

## Experimental Investigation of a Solar-Convective Unit for Drying Plant Raw Materials

Ketevan Archvadze\*, Iia Chachava\*, Ia Chitrekashvili\*,  
Nora Dokhturishvili\*, Eter Gavashelidze\*, Nanuli Khotenashvili\*

\* *Petre Melikishvili Institute of Physical and Organic Chemistry, Ivane Javakhishvili Tbilisi State University, Georgia*

(Presented by Academy Member Ramaz Gakhokidze)

**Abstract.** A solar-convective drying unit based on natural draft and combined heat transfer has been developed. For the first time, the use of interchangeable covers (polyethylene and tin) to regulate thermal regimes depending on the raw material type is experimentally substantiated. This study demonstrates highly efficient, electricity-free drying that effectively preserves bioactive substances. The research aimed to evaluate the unit efficiency under minimal energy costs, analyze temperature regimes and drying kinetics, and compare solar drying (SD) with natural drying (ND) regarding Vitamin C preservation. Experimental results indicate that the polyethylene cover increased the chamber temperature by 20 to 35°C above ambient levels, whereas the tin cover provided an increase of 8° to 15°C. The drying duration for St. John's wort in the unit (8 h) was 12.5 times shorter than ND in the shade. Cherry drying was 3 times faster, with Vitamin C losses at 40% compared to 82% under ND. The developed unit ensures energy-saving drying within the 30-55°C range. Its application reduces energy costs by 85-100%, significantly shortens processing time, and enhances final product quality. © 2026 *Bull. Natl. Acad. Sci. Georg.*

**Keywords:** solar dryer, drying duration, St. John's wort, cherry, Vitamin C

### Introduction

Solar-air drying is weather-dependent, requiring high temperatures and low humidity for effective dehydration. Insufficient heat degrades organoleptic properties and nutrient retention, while the process can last 4-15 days. During drying, raw materials must be protected from dust, moisture, and insects. Despite these limitations, the method remains relevant for long-term storage and preservation of nutritional value. In small-scale farming, even basic solar-convective dryers can signi-

ficantly enhance efficiency and minimize losses (Deng et al., 2021; Sharma et al., 2012; Khakimova et al., 2023).

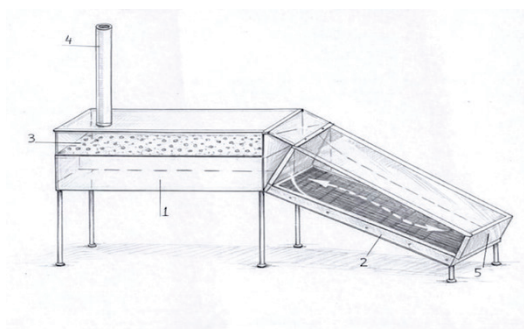
### Materials and Methods

Based on global designs, a solar-convective drying unit was developed and tested for fruits, vegetables, mushrooms, and medicinal plants. The air heater features a black-coated metal absorber, an air duct, and a translucent cover made of glass or polymers like polycarbonate and polyethylene. The system

utilizes natural draft: heated air enters the lower chamber, flows through the product, and exits via a chimney. Insulated or dark-colored walls enhance heat absorption, while direct solar exposure provides additional warming. This design overcomes common drying limitations by utilizing the greenhouse effect to maintain internal temperatures 25-30°C above ambient levels (Mohana et al., 2020; Fudholi et al., 2010; Mtchedlishvili et al., 2024; Iremashvili et al., 2025; Arunraja et al., 2018).

The solar unit consists of two metal chambers (Fig. 1) with metal-lined sides and bases. Air is heated by solar radiation through the glass covers and lateral surfaces. Chamber 1 features an exhaust chimney (4) at the top and a fresh-air inlet (5) at the bottom, with a vertical height difference of approximately 2.0 m between them.

This height gradient, combined with temperature and pressure differentials, drives natural convection, while wind passing over the chimney outlet further accelerates air circulation. The black-painted housing maximizes thermal absorption. Raw materials are placed on a mesh tray (3) within chamber 1, which is then sealed with glass frames or metal sheets depending on the specific drying requirements.



**Fig. 1.** Solar-convective drying unit. 1 – drying chamber; 2 – solar air heater; 3 – product tray; 4 – exhaust chimney; 5 – air inlet.

Natural draft is established via the bottom air inlet (5) and top chimney (4), facilitating effective moisture removal. Increased wind speed creates a pressure drop at the outlet, further displacing air from the chamber. This synergy of convection and solar heating ensures process efficiency with zero electricity consumption. While external ventilation or fans may be integrated if necessary, sensitive products like medicinal plants require the controlled thermal regimes provided by interchangeable covers (Venkateswarlu and Kota Reddy, 2024; Sharma et al., 2009). Experimental trials included glass, polyethylene, and tin covers. This paper focuses on findings for polyethylene and tin; the

**Table 1.** Experimental parameters for the solar-convective dryer equipped with a tin cover

Time of day(hours)	Relative humidity (%)	Atmos. Pressure (kPa)	Wind speed (km/h)	Ambient air temperature (°C)	Air temperature in direct sunlight (°C)	Drying chamber temperature (°C)
10	45	101.30	6	30.0	33.0	38.0
12	44	101.30	6	34.0	38.0	48.0
14	26	101.00	13	34.5	39.5	49.0
16	30	101.00	18	34.5	40.0	48.0
18	38	100.90	17	35.5	38.5	46.0
20	40	100.80	17	32.0	32.0	35.0

**Table 2.** Experimental parameters for the solar-convective dryer equipped with a polyethylene cover

Time of day(h)	Relative humidity (%)	Atmos. pressure (kPa)	Wind speed (km/h)	Ambient air temperature (°C)	Air temperature in direct sunlight (°C)	Drying chamber temperature (°C)
10	51	102.1	6	19.5	22.0	40.5
12	42	102.0	9	21.0	24.5	46.5
14	42	101.9	9	22.5	26.0	54.0
16	37	101.5	9	22.5	24.5	51.5
18	40	101.8	12	21.5	21.5	31.0

latter was specifically used for herbs to maintain temperatures below 55°C and minimize direct solar radiation (Archvadze et al., 2018; Archvadze et al., 2017; Abutidze et al., 2025).

Tables 1 and 2 present environmental parameters: air temperature (inside the dryer, in the sun, and in the shade), atmospheric pressure, wind speed, and relative humidity. Test results for the unit with polyethylene and tin covers are shown in Figs. 2 and 3.

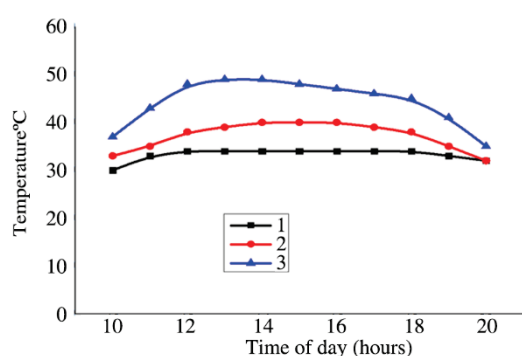


Fig. 2. Diurnal variation of air temperature: 1 – in the shade; 2 – in the sun; 3 – inside the solar dryer.

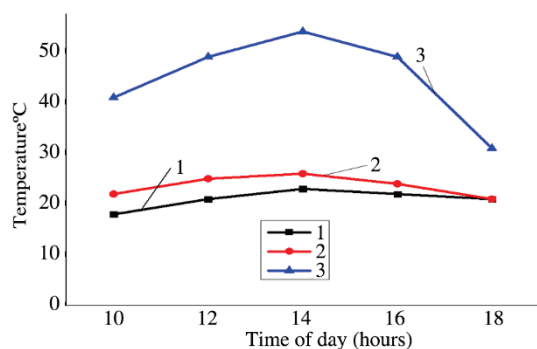


Fig. 3. Diurnal variation of air temperature: (1) in the shade; (2) in the sun; (3) inside the solar dryer.

With the polyethylene cover, internal temperatures exceeded ambient levels by 20-35°C, accelerating evaporation and shortening drying duration. The tin cover provided a moderate increase of 8-15°C, ensuring a gentle regime essential for preserving bioactive compounds and preventing medicinal plant overheating. This temperature differential is governed by environmental factors—humidity, ambient temperature, wind speed, and

atmospheric pressure – all of which must be considered when optimizing drying modes.

### Experimental Setup

Raw material preparation involved: (1) sorting and grading of the initial material; (2) calibration by size and mass; (3) slicing or pitting, when required; (4) dividing samples into two equal groups for comparative natural and solar drying; (5) initial weighing of the product; (6) loading onto drying trays; (7) periodic weighing at set intervals (10:00-20:00; 10:00-18:00 in autumn/spring); and (8) data processing, including tabulation and graphical analysis for result visualization.

Various agricultural products were dried in the solar-convective drying unit. This paper presents the drying results for the medicinal plant St. John's wort in a solar dryer with a tin cover, used to prevent overheating and mitigate direct solar radiation. The findings are compared with the results of drying the same raw material under natural conditions in the shade.

Table 3. Comparative analysis of experimental results

Product name		
St. John's wort		
	SD	ND
Initial mass $m_0$ (g)	720	710
Final mass $m_f$ (g)	212	213
Mass reduction $\Delta m$ (%)	70.5	70
Drying time $t$ (h)	8	100

Experimental data indicate that the drying time for St. John's wort in the unit was 8 hours, compared to over 4 days (approx. 100 hours) for natural shade drying. Thus, the solar dryer reduced processing time by 12.5 times. Beyond efficiency, the unit offers several quality-related advantages:

**Preservation of active compounds:** St. John's wort contains thermosensitive components, such as hypericin and flavonoids. Prolonged natural drying may lead to their degradation via oxidation and enzymatic activity. Rapid solar drying minimizes

exposure to oxygen and light, reducing the loss of active substances and enhancing the herb's pharmacological value; reduced risk of mold and microbial contamination; Stability of color and aroma (Dudek et al., 2022; Babaei Rad et al., 2025; Gamkrelidze, 2022).

The drying of cherries was conducted in the solar-convective drying unit equipped with a polyethylene cover. The experimental results are presented in Table 4.

**Table 4. Comparative analysis of experimental results**

Product name		
Cherry		
	SD	ND
Initial mass $m_0$ (g)	530	530
Final mass $m_f$ (g)	170	165
Mass reduction $\Delta m$ (%)	68	69
Drying time $t$ (h)	58	178

Experimental data indicate that the drying duration in the solar dryer was three times shorter than in open-air drying, confirming the technology's high efficiency for succulent plant raw materials. This time reduction offers several key advantages:

*Quality and nutrient preservation:* 1. Cherries contain vitamins, anthocyanins, and antioxidants that degrade under prolonged exposure to oxygen, light, and heat. 2. Rapid drying minimizes oxidative processes, nutrient loss, and undesirable changes in color and flavor. 3. Laboratory analysis revealed that Vitamin C losses were approximately 40% of the initial level, compared to 82% with the traditional method.

**Reduced spoilage risk:** Rapid drying virtually eliminates the growth of microorganisms and mold, enhancing product safety. In contrast, natural drying intensifies enzymatic activity (e.g., ascorbate oxidase), while constant oxygen contact and direct UV radiation accelerate ascorbic acid degradation (Horuz et al., 2017; Yeni et al., 2025; Malwad and Sonawane, 2024; Sharma et al., 2009).

The advantages of this design in terms of vitamin preservation are determined by a combination of interrelated factors. The placement of berries

within an enclosed chamber provides protection from ultraviolet radiation, thereby preventing the photodegradation of vitamin C. At the same time, the exhaust pipe configuration creates so-called chimney effect, generating natural draft and maintaining continuous flow of warm air, which accelerates moisture removal. Due to the preliminary heating of air in the collector, the temperature inside the drying chamber exceeds the ambient temperature, allowing the drying process to be intensified by approximately three times and thus reducing the duration of the product's exposure to oxygen. An important additional factor is the maintenance of an optimal temperature range of 45-55°C, at which vitamin C losses are minimized and the biological value of the raw material is preserved. (Gvinianidze et al., 2025; Abutidze et al., 2025)

## Results and Discussion

The operation of a solar convective drying unit with polyethylene and metal (tin) coverings has been studied. With the polyethylene covering, the temperature inside the chamber exceeded the ambient temperature by 20-35°C, ensuring intensive moisture evaporation and reducing the drying time. With the metal covering, the temperature increase amounted to 8-15°C, allowing for a gentle mode that does not exceed 55°C. Experimental drying of St. John's wort with the tin cover lasted 8 hours, compared to 100 hours for natural shade drying (a 12.5-fold reduction). Cherry drying with the polyethylene cover was approximately 3 times faster than open-air drying methods. Stable natural convection was maintained in all modes without the use of electricity. Vitamin C losses in the unit were nearly half of those observed in traditional drying. The results confirm that solar-convective drying is significantly more effective than natural methods. The synergy of radiant heating and organized natural convection intensifies heat and mass transfer, accelerating moisture removal.

Polyethylene covers are recommended for high-moisture fruits and vegetables requiring higher thermal levels.

Tin covers are ideal for medicinal plants as they mitigate direct UV exposure and prevent overheating.

Reducing the drying duration suppresses oxidative and enzymatic processes, ensuring superior preservation of bioactive compounds, vitamins, color, and aroma while minimizing the risk of microbial spoilage (Revishvili et al., 2023; Gamkrelidze, 2022).

## Conclusion

The developed solar-convective drying unit serves as an efficient, environmentally safe, and energy-

saving solution for processing plant raw materials. The application of this solar dryer enables: (1) a significant reduction in process duration by 3 to 12.5 times; (2) maintenance of the optimal temperature range of 30-55°C; (3) enhanced product quality through the preservation of bioactive substances (e.g., Vitamin C losses in cherries were reduced to 40%, compared with 82% during natural drying); (4) Substantial energy savings of 85-100% and the complete elimination of CO<sub>2</sub> emissions.

The simplicity of the design, combined with low operational costs and adjustable operating modes, makes this unit a highly promising solution for farms and small-scale processing enterprises.

## სურსათის მეცნიერება

# მცენარეული ნედლეულის გასაშრობად განკუთვნილი მზის კონვექციური საშრობი დანადგარის ექსპერიმენტული კვლევები

ქ. არჩვაძე\*, ი. ჩაჩავა\*, ი. ჩიტრეკაშვილი\*, ნ. დობტურიშვილი\*,  
ე. გავაშელიძე\*, ნ. ხოტენაშვილი\*

\* ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, პ. მელიქიშვილის ფიზიკური და ორგანული ქიმიის ინსტიტუტი, საქართველო

(წარმოდგენილია აკადემიის წევრის რ. გაბოკიძის მიერ)

შემუშავებულია მზის კონვექციური საშრობი დანადგარი, რომელიც ფუნქციონირებს ბუნებრივი წვევისა და კომბინირებული თბოგადაცემის საფუძველზე. ჩვენ მიერ არის ექსპერიმენტულად დასაბუთებული ცვლადი საფარების (პოლიეთილენის და თუნუქის) გამოყენება

ტემპერატურული რეჟიმების რეგულირებისათვის, ნედლეულის ტიპიდან გამომდინარე კვლევა აჩვენებს ეფექტურ, ელექტროენერჯის გარეშე შრობას ბიოლოგიურად აქტიური ნივთიერებების შენარჩუნებით. კვლევის მიზანი იყო დანადგარის ეფექტურობის შეფასება მინიმალური ენერგოდანახარჯების პირობებში, ტემპერატურული რეჟიმებისა და შრობის კინეტიკის ანალიზი, ასევე მზის შრობისა და ბუნებრივი შრობის შედარება C ვიტამინის შენარჩუნების კუთხით. დადგინდა, რომ პოლიეთილენის საფარმა საშრობ კამერაში ტემპერატურა გარემოსთან შედარებით 20-35°C-ით გაზარდა, ხოლო თუნუქის საფარმა – 8-15°C-ით. კრაზანას შრობის დრო დანადგარში (8 სთ) 12,5-ჯერ ნაკლები აღმოჩნდა ჩრდილში ბუნებრივ შრობასთან შედარებით. ალუბლის შრობა 3-ჯერ დაჩქარდა, ამასთან C ვიტამინის დანაკარგი შეადგენდა 40%-ს, ბუნებრივი შრობისას დაფიქსირებულ 82%-თან შედარებით. შეიძლება დავასკვნათ, რომ დანადგარი უზრუნველყოფს ენერგოდამზოგავ შრობას 30-55°C ტემპერატურულ დიაპაზონში. მისი გამოყენება 85-100%-ით ამცირებს ენერგოდანახარჯებს, მნიშვნელოვნად ამოკლებს გადამუშავების დროს და აუმჯობესებს საბოლოო პროდუქტის ხარისხს.

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