

V International Scientific and Technical Conference Actual Issues of Power Supply Systems

Design and study of a laboratory-experimental ultraviolet irradiation device

AIPCP25-CF-ICAIPSS2025-00208 | Article

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Design and study of a laboratory-experimental ultraviolet irradiation device

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Abstract: The article provides a comprehensive analysis of modern approaches to extending the shelf life of cherries, which is largely determined by the high perishability of this berry crop and its susceptibility to microbiological spoilage. Special attention is given to innovative non-chemical fruit treatment technologies, among which the use of ultraviolet (UV) irradiation is highlighted. The mechanism of UV action is examined, based on the inactivation of surface microorganisms, including bacterial and fungal pathogens, which helps reduce spoilage processes and slow down physiological changes in the fruit. Data are presented demonstrating the positive effect of UV treatment on preserving the commercial and organoleptic qualities of cherries during storage. The article substantiates the feasibility of using UV devices in post-harvest fruit processing as a promising, environmentally safe, and effective method for increasing the product's shelf life.

INTRODUCTION

According to statistical data, 218 tons of cherries were grown in Uzbekistan in 2023, and 209 tons in 2024, and this figure continues to increase every year. Part of the harvested cherries is supplied to the domestic market, while another part is exported. However, as is well known, exporting cherries is a complex process that requires maintaining high quality and freshness of the fruit during long transportation. As a result, exporters face the issue that not all batches of cherries reach consumers in fresh condition. [1-2]

Table 1. Statistics of harvested cherries in the Republic of Uzbekistan

Classifier	2017	2018	2019	2020	2021	2022	2023	2024
Republic of Uzbekistan	136,6	172,0	175,8	185,1	213,6	216,9	218,9	209,0
Republic of Karakalpakstan	1,4	0,5	0,5	0,4	0,5	0,4	0,4	0,4
Andijan region	61,3	74,8	74,2	74,9	91,5	88,2	73,7	67,5
Bukhara region	7,5	12,3	18,4	13,7	8,5	10,8	10,2	7,2
Jizzakh region	7,4	5,6	6,0	8,0	11,8	5,9	5,9	6,0
Kashkadarya region	4,7	4,8	4,7	4,8	4,7	6,9	13,3	12,9
Navoi region	5,0	5,7	5,8	6,4	8,9	7,0	6,9	6,6
Namangan region	11,0	12,8	13,7	14,8	13,8	19,9	24,0	20,4
Samarkand region	8,5	15,7	16,4	22,1	29,4	28,9	25,8	29,3
Surkhandarya region	0,0	0,0	0,1	0,0	0,1	0,1	0,1	0,1
Syrdarya region	1,2	1,4	1,4	1,5	1,7	1,2	1,0	1,1
Tashkent region	8,9	5,8	5,6	9,9	15,4	17,0	19,8	17,4
Fergana region	8,8	10,5	11,4	15,1	16,3	19,1	20,3	17,7
Khorezm region	0,1	0,1	0,0	0,0	0,0	0,4	0,4	0,3
Tashkent city	0,5	0,1	0,2	0,1	0,2	0,0	0,1	0,1

In this regard, the need for treating cherries with various chemical substances is increasing, which in turn may lead to a deterioration in product quality and a reduction in its consumer appeal. As an alternative to chemical methods, we propose a technology for treating cherries with ultraviolet irradiation, aimed at enhancing microbiological safety and extending the shelf life of the fruit without the use of chemical reagents.

Use of Ultraviolet Rays. Ultraviolet germicidal radiation is widely used abroad at food industry enterprises (meat, fish, dairy, bakery, brewing, fruit and vegetable processing facilities, as well as food warehouses, storage facilities, etc.) for disinfecting air and surfaces in order to meet hygiene requirements for the quality and safety of food raw materials and food products [3-4].

EXPERIMENTAL RESEARCH

We conducted experiments on the use of ultraviolet rays for treating fruits in order to extend their shelf life. During the study, a laboratory-experimental UV irradiation unit was designed, allowing controlled exposure to the surface of the fruit. The unit ensures uniform distribution of UV radiation, and the irradiation parameters (dose, intensity, and exposure time) were selected based on the sensitivity of different types of fruits to ultraviolet light [5-6].

The application of this technology leads to the inactivation of microorganisms present on the surface of the fruit, which slows down biological degradation processes and increases the shelf life of the product. The experiments showed that optimal irradiation parameters make it possible to extend the shelf life of fruits by several days without the use of chemical preservatives, while preserving their organoleptic and nutritional properties [7-9].

The proposed ultraviolet irradiation technology proves to be promising for implementation in post-harvest fruit processing and can serve as an effective alternative to chemical treatment, enhancing the microbiological safety of the product and reducing losses during transportation and storage.

Structural elements of the proposed device:

- metal supports;
- plastic with aluminum coating;
- movable metal surface for samples;

External dimensions:

- height 110 cm;
- width – 120 cm;
- length – 140 cm.

Internal dimensions of the device:

- Distance from the lamps above the support surface – 27 cm; 10–50;
- Distance between the two long side lamps – 37 cm; from 35 to 120 cm;
- Distance between the lower lamps and the support surface – 41–35 cm;
- Distance between the top lamp and the cover – 10 cm.

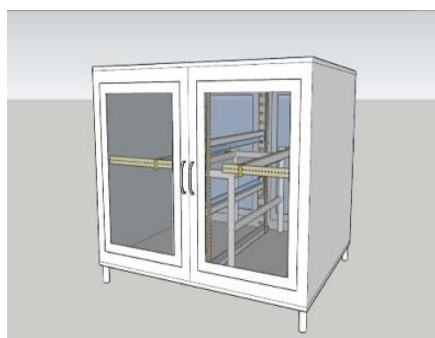


FIGURE 1. General view of the laboratory-experimental setup UV device

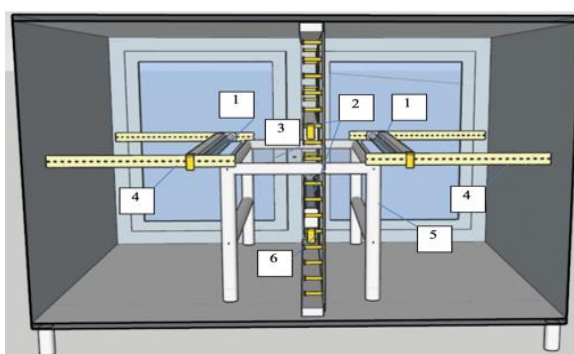


FIGURE 2. Internal view of the laboratory-experimental UV device

Individual average values:

- Lamp located at the top:
- At a distance of 27 cm: 921 W/cm²;

- At a distance of 17 cm: 1171 W/cm²;
- Left side lamp, front view:
 - At a distance of 27 cm: 793 W/cm²;
 - At a distance of 17 cm: 1028 W/cm²;
- Right side lamp, front view at a distance:
 - 27 cm: 781 W/cm²;
 - 17 cm: 1013 W/cm²;
- Lamps located at the bottom at a distance:
 - 27 cm and 17 cm: 0 W/cm²
- UV lamps:
 - 4 long tubes, 90 cm each.

This device allows for modeling and calculating the technological process of cherry treatment with ultraviolet radiation. It enables the determination of optimal irradiation parameters, such as UV intensity, exposure time, distance between the radiation source and the fruit, as well as uniformity of energy distribution on the surface of the berries. The use of the device makes it possible to predict the effectiveness of microorganism inactivation on the surface of cherries and to assess the impact of the treatment on preserving the organoleptic and nutritional qualities of the fruit. Thus, the device serves as a tool for optimizing UV treatment regimes and enhancing the microbiological safety of the product [10-12].

RESEARCH RESULTS

Analysis of the results showed that the percentage of cherry weight loss increases approximately linearly during the first 20 days of storage, while the rate of loss decreases at later stages. The main component of the fruit is water, which constitutes 89–94% of its content. The fruits are extremely sensitive to dehydration, and those with a high respiration rate exhibit increased water loss. This manifests as shriveling, reduction in mass, and deterioration of organoleptic characteristics, negatively affecting the texture and juiciness of the fruit [13-15].

The transpiration rate is determined both by the biological characteristics of the specific product and by the environmental conditions in which it is stored. Transpiration is the process of water vapor transfer from fruit tissues to the surrounding air. This process is one of the key factors in fruit quality deterioration, especially during the post-harvest period. High water content in the fruit contributes to significant mass loss and reduced visual appeal, ultimately decreasing product quality and its commercial value [7-8].

RESULTS AND DISCUSSION

Table 2. presents the results of Duncan's multiple comparison test, showing that there is a significant difference between the treatment methods, indicated by the formation of subsets. Cherries were treated with UV irradiation and stored at 4 °C for 20 days. The weight losses observed were: up to 9.72% for samples treated at 1 kJ/m², 10.7% at 3 kJ/m², and 10.1% at 5 kJ/m². The control sample (0 kJ/m²) showed a weight loss of 11.6%. These treatment methods are statistically equivalent.

TABLE 2. Duncan's test for weight loss of cherries treated with UV-C

Parameters	Results %					
	1	2	3	4	5	6
0 kJ/m ² – 0 days	0,0					
1 kJ/m ² – 0 days	0,0					
3 kJ/m ² – 0 days	0,0					
5 kJ/m ² – 0 days	0,0					
0 kJ/m ² – 2 days		2,8				
1 kJ/m ² – 2 days		2,6				
3 kJ/m ² – 2 days		1,9				
5 kJ/m ² – 2 days		1,5				
0 kJ/m ² – 5 days			5,9			
1 kJ/m ² – 5 days			5,4			
3 kJ/m ² – 5 days			5,1			
5 kJ/m ² – 5 days			4,9			
0 kJ/m ² – 10 days				8,7		
1 kJ/m ² – 10 days				8,3		
Continuation of Table 2						
3 kJ/m ² – 10 days				7,8		
5 kJ/m ² – 10 days				7,7		
0 kJ/m ² – 15 days					9,5	
1 kJ/m ² – 15 days					9,3	
3 kJ/m ² – 15 days					8,8	
5 kJ/m ² – 15 days					8,5	
0 kJ/m ² – 20 days						11,6
1 kJ/m ² – 20 days						10,7
3 kJ/m ² – 20 days						10,1
5 kJ/m ² – 20 days						9,3

Table 3 shows the results of Duncan's multiple comparison test, indicating that there is a significant difference between treatments, as reflected by the formation of subsets. Cherries were treated with UV-C and stored at 4 °C for 20 days. The titratable acidity was: 11.1% for samples treated at 1 kJ/m², 9.1% at 3 kJ/m², and 8.9% at 5 kJ/m². The control sample (0 kJ/m²) had a titratable acidity of 10.6% [16-23].

On the 15th and 20th days of storage, a decrease in overall acceptability of the cherries was observed. The highest organoleptic score was given to the sample treated with ultraviolet radiation at a dose of 5 kJ/m², which had the best perceived bittersweet flavor, with an average rating of 2.08. On the 20th day, the control sample showed the lowest level of acceptability: tasters noted less pronounced sweetness, a slightly more acidic taste, and a semi-soft texture, which did not elicit strongly positive or negative impressions.

TABLE 3. Duncan's test for titratable acidity of cherries treated with UV-C

Parameters	Results %					
	1	2	3	4	5	6
0 kJ/m ² – 0 days	10,1					
1 kJ/m ² – 0 days	9,7					
3 kJ/m ² – 0 days	9,4					
5 kJ/m ² – 0 days	10,0					
0 kJ/m ² – 2 days		9,1				
1 kJ/m ² – 2 days		6,4				
3 kJ/m ² – 2 days		10,0				
5 kJ/m ² – 2 days		7,1				
0 kJ/m ² – 5 days			9,7			
1 kJ/m ² – 5 days			7,1			
3 kJ/m ² – 5 days			8,1			
5 kJ/m ² – 5 days			6,2			
0 kJ/m ² – 10 days				5,0		
1 kJ/m ² – 10 days				7,12		
3 kJ/m ² – 10 days				6,9		
5 kJ/m ² – 10 days				9,8		
0 kJ/m ² – 15 days					8,0	
1 kJ/m ² – 15 days					6,0	
3 kJ/m ² – 15 days					8,4	
5 kJ/m ² – 15 days					7,2	
0 kJ/m ² – 20 days						10,6
1 kJ/m ² – 20 days						11,1
3 kJ/m ² – 20 days						9,1
5 kJ/m ² – 20 days						8,9

The quality of food products is determined by a combination of parameters, including appearance, texture, taste, aroma, and nutritional value. The influence of each attribute on product perception depends on the type of product, with visual characteristics being one of the key factors determining consumer choice at the time of purchase.

CONCLUSIONS

1. A technological process scheme for UV treatment of cherries was developed, complying with hygienic and sanitary standards, ensuring the production of a safe, high-quality product.
2. An experimental ultraviolet device was created, allowing simulation and calculation of treatment parameters, optimization of energy consumption, and improvement of product quality.
3. Cherry weight loss after 20 days of storage at 4 °C depended on UV irradiation intensity: 1 kJ/m² – 9.72%, 3 kJ/m² – 10.1%, 5 kJ/m² – 9.3%.
4. Refractometric dry matter content decreased with increasing UV intensity: 1 kJ/m² – 11.5 °Brix, 3 kJ/m² – 10.0 °Brix, 5 kJ/m² – 10.1 °Brix; control sample – 11.9 °Brix.
5. Fruit firmness after treatment and storage was: 1 kJ/m² – 1.7%, 3 kJ/m² – 1.6%, 5 kJ/m² – 1.6%.
6. Titratable acidity changed as follows: 1 kJ/m² – 11.1%, 3 kJ/m² – 9.1%, 5 kJ/m² – 8.9%.
7. Treatment at 5 kJ/m² provided the highest brightness, stability, titratable acidity, and anthocyanin content, as well as minimal weight loss and low levels of mold and yeast.
8. It was determined that the optimal UV irradiation intensity for maintaining the organoleptic, physicochemical, and microbiological properties of cherries during long-term storage is 5 kJ/m².

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