capacity, some researchers have proposed the use of an additional solar air collector with greenhouse dryers (Azam et al., 2020; Rezvani et al., 2022a). The other drawback of greenhouse dryers is that they are usually direct solar dryers through them solar light impinges the product surface directly, this although enhances the dying rate, harms the apparent quality of the product (Hosseini et al., 2023). Moreover, results of previous studies show that airflow over the product under drying could improve both drying rate and quality attributes (Hosseini et al., 2023) . Therefore, in this study, to address the concerns of the low temperature, and quality loss due to direct drying of greenhouse dryers, a solar greenhouse dryer equipped with a solar absorber plate was developed for barberry drying. The review of the literature indicated that no similar configured greenhouse dryer has been reported, so far. Therefore, the aim of the present study was to experimentally investigate the performance of the proposed dryer.

MATERIALS AND METHODS

Description of the proposed dryer

The proposed dryer contains the main three parts of a greenhouse, a solar absorber plate, and product trays (Figure1)

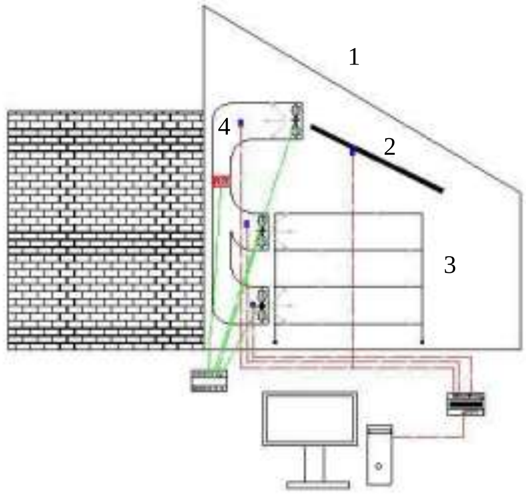

Figure1. Diagram of the main parts of the proposed solar greenhouse dryer:1) greenhouse, 2) SAP, 3) product trays, 4)air distribution mechanism

The greenhouse,

Greenhouse is the core of the system, provides an insulated atmosphere for the product to be dried far from the harms of outdoor contaminant factors like dust, rain, insects, and birds. The roof and side walls of the greenhouse are completely sealed for water and should be constructed from highly transparent with low conductivity material. Causes solar light penetrate the dryer and warms up it, even during winter days, when the ambient air is so cold.

The solar Absorber plate (SAP)

The SAP is a black-painted metal plate employed to absorb sunlight and convert it to heat. The accumulated heat in the SAP is transferred to the greenhouse atmosphere via conduction and radiation mechanisms. Actually, the SAP is a flat plate solar air collector integrated in the greenhouse dryer.

The SAP is installed just front of the product trays to care the product from the sun light. This provides an indirect configuration for the dryer (Rezvani et al., 2022b).

Product trays

Since separation of the barberry fruit clusters from their branches, when they are fresh, is too hard and time-consuming, most of farmers prefer to harvest barberries by branch cutting method and dry the fruit on branch. Dried fruits and leaves easily separate from the branch, even with a weak shake (Alavi & Mazloumzadeh, 2012). Therefore, the product trays constructed from mechanical resistant large meshed sieves with large mesh sizes. This in the one hand, facilitates the drying air ventilation among the product bulk, and on the other hand allows the operator to easily separate barberry fruit from the branches, after drying.

Air distribution mechanism

The air distribution mechanism includes an air suction fan, air duct, and tray fans.

The air suction fan intakes the heated air at the vicinity of the SAP to the duct to feed the tray fans. An electric heater is installed inside the duct to raise the air temperature to the pre-set point when the temperature of the circulating air is low.

Several outlets are deployed on the air ducts, each for one tray, on which, a fan is installed to force the drying air over the product tray. The speed of tray fans is individually adjustable.

Experimental evaluation of the proposed dryer

To investigate the performance of the proposed system a prototype was constructed based on its design instructions. Technical details of the prototype are given as follows:

Prototype Description

A complete-view photo of the designed dryer is indicated in Fig.2 the greenhouse was constructed from a steel frame, 6-mm-thick double-ply transparent polycarbonate sheet, because of its high transmissivity and low thermal conductivity, was used as the transparent cover of the greenhouse. An axial fan with a nominal power of 150W was employed to serve as the suction fan, the tray fans were 60-W-power. The electric heater installed inside the duct was 1500W, and product trays were constructed from stainless steel material with dimensions of 0.5m×1m and mesh size of

2cm×2cm. the trays were installed on a wheel table. Photographs of the dryer components are indicated in Fig. 3.

Figure 2. A view of the constructed prototype dryer

a b c d

Figure 3. Photos of different components of the prototype: a) The SAP, and the air distribution mechanism, b) barberry branches on the product trays during the tests, c) product trays, and d) dried products

Experimental procedure and measurement instruments

To experimentally evaluate the proposed dryer an experimental plan was designed to investigate the effect of the different drying air velocities and temperatures on drying time and Specific energy consumption. For this reason, around 500 kg of fresh barberry branches were provided from a garden located in Qaen City, South Khorasan, and Iran and stored in large baskets placed in a container with cold and dry conditions until beginning the tests. The tests were conducted at three air velocities of 0.5, 1 and 1.5 m/s and three temperatures of 35, 45 and 55 ℃. The tests were carried out at the open yard of solar Energy Laboratory of Bozorgmehr university of Qaenat, Qaen, Iran. In each test around 30kg of the barberry branches were spread on the product trays to be dried under the test condition. Moisture content of the product, temperatures of ambient, greenhouse atmosphere, the SAP, the inlet and outlets of the air duct, as well as electrical energy consumed by the dryer components were measured and recorded by time intervals of 30 minutes during the tests. Tests were continued until the product moisture content remained unchanged for 3 consecutive measurements. The moisture content of the barberry fruits was determined using the Oven method described by (Gorjian et al., 2011) for this reason, the product sample was collected from at least 6 randomly selected points on each tray. In addition, specific energy consumption was calculated by the following expression:

$$SEC = \frac{E_{cons.}}{M_w} \quad (1)$$

Where $E_{cons.}$, electrical energy consumed during the tests (kWh), was measured directly by an electric power meter (UT230 model, Uni-T Company, China); and M_w is mass of moisture removed from the product (kg). An important quality index for dried barberry fruits is bulk density, which indicates how much the product is puffy. The bulk density of dried products after each test was determined based on the method described by (Alavi & Mazloumzadeh, 2012) (Fig.4). Temperature sensors employed for the experiment wereLM35, fabricated by TIKA Company, Iran, the sensors were connected to a personal computer using a temperature transmitter (TM1320, Tika Company, Iran)

Figure 4.: determination of the product bulk density regarding the method of (Alavi & Mazloumzadeh, 2012)

RESULTS AND DISCUSSION

Drying Time

The effect of the air temperature and velocity on drying time of barberry fruit is shown in Fig.5. Drying time is a key factor for barberry producers. Because rapid drying helps them to manage their products, relaxly, during the harvest season. Increasing the air temperature as well as velocity shortens the drying time such that it can be stated from the results that raising the temperature from 30 to 55ºC reduced the time by around 8%, on average. This was around 24% when the air velocity increased from 0.5 to 1.5m/s. The increase in the diffusion of water inside the fruit due to the internal temperature rise and the declination of the vapor pressure of the surrounding air are the reasons for drying time reduction due to the temperature and velocity, respectively. These findings comply with the results of (Aghbashlo et al., 2009; Gorjian et al., 2011).

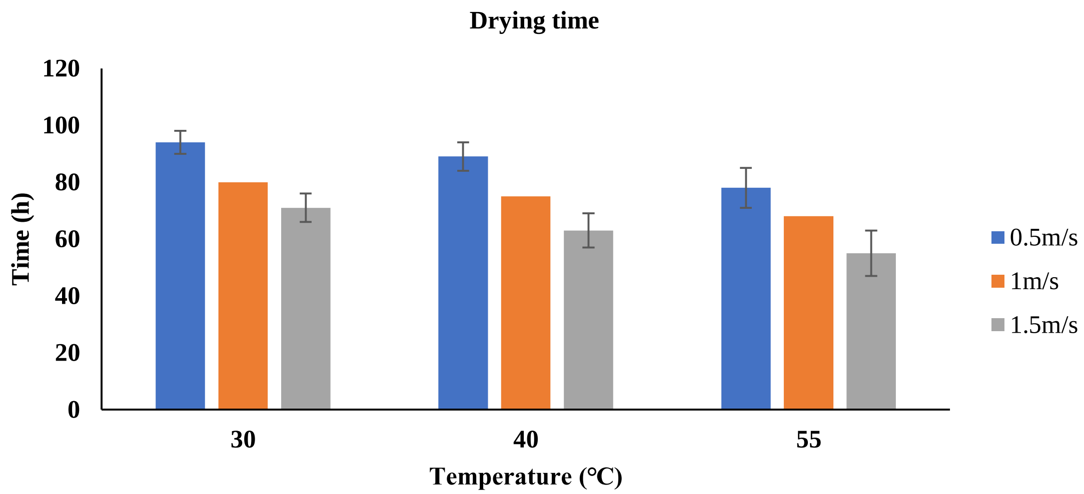

Figure 5. Variations of drying time under the influence of the drying air condition

Specific Energy Consumption

Variations of the SEC values with the different air temperatures and velocities are given in Fig.6 raising the temperature led to an increment in energy consumption. Because the load of temperature rise is compensated by the electric heater. In other words, to temperature rise the electric heater should be engaged higher. This needs higher energy. Since increasing the air velocity decreased process time, significantly. It overall caused a reduction in the SEC. It can be observed in Fig.6 that the SEC values ranged between 0.11 and 1.1kWh/kg.

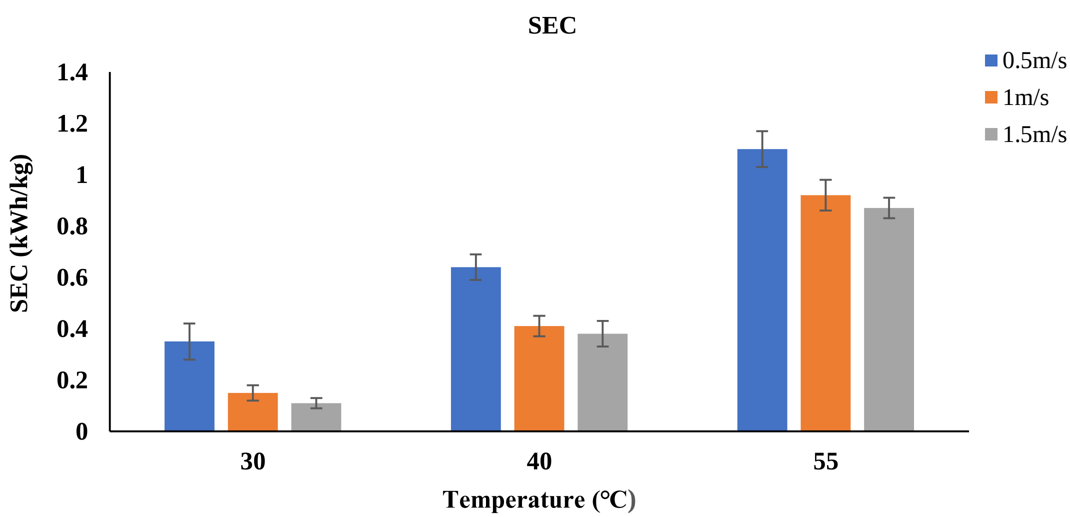

Figure 6. Variations of the SEC values with the different drying air conditions

Bulk Density of products

The effect of the drying air condition on the bulk density of products is indicated in Fig. 7. It is clear from Fig.7 that the higher air temperatures and velocities result in lower bulk densities. In other words, it seems that increasing the process intensity produced much puffier products. This is because the voids in the fruit body which form the channels of water diffusion during the process become bigger when the drying process is accomplished with higher intensities. It can be stated from the observation that raising the temperature from 30 to 55 ℃, on average, decreased the bulk density by about 30%. Whereas, increasing the velocity from 0.5 to 1.5m/s led to a decrease of around 18% in the bulk density.

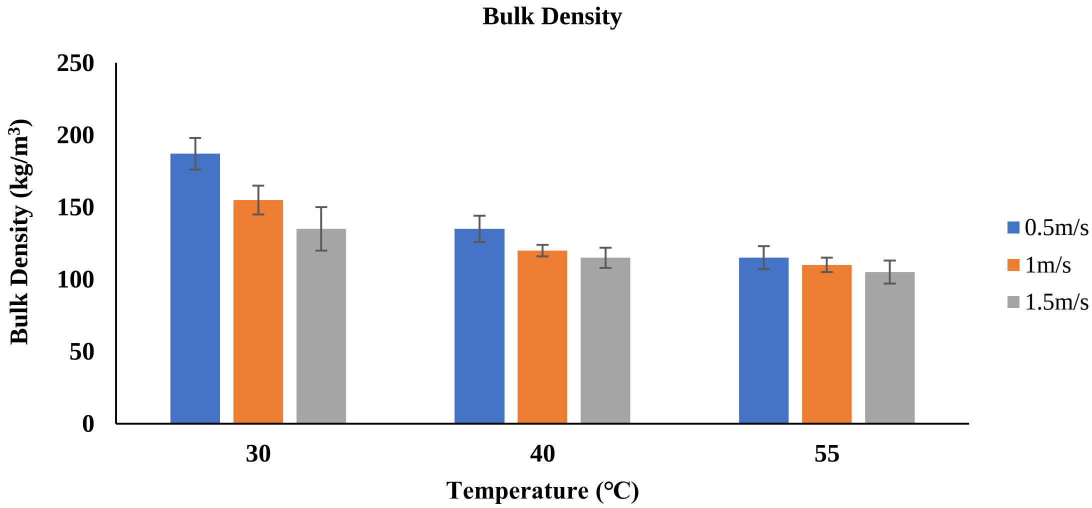

Figure 7. Variations of the bulk density value with the different drying air conditions

CONCLUSIONS

In the present paper, an indirect forced- flow solar greenhouse dryer was proposed for barberry drying.

To experimentally evaluate the performance of the proposed dryer a prototype was constructed and an experimental design was organized such that investigated the effect of drying air temperature and velocity on the performance parameters of the dryer. The obtained results revealed that:

- Increasing the air temperature and velocity from 30 to 55ºC and 0.5to 1.5m/s decreased the drying time by 8 and 24 percent, respectively.
- Specific energy consumption increased with increasing the temperature, while the air velocity reduced specific energy consumption.
- The higher drying rates, the puffier products.

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