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ASSESSMENT OF THE IMPACT OF DIRECT AND INDIRECT NATURAL CONVECTION-BASED SOLAR DRYERS ON THE DRYING PROCESS

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Abstract: The drying process is considered a crucial technological stage in the storage and processing of agricultural products. In recent years, there has been a growing interest in solar-powered drying systems to utilize energy-efficient and environmentally friendly technologies. This article analyzes the impact of direct and indirect solar dryers operating on natural convection on the process of drying fruits and vegetables. During the drying process, key parameters such as temperature, relative humidity, airflow velocity, and product moisture content were evaluated. The analysis results show that indirect solar dryers better preserve product quality and increase drying efficiency. The research results demonstrate the potential for the widespread application of solar-based drying technologies in the processing of agricultural products.

Keywords: Solar dryer, natural convection, indirect drying, direct drying, drying kinetics.

Introduction: Drying is considered one of the crucial technological stages during the storage and processing of agricultural products. Due to the high moisture content in fruits and vegetables, they are prone to microbiological spoilage and chemical changes. Therefore, by reducing the moisture content in the product, it is possible to extend its shelf life and preserve its quality. In recent years, there has been a growing interest in energy-efficient drying technologies to ensure food security and reduce post-harvest losses [1–2]. Research indicates that post-harvest losses in developing countries reach 30-40% in some cases, necessitating the implementation of effective drying technologies [1].

Traditional sun-drying is considered one of the most widely used methods in agriculture. However, this method can lead to product contamination with dust, insects, and other external factors. Furthermore, during the open drying process, critical parameters such as temperature, humidity, and airflow are not controlled, which leads to a decrease in product quality. Therefore, modern solar dryers are being proposed as an alternative technology for the efficient and hygienic drying of agricultural products [2–3].

Solar energy is considered one of the most widespread and environmentally friendly energy sources among renewable energy sources. Solar dryers use solar radiation to heat the air in the drying chamber and evaporate moisture from the product. In scientific literature, solar dryers are typically divided into direct, indirect, combined, and hybrid types [3-4]. In direct solar dryers, products are dried under direct sunlight, while in indirect dryers, the air heated in the solar collector is fed into the drying chamber. Indirect dryers better preserve food quality and color because they protect the product from direct sunlight [4-5].

Solar dryers powered by natural convection are classified as low-energy technologies. In these systems, air movement occurs as a result of temperature differences: under the influence of solar radiation, the density of heated air decreases and rises, creating natural air circulation in the drying chamber. As a result, the moisture in the product evaporates, and the drying process occurs. Research indicates that solar dryers based on natural convection allow for the efficient drying of many agricultural products in the temperature range of 40–70 °C [4–6].

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In recent years, numerous scientific studies have been conducted aimed at improving the design of solar dryers, increasing thermal efficiency, and optimizing the drying process. For example, it has been established that drying efficiency can be significantly increased by modifying the design of solar collectors, using heat accumulation materials, and optimizing airflow [5-7]. Furthermore, it is possible to conduct a deeper analysis of the drying process by mathematical modeling of heat and mass transfer processes in solar dryers [6].

Scientific literature notes that the operational efficiency of solar dryers based on natural convection depends on the intensity of solar radiation, the design of the device, the airflow rate, and the physicochemical properties of the product. Additionally, the efficiency of direct and indirect dryers can vary significantly depending on the type of product [7-8]. Therefore, analyzing the influence of various types of solar dryers on the drying process and evaluating their efficiency is one of the most pressing issues from a scientific and practical perspective.

From this perspective, this study analyzes the impact of direct and indirect solar dryers operating on natural convection on the drying process and evaluates their efficiency during the drying of various fruits and vegetables.

Main part. The efficiency of the drying process in solar dryers depends not only on the design of the device but also on the heat and mass transfer processes occurring during the drying process. During the drying process, thermal energy is required to evaporate moisture from the surface of the product. This energy is transferred to the product using hot air generated by solar radiation. As a result, the moisture inside the product evaporates to the surface through the diffusion process. Therefore, an in-depth study of heat and mass transfer processes is important for optimizing the drying process [8-9].

In many studies, various structural solutions have been proposed to increase the operational efficiency of solar dryers. For example, studies conducted by Fudholi et al. have shown that drying efficiency can be increased by optimizing the collector surface of solar dryers and improving airflow [9]. Researchers noted that thermal efficiency in solar dryers often ranges from 20 to 40%.

The use of thermal storage materials in solar dryers is also being widely studied to increase energy efficiency. For example, it has been found that using phase-changing materials (PCM) can store solar energy throughout the day and continue the drying process until late in the evening [10]. This contributes to increasing the stability of the drying process, especially in regions with variable solar radiation.

In addition, the speed of air flow also plays an important role in drying agricultural products. A very low airflow can slow down moisture evaporation, while a very high airflow can cause heat loss. Therefore, it is important to ensure an optimal air flow rate inside the drying chamber. Research shows that the optimal air flow rate for most products is within the range of 0.5–2 m/s [10–11].

The use of solar dryers also has a positive effect on product quality. For example, it has been found that during the drying of products such as tomatoes, apricots, and grapes in solar dryers, their color index, vitamin content, and antioxidant properties are better preserved compared to the traditional open-air drying method [11]. This will increase the possibilities of using solar dryers in the food industry.

Drying parameters of products are important for the effective organization of the drying process in solar dryers. For different fruits and vegetables, the drying temperature, initial moisture content, and drying duration vary significantly.

Parameters for drying certain fruits and vegetables in solar dryers

No.	Product	Initial Humidity (%)	Drying Temperature (°C)	Drying Time (hours)

No.	Product	Initial Humidity (%)	Drying Temperature (°C)	Drying Time (hours)
1	Apple	84–86	50–60	8–12
2	Grapes	78–80	45–55	10–14
3	Apricots	82–85	50–60	12–18
4	Peaches	85–88	50–60	10–16
5	Banana	70–75	55–65	8–10
6	Pineapple	80–85	55–65	10–14
7	Mangoes	78–82	55–65	8–12
8	Strawberry	88–90	45–55	8–10
9	Plum	80–83	50–60	12–16
10	Pomegranate	75–80	50–60	10–12
11	Tomato	93–95	50–60	10–14
12	Carrots	86–88	55–65	8–12
13	Potato	75–80	55–65	8–10
14	Onion	88–90	50–60	6–10
15	Garlic	65–70	45–55	6–8
16	Pumpkin	90–92	50–60	10–14
17	Eggplant	90–92	50–60	10–12
18	Bell Pepper	88–90	50–60	8–12
19	Cabbage	90–93	50–60	8–12
20	Beets	85–88	55–65	10–14

As seen from the table, the drying temperature and duration for different products vary depending on their moisture content and physical structure. For example, vegetables such as tomatoes and pumpkins have a relatively long drying process because their initial moisture content is very high. Some fruits, such as bananas and mangoes, have relatively low moisture content, and their drying process is completed faster [6-8].

In scientific research conducted in recent years, great attention has been paid to evaluating the efficiency of solar dryers through mathematical modeling. Modeling the drying process allows for the determination of drying kinetics, moisture loss rates, and thermal efficiency. Such models are important for optimizing the drying process and designing new dryer designs [12].

Overall, research indicates that natural convection-based solar dryers are an energy-efficient and environmentally friendly technology for drying agricultural products. Although direct and indirect solar dryers differ in their design and operating principle, both types of devices allow for the efficient drying of products. Therefore, the improvement of these devices and the in-depth study of their impact on the drying process are of great scientific importance.

Conclusion. This study analyzed the impact of direct and indirect solar dryers operating on the basis of natural convection on the drying process of agricultural products. The results of the study showed that drying technologies based on the use of solar energy

have significant advantages over traditional drying methods due to their energy efficiency and environmental friendliness.

According to the analysis results, direct solar dryers are simple in design and economically affordable, making them convenient for use in small and private farms. However, drying products under the influence of direct sunlight can, in some cases, lead to a change in color and a decrease in biologically active substances. Indirect solar dryers stabilize the drying process by using air heated in the solar collector, allowing for better preservation of product quality.

The research results show that the efficiency of the process of drying fruits and vegetables in solar dryers is directly dependent on the intensity of solar radiation, the design of the drying chamber, the air flow rate, and the initial moisture content of the product. For most agricultural products, the optimal drying temperature is within the range of 45–65 °C, allowing for the preservation of vitamins and other biologically active substances within the product.

Additionally, during the study, drying parameters for various fruits and vegetables were analyzed, and it was determined that their initial moisture content and drying duration depend on the physicochemical properties of the product. Due to the high sugar content in fruits, it was observed that their drying process proceeds more slowly compared to vegetables. Vegetables, on the other hand, evaporate moisture faster due to their fibrous structure and relatively low sugar content.

Overall, solar dryers based on natural convection are an energy-efficient, environmentally friendly, and cost-effective technology for drying agricultural products. In the future, the efficiency of this technology can be further increased by improving the design of solar dryers, using heat accumulation materials, and mathematical modeling of the drying process.

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