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Evaluation of algae drying process using a solar air dryer built from recycled materials

Evaluarea unui uscător solar cu aer, construit din materiale reciclate, pentru uscarea algelor

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Abstract. *This article presents a preliminary evaluation of a low-cost solar drying system, built entirely from recycled materials and tested for marine biomass applications. The experiment was set up using an air solar collector constructed from a reused window frame and a drying chamber housed inside a repurposed refrigerator. Tests were conducted on commercial wakame (Undaria pinnatifida) under forced convection, using a solar simulator with 2.0 kW halogen lamps. After 3.75 hours of system operation, a 47.2% reduction in mass was observed, from 477.7 g to 252.3 g. The recycled collector raised the drying air temperature by about 14...15°C above ambient, with a peak of 33.9°C and an air velocity of 0.5...0.6 m/s. The results show that the system is promising, but insulation and airflow need improvement to increase even further the drying air temperature.*

Key words: *solar drying, TSC, recycled materials, algae, energy efficiency*

1. Introduction

1.1 Background

Interest in algae applications is increasing worldwide due to the fact that they contain high levels of protein, minerals, antioxidants, and other important active compounds. These qualities make seaweed useful for many purposes, such as food, beauty products, medicine, and green energy. New studies show that seaweed is important for the production of sustainable and environmentally friendly products [1], [2]. However, the final product after extracting the substances necessary for cosmetics can be further used as algae pellets. In order to reach this format, the drying process is high energy consumer.

Undaria pinnatifida, which people call wakame, is one of the most eaten brown seaweeds globally. It has good nutritional value, including lipids, essential minerals, and

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pigments such as fucoxanthin [3], [4]. Wakame naturally has a high level of humidity, often more than 80%, fact generally common in the case of algae and from the point of view of elemental composition is similar with a vast range of algae species.

Drying, besides being a necessary process before transforming algae into pellets, is the most common way to keep seaweed fresh and prevent spoilage. If dried properly, seaweeds become safer to store, easier to move, and last longer. But the drying method can significantly alter important features, such as color, chemical composition, and antioxidant activity of the seaweed [5-7].

A number of drying methods are currently available for processing seaweeds, such as sun drying, hot-air drying, lyophilization, and microwave drying. While freeze-drying produces an excellent-quality product, the high cost makes it impractical for smaller producers. Hot-air drying is easy to manage but, over time, it can destroy sensitive compounds. Recent research on modern drying techniques has shown that they can alter the levels of pigments and antioxidants in wakame [8], [9].

Solar drying is an energy efficient alternative. By using renewable energy, the operational costs are cut down on. Studies suggest solar dryers can significantly speed up the drying process. Furthermore, they keep the material safe from dust and contamination [10], [11]. Researchers have already tested various types of solar systems, for example mixed-mode or forced-convection, for different seaweeds [12-14]. It is worth noting that the method has even been used successfully to dry microalgae [15].

In Romania, green seaweeds like *Ulva*, *Enteromorpha*, and *Cladophor*a are common along the Black Sea coast [16]. Although these species could be useful for supplements (nutraceutical) or industry, there are still very few studies about using solar dryers for marine algae in this specific region, as well as the possibility to valorize them in efficient burning equipment.

Studies on macroalgae drying show that moderate air velocity (about 0.3 to 2 m/s) works best, as it can efficiently remove moisture without overheating the biomass [17]. Still, there is very little information available on simple, low-cost solar collectors. Specifically, there is a lack of data on those built with recycled materials and tested in colder and temperate climates.

Because of these gaps in the research, the current study aims to investigate a low-cost solar air heater built from recycled materials for drying *Undaria pinnatifida*. The main goal is to understand how this system performs under controlled airflow and assess its potential for use in areas with variable sunlight, such as the Romanian region.

2. Methodology

2.1 Algae from Romania and target species

There are several types of seaweed that grow along the Romanian Black Sea coast, the most common being *Ulva lactuca, Enteromorpha intestinalis*, and

Cladophora vagabunda [16]. These algae contain numerous bioactive compounds such as polysaccharides, pigments, vitamins, and minerals. They are therefore considered promising sources for new nutraceutical products. Researchers are also studying polysaccharides from green algae, such as ulvan, for use in edible films and coatings for food packaging [18].

Due to climatic and seasonal conditions, Romanian green algae were not used in this experiment. Instead, *Undaria pinnatifida*, also known as wakame, was chosen as the model algae, a well-studied brown alga. *The goal of the study was to evaluate the time interval needed to reduce the mass to around 50% from the initial mass through drying*. It has a complex lipid profile, including many glycolipids and phospholipids, which makes it highly nutritious [3], [4]. Recent research has used wakame to compare different drying methods and their effects on pigments and antioxidant compounds [6-8], [19].

Wakame contains more than 80% water (very similar to other types of macroalgae), so it spoils quickly if not processed immediately after harvesting. This makes it a good material for testing new drying systems. In this project, the use of wakame is only the first step. Our main goal is to apply this solar dryer project to local green algae in Romania, after perfecting the system and, of course, during the appropriate season.

2.2 Solar air collectors for drying

Solar drying is tested for processing seaweed and other foods, as it relies on renewable energy and helps reduce costs. Studies show that solar dryers can dry algae faster and offer better protection against contamination than traditional sun drying [12-14]. Many projects use simple or recycled materials, making this technology easy for small producers to adopt [20], [21].

The effectiveness of the drying process depends mainly on temperature and air flow. Some studies on macroalgae suggest using temperatures between 40 ... 60 °C and moderate air flow rates of 0.3...2.0 m/s. These settings help to remove moisture efficiently without overheating the product or causing any type of degradation [17], [22]. Air speeds of 0.5 to 1.0 m/s are presented as a good balance between efficiency and energy use.

3. Experimental Set Up

The experimental drying setup is illustrated in Figure 1, comprising a solar air collector and a drying chamber. The detailed internal configuration of the chamber is shown in Figure 1(a), while the full assembled system can be seen in Figure 1(b). The controlled heat input was provided by a solar simulator, as depicted in Figure 1(c).

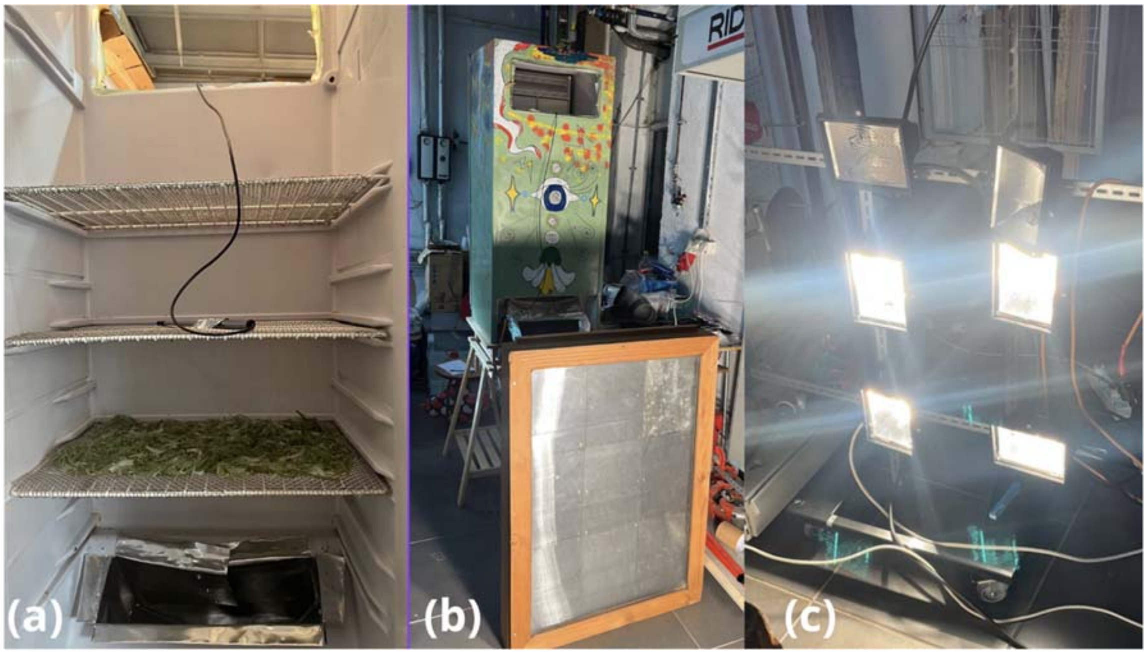

Fig. 1. Drying setup. (a) Interior of the drying chamber with seaweed samples on trays. (b) Overall view of the recycled solar dryer, showing the solar air collector and the drying chamber. (c) Halogen lamps used as a solar simulator to provide a controlled heat source.

3.1 Solar Air Collector (Recycled Window Frame)

The solar air collector was made from an old window frame, using a glass panel as the cover. The inside was painted black to absorb more heat. Air entered through a back lower opening, passed through the heated collector, and exited through an upper outlet into the drying chamber. This design warmed the air efficiently with sunlight or artificial light and kept the structure lightweight and inexpensive.

3.2 Drying Chamber (Repurposed Refrigerator Body)

The drying chamber was constructed from the body of an old refrigerator which is no longer in operation. All internal parts were removed or adapted as drying trays. In addition, insulation was applied to maintain a stable temperature during testing. The algae samples were spread in a single thin layer to ensure that air flowed evenly over the entire material. The fan speed was adjusted to maintain an air velocity in approximately 0.5 m/s inside the chamber (the recommended speed for gently and efficiently drying macroalgae), and the speed was measured with a Testo 410-2 pocket anemometer.

The dryier indoor temperature and velocity were measured using a Testo 425 hot wire anemometer. Moisture loss was determined gravimetrically.

3.3 Light Source (Solar Simulator)

To provide constant heat (in the absence of natural sunlight), four halogen lamps (J500-118 Ecolite, 500 W) were mounted above the collector. These lamps acted as a solar simulator, providing a constant heat source so that the system could operate under controlled and repeatable conditions, even indoors or when there was insufficient natural light.

3.4 Sample Preparation and Procedure

The experiment used a commercially available frozen algae salad mix comercially available. The product was brought to the room temperature and then rinsed three times with fresh water to remove oils and sugars [6], [23]. After the final wash, the seaweed was drained. The initial mass was measured, and the algae was spread evenly on the drying tray. The samples were weighed before and after drying to monitor moisture loss, which marked the end of the process.

4. Results and discussions

4.1 Drying Conditions

During the test, the air temperature entering the collector was mantained at 20±1°C. The temperature inside the drying chamber gradually increased during the process reaching 33.9 °C by the end of the test. This showed that the recycled system could raise the air temperature by roughly 14...15 °C above ambient air temperature. The air velocity inside the chamber remained stable at 0.5-0.6 m/s.

The total drying time was 3.75 h, achieved using the four 500 W halogen lamps to simulate sunlight.

4.2 Mass Loss of the Seaweed

Table 1 summarizes the main results for the single batch of commercial algae.

Table 1

Drying performance of the recycled solar dryer (single batch)

Parameter	Value
Initial mass, m_0 (g) Final mass, m_0 (g) Mass Loss, Δ_m (g)	477.7 252.3 225.4
Relative mass loss (%) Drying time (h)	47.2 3.75
Air temperature range (C)	28.7...33.9
Air velocity (m/s)	0.5...0.6

The relative mass loss was calculated using a simple gravimetric approach:

$$Mass\ loss\ (\%) = \frac{m_0 - m_f}{m_0} \times 100 \tag{1}$$

The system removed about 47% of the initial mass in 3.75 h. The results clearly show that the small, recycled stand successfully removed a significant amount of water from the biomass under mild drying conditions.

Visual analysis of the samples shown in Figure 2 confirms a mild alteration in the algae green color following the drying process. This change suggests that even the low air temperature range of 28.7...33.9°C employed was sufficient to affect the pigments of the wakame sample. This observation is relevant because the drying method, even at low temperatures, can affect the color and quality of the final product, a finding often discussed in the literature regarding pigment degradation [5], [6].

Figure 2. Comparison of the seaweed sample mass before and after drying. (a) Initial mass of the fresh sample (477.7 g) used for the experiment. (b) Final mass of the dried sample (252.3 g) after 3.75 hours of operation.

To reach the recommended 40...60°C range for algae drying, the optimum period is during summer, when the average temperature in Romania is around 30°C. By increasing the air temperature at the dryer inlet, the temperature around the algae will also rise. Additional improvements include using better insulation around all components of the setup and eliminating unsealed areas.

4.3 Practical Implications and Scalability

Even with these limits, the experiment shows that a low-cost dryer made from recycled materials can raise temperatures and effectively remove water from seaweed. Reusing a window frame as a collector and a refrigerator body as a chamber confirms that simple materials work well for drying applications to promote sustainability and smart recycling.

Although only one batch was tested, the stand's design allows more trays to be added inside the recycled refrigerator body. This means the system can be scaled up to process larger amounts by increasing the drying area. Future work will focus on improving insulation, testing the set up under real outdoor sun, and applying this method to local green macroalgae from the Romanian Black Sea coast or even invasive species present in lakes in Bucharest. After drying these products can be further used as pellets in thermal efficient burning equipment.

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