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INVESTIGATION OF DRYING EFFICIENCY IN A SOLAR INSTALLATION WITH COMPOSITE POLYETHYLENE FILM DEPENDING ON THE PRODUCT THICKNESS

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Abstract: This article is devoted to studying the effect of the thickness of the slices and the type of transparent coating material on the efficiency of solar drying of eggplant slices. The experiments were conducted in a solar dryer coated with a functional ceramic-based composite polyethylene film (Composite) and a conventional solar dryer using a regular polyethylene film. The results of drying in the open sun were also compared. For the study, fresh eggplants were cut into 5 mm and 10 mm thick slices and dried in both devices under the same environmental conditions (solar radiation intensity, ambient temperature, relative humidity, wind speed). During the drying process, the weight of the eggplant slices, the temperature inside the drying chamber, and the relative humidity were continuously recorded. The results obtained showed that the drying efficiency depends on the product thickness and the drying method. For 5 mm thick eggplant, the Composite device was found to be the most efficient method, achieving the lowest final residual mass. For 10 mm thick eggplant slices, the open sun method achieved the highest efficiency.

Keywords: Solar dryer, eggplant, drying efficiency, coating material, residue mass, solar radiation, functional ceramics, infrared radiation, temperature, humidity, product.

Introduction. Currently, the most important problem is the economical use of material and technical, fuel and energy resources. The storage and processing of agricultural products is also relevant, since proper nutrition is an integral part of a healthy lifestyle. In this regard, the number of research and development works on the use of renewable energy sources has significantly increased. It is also necessary to simultaneously address the problems associated with insufficient energy efficiency, regardless of the type of energy used. Analysis of energy-intensive processes shows that there are large reserves for reducing energy consumption[1,2,3].

Drying is a method of processing agricultural products and various industrial materials for long-term high-quality storage or service by removing moisture from the product being dried to a safe limit. Removing excess moisture from the product is an energy-intensive process, and the energy required for this process is mainly obtained from fossil fuels that have a negative impact on the environment[4]. It should be noted that currently, the improper organization of the drying method used for storing food and other types of products, or the lack of processes, is the cause of spoilage and waste of most products[5]. The drying method causes problems related to external drying parameters, such as humidity, moisture content, temperature, drying rate, and other factors such as wind, rain, insects, and animals [6].

The use of functional ceramics for drying various objects leads to a significant reduction in energy consumption and drying time. Also, the use of functional ceramics can not only save energy or reduce process time, but also reduce drying areas and improve the quality of the target product[7].

Traditional methods of drying fruits and vegetables, that is, in conventional dryers and ovens, as well as in microwave ovens, do not give positive results. This is because some products are very sensitive to heat due to their high sugar content. Due to overheating of the product, it gives products the taste of burnt sugar and contributes to the loss of extractive fragrances, which leads to the loss of the specific taste characteristic of each product. Traditional low-temperature drying, however, does not allow drying to the minimum moisture content of the product when high quality characteristics of the product are achieved. Positive results can be obtained only in a drying unit equipped with radiation elements coated with special functional ceramics[8-12].

Below, a drying oven using a liquefied state of functional ceramic powder used for drying from an electric furnace and a solar drying unit using a ceramic composite polyethylene film were developed. Experiments were conducted by combining them.

The conversion of electrical energy and solar radiation was carried out by converting energy into pulsed infrared radiation.

Methodology & empirical analysis. The study focuses on the influence of the effectiveness of sun drying of eggplant pieces on the drying efficiency of the thickness of the pieces and the type of transparent coating material. Experiments were conducted on solar dryers of two different designs: one using composite polyethylene film based on functional ceramics, and the other using ordinary polyethylene film without any additives.

Two identical solar dryers were developed for the experiments, differing only in the transparent coating material. Composite polyethylene film based on functional ceramics has the ability to generate solar energy at a wavelength of 6-8 μm. The results obtained from the proposed solar dryer in the study were compared with the results obtained from a conventional polyethylene film solar dryer[13-14].

When preparing the sample - fresh eggplants were taken from the local market and cut evenly in two different thicknesses of 5 mm and 10 mm. For each stage of the experiment, pre-prepared eggplant pieces (5 mm or 10 mm) were evenly distributed in the drying chamber of both solar dryers. The drying process was carried out simultaneously in both dryers under the same environmental conditions (intensity of solar radiation, ambient temperature, relative humidity).

During the drying process, the following parameters were recorded at regular intervals:

The weight loss of eggplant pieces was measured using precise scales to determine the rate of moisture loss.

The temperature inside the drying chamber was recorded using thermometers installed in the chamber.

Ambient temperature - controlled taking into account the influence of the external environment.

Relative humidity was measured inside and outside the drying chamber.

The intensity of solar radiation was recorded using the results obtained from the metostation for the quantitative assessment of available solar energy.

The drying process was carried out in accordance with the standard food storage rules until the eggplant pieces reached a moisture content safe for long-term storage.

Figure 1. Experimental process

Results: The data in Tables 1.2.3 below are presented on the basis of such parameters as solar radiation, chamber temperature, and relative humidity as the change in the residual mass (weight) of products with a thickness of 5 mm using three different drying methods: Composite, Traditional, and Open solar.

Table 1. Residual mass in a traditional drying unit (5 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	27,33
9:00	598	36,2	33	19,84
10:00	746	40,9	27	14
11:00	426	42,8	24	10,85
12:00	808	46,7	22	7,93
13:00	812	49,6	18	4,61
14:00	820	53,1	16	2,13
15:00	675	51,8	16	1,77
16:00	490	39,2	22	1,64
17:00	293	38,6	20	1,61
18:00	111	27	31	1,61

In Table 1 above, the initial mass of the product in the composite device decreased from 27.33 grams to 1.61 grams. The drying process mainly proceeded intensively until 14:00, after which the residual mass did not change significantly. This corresponds to the time when the temperature of the chamber (53.1 °C) and solar radiation (820 W/m^2) are highest.

Table 2. Residual mass in a traditional drying unit (5 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	29,4
9:00	598	36,6	29	22,28
10:00	746	41,7	23	16,11
11:00	426	45	20	12,86
12:00	808	47,3	17	9,93
13:00	812	50,1	12	6,28
14:00	820	52,4	12	3,05
15:00	675	51,8	12	2,23
16:00	490	39,4	16	1,88
17:00	293	39,4	16	1,78
18:00	111	26,8	26	1,76

In Table 2 above, the initial mass of the product in the traditional device decreased from 29.4 grams to 1.76 grams. The drying process was slower, but more steady compared to the composite unit. Significant drying was observed before 14:00.

Table 3. Residual mass in the open sun (5 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	28,49
9:00	598	33,9	35	20,08
10:00	746	39,3	28	12,67
11:00	426	44,2	23	8,91
12:00	808	44,3	18	5,64
13:00	812	48,1	16	2,78
14:00	820	48,7	16	1,76
15:00	675	46,7	16	1,71
16:00	490	37,2	16	1,7
17:00	293	36,9	21	1,7
18:00	111	26	30	1,7

In Table 3 above, the initial mass of the product under direct sunlight decreased from 28.49 grams to 1.7 grams. With this method, the drying process was also effective, especially in the middle of the day when there is high solar radiation and temperature. The lowest residual mass was achieved after 14:00.

The following tables 4, 5, and 6 show the change in the residual mass (weight) of products with a thickness of 10 mm using three different drying methods (composite, traditional, and open-solar). These results made it possible to analyze changes under the influence of external factors such as solar radiation, chamber temperature, and relative humidity.

Below is an analysis of the residual mass and corresponding parameters for each drying method.

Table 4. Residual mass of the composite drying unit (10 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	49,35
9:00	598	36,2	33	41,21
10:00	746	40,9	27	33,77
11:00	426	42,8	24	30,16
12:00	808	46,7	22	26,26
13:00	812	49,6	18	20,75
14:00	820	53,1	16	13,63
15:00	675	51,8	16	10,63
16:00	490	39,2	22	8,21
17:00	293	38,6	20	6,64
18:00	111	27	31	5,38

In Table 4 above, the initial mass of the product with a thickness of 10 mm in the composite device decreased from 49.35 grams to 5.38 grams. The drying process occurred most rapidly between 13:00 and 14:00, with the highest chamber temperature (53.1 °C) and the lowest relative humidity (16%). The residual mass decreased more slowly after 14:00 and stabilized by evening.

Table 5. Residual mass in a traditional drying unit (10 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	46,56
9:00	598	36,6	29	39,67
10:00	746	41,7	23	32,81
11:00	426	45	20	29,19
12:00	808	47,3	17	25,48
13:00	812	50,1	12	20,19
14:00	820	52,4	12	13,48

15:00	675	51,8	12	10,87
16:00	490	39,4	16	8,26
17:00	293	39,4	16	6,61
18:00	111	26,8	26	5,26

In Table 5 above, the initial mass of the product with a thickness of 10 mm in the traditional device decreased from 46.56 grams to 5.26 grams. In this method, the drying process slowed down towards evening, and the most effective drying hours occurred between 13:00-15:00.

Table 6. Residual mass under the open sun (10 mm)

Time	Solar radiation W/m²	Camera temperature °C	Relative humidity %	Residual mass g
8:00	462	26	48	46,18
9:00	598	33,9	35	38,58
10:00	746	39,3	28	30,95
11:00	426	44,2	23	26,15
12:00	808	44,3	18	21,46
13:00	812	48,1	16	15,74
14:00	820	48,7	16	9,28
15:00	675	46,7	16	6,82
16:00	490	37,2	16	5,28
17:00	293	36,9	21	4,4
18:00	111	26	30	3,79

In Table 6 above, the initial mass of the product with a thickness of 10 mm under direct sunlight decreased from 46.18 grams to 3.79 grams. In this method, the drying process was also effective, especially the fastest drying was observed in the period from 13:00 to 14:00. In terms of residual mass, this method achieved the lowest indicator among the three methods.

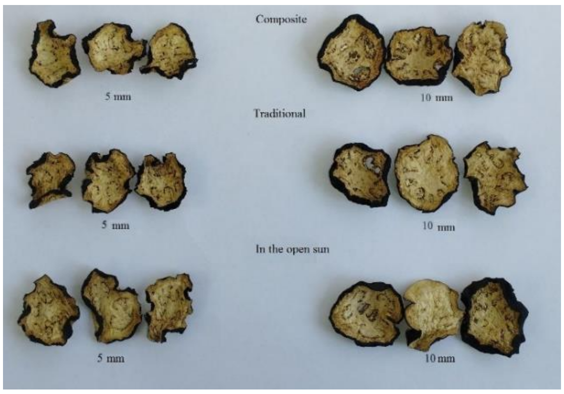

Figure 2. Dried product

Discussion. All three methods for drying efficiency showed drying efficiency, significantly reducing the moisture content of the product. The composite device achieved the lowest final residual mass of 1.61 g, which indicates that it is the most effective drying method. For a product with a thickness of 10 mm, the open-solar method achieved the lowest final residual mass (3.79 g), which indicates that it is the most effective drying method. Composite (5.38 g) and Traditional (5.26 g) devices also showed good results, but have a slightly higher residual mass than open sun.

In terms of drying rate, the most intensive drying was observed in the middle of the day, when solar radiation and chamber temperature were highest, and relative humidity was lowest (approximately 13:00-15:00). During the hours of peak solar radiation and temperature, from 12:00 to 14:00, the drying process was accelerated by all methods.

Compared to the results of the previous 5 mm thickness in terms of thickness effect, it took more time to dry the 10 mm thickness product and the final residual mass was higher. This indicates the direct influence of the product thickness on the drying process.

A sharp decrease in relative humidity inside the chamber during the day in terms of moisture decrease increased the drying efficiency. This confirms that the dryness of the drying medium plays an important role in moisture removal.

After 15:00 hours on the final residual moisture content, the change in the residual mass in all methods was minimal, which means that the product approaches the requirements of GOST.

Due to the influence of environmental factors, high solar radiation, an increase in the chamber temperature, and a decrease in relative humidity led to faster drying of the product.

These results are crucial for optimizing the drying process, evaluating the effectiveness of various drying methods, and determining how the initial properties of the product (e.g., thickness) affect the drying results.

Conclusion. The effectiveness of the drying methods depends on the thickness, for eggplant pieces with a thickness of 5 mm, the Composite drying unit showed the highest effectiveness, reducing the final residual mass to 1.61 g. As a result, the open sun method with 10 mm thick eggplant pieces was the most effective, reducing the residual mass of the product to 3.79 g.

Since the intensity of the drying process depends on time and environmental factors, in all drying methods, the drying process was most intensive in the middle of the day (approximately 12:00-15:00). As a result, the high intensity of solar radiation, the maximum increase in the temperature inside the chamber (up to 53.1°C in the composite device), and a sharp decrease in relative humidity (up to 12-16%) led to rapid moisture loss.

Influence of product thickness on drying time and final moisture, according to the experimental results, eggplant pieces with a thickness of 5 mm were practically dry by 14:00-15:00, while for samples with a thickness of 10 mm, this process was slower and the final residual mass was higher. As a result, it was shown that with an increase in the thickness of the product, the time required for drying can increase and the final moisture content can be higher.

Influence of the transparent coating material on drying efficiency (Composite vs Traditional), the composite polyethylene film based on functional ceramics (Composite device) used in the study dried samples with a thickness of 5 mm to a lower final residual mass (1.61 g versus 1.76 g) compared to the traditional polyethylene film device. As a result, it was found that the ability of the composite material to generate infrared rays can make the drying process more efficient, especially for eggplant pieces up to 5 mm.

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