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Drying Process Development for Lignocellulosic Water Hyacinth Fibers: Design and Performance Evaluation of an Innovative Dryer Machine for Small-Scale Craft Industry

Khakam Ma'ruf [1], Rizal Justian Setiawan [2,*], Taufik Akbar [1], Rheina Khaisa Rhehani Putri [1], Zaky Ahmad Aditya [1], Afan Sutopo [1], Muhamad Yogi [1] and Yu-Tzu Chen [2]

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Highlights

What are the main findings?

- The developed dryer machine reduces drying time from approximately four days to 280 minutes while achieving a final moisture content below 10%, suitable for handicraft applications.
- The machine produces higher-quality fibers with lower residual moisture (9%) and eliminates unusable material caused by contamination, unlike manual drying which produces around 9.2% damaged fibers.
- Over extended operation (180 days), the dryer machine processes up to 7200 kg of wet water hyacinth compared to only about 4400 kg using manual drying, demonstrating significantly higher production capacity.

What are the implications of the main findings?

- Controlled drying technology ensures optimal moisture content, improving fiber flexibility, quality, and usability for handicraft production.
- Continuous and weather-independent operation significantly enhances production stability and scalability in small-scale industries.
- The utilization of water hyacinth supports sustainable and export-oriented production by converting invasive biomass into valuable handicraft products within a circular economy framework.

Abstract

Water hyacinth (Eichhornia crassipes) is an invasive aquatic plant with high lignocellulosic content, offering potential as a natural fiber resource for craft-based industries. However, its extremely high initial moisture content (≈95%) presents a major challenge in fiber processing, particularly for small-scale industries that rely on traditional sun-drying methods. These methods are highly dependent on weather conditions, prone to contamination, and produce inconsistent fiber quality. This study adopts a research and development (R&D) approach to design and evaluate an innovative dryer machine specifically for water hyacinth fiber processing. The proposed system utilizes LPG-based heating and controlled airflow to achieve stable drying conditions. Experimental results show that the dryer machine can process 10 kg of wet water hyacinth within 280 minutes, significantly shorter than approximately four days required for manual drying. The system reduces the moisture content to below 10%, resulting in improved fiber cleanliness, uniformity, and usability. Although the dried mass produced by the machine is slightly lower compared to manual drying, this is attributed to more effective moisture removal, leading to lower residual water content in the final product.

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Productivity analysis indicates improved operational consistency and higher processing capacity over extended periods (30–180 days), particularly under varying weather conditions. These findings demonstrate that controlled drying technology provides a reliable and efficient solution for lignocellulosic fiber processing in small-scale industries, contributing to improved material utilization and sustainable biomass management.

Keywords: crafts; craftsmen; dryer machine; fiber; water hyacinth

1. Introduction

Natural fibers are parts of plants that can be transformed into valuable products for daily life. Moreover, numerous types of natural fibers can be utilized across creative industries such as handicrafts to earn profits [1–3]. One fiber that can be used for crafts is water hyacinth [4], which is generally classified as a weed due to its reducing oxygen levels for fish [5], blocking waterways [6], limiting boat traffic [7], creating an ideal habitat for disease-carrying mosquitoes [8], and can be utilized as a craft product that holds considerable economic value [9–11].

Water hyacinth *(Eichhornia crassipes)* is a lignocellulosic biomass composed primarily of cellulose, hemicellulose, and lignin, which are the principal structural components of most plant-based fibers [12,13]. Previous studies have reported that water hyacinth exhibits relatively high cellulose content, indicating its suitability for fiber-based applications such as handicrafts and woven products [4,14]. Despite this potential, the utilization of water hyacinth fibers is severely constrained by their extremely high moisture content, which can exceed 90% on a wet basis [14,15].

In lignocellulosic material processing, drying is recognized as a fundamental preprocessing step that directly affects storage stability, biological durability, and fiber usability [16,17]. Insufficient or uncontrolled drying may promote microbial degradation, surface contamination, and non-uniform moisture distribution, ultimately reducing material quality and limiting downstream processing performance. These challenges are particularly pronounced in small-scale production systems where drying is often conducted outdoors under uncontrolled environmental conditions.

In Indonesia, several areas have very abundant water hyacinths The reservoir area in Walahar Village, Karawang Regency, West Java is one of the centers for crafting water hyacinth fiber into functional products like bags, hats, photo frames, pencil cases, and others [18]. Since there are around 20-30 tons of water hyacinths lifted from the river and lake every year by the local government [19–21]. The abundance of water hyacinths has led many residents to build handicraft businesses using water hyacinths.

This resource is a source of income for Small and Medium Enterprises (SMEs) in local communities of up to hundreds of millions of rupiah per month [22]. Apart from being sold throughout Indonesia, this craft is exported to Europe [23,24]. One of the water hyacinth craftsmen in Walahar Village stated that they could get an order for 500 water hyacinth goody bags in a month. This order not only comes from Indonesia but also from abroad such as Russia, Saudi Arabia, and Madagascar [25]. However, the process of drying water hyacinth raw materials is still conducted manually, which sometimes hampers productivity.

Currently, water hyacinth fiber is produced by sun-drying freshwater hyacinth for about four days [15]. During the rainy season, the process of producing water hyacinth fiber can be hindered as more clouds tend to cover the incoming sunlight. This poses a challenge for craftsmen and requires a solution to overcome the obstacle and ensure optimal production of fiber [26]. The fluctuating manual drying time and the uncontrollable outdoor environment make the inconsistent quality and productivity of fibers. Therefore, the researchers used the R&D method to develop a drying machine that provides consistent and improved drying methods with technology.

Regarding drying technology for water hyacinth fiber, there is currently a lack of research specifically focused on the development or fabrication of dryer machines tailored for this material. Existing literature primarily centers on the design and manufacture of dryers for other fiber materials.

Due to there are no prior studies dedicated to water hyacinth dryer machine, this study draws upon existing research on drying technologies for other plant-based materials such as bamboo and leaves. A comparative analysis of six dryer machine models, including respective advantages and limitations, is presented in Table 1.

Table 1. Previous Research regarding Fiber Dryer Machine.

Dryer Model	Advantages	Limitations	References
Greenhouse Dryer	• Does not require high operational costs • Hybrid energy	• Requires a large area (20m²) • Dependent on weather • Long drying time (2 days) • High initial cost	[27]
Oven	• Flexibility in operation • Proven to increase productivity • Removes moisture content	• The machine only tested to dry hard fibers with less moisture content (bamboo) • Overheating may take place because there is no control for the blower • Heat distribution is not comprehensive	[28,29]
Cabinet and Chamber	• Simplicity of construction • Good drying conditions for grains requiring long and not too intensive drying • Low price of construction	• Unevenness of the drying process in different parts of the dryer • Long drying time • Significant heat loss during loading and unloading	[30,31]
Rotary Model	• High versatility of applications • High thermal efficiency • Uniform temperature distribution	• Costly in manufacturing and operation • Machine size is too large for SME	[32,33]
Bed dryers	• Possibility of drying grains or fibers with large diameters • Facilitating drying of easily agglomerating grains • Possibility to work in a batch and continuous mode moving part	• Limited bed height (for apparatuses without the draft tube) • Due to intensive circulation possible damage to grains with low mechanical strength	[34,35]
Belt convective dryers	• Uniformity of drying for crossflow dryers • No dust formation or material crumbling • Easy adjustment of process conditions and plant performance	• Unevenness of drying in the dryers with the gas flow along the bed • Large air pressure drops in the dryers with the gas flow through the bed	[36,37]

These references can be utilized for the development of water hyacinth dryer machines, serving as a guide and benchmark for researchers to create suitable fiber drying machines for water hyacinths. The water hyacinth fiber drying machine created is a technological innovation developed specifically to dry water hyacinth material effectively and efficiently. Designed with an optimal temperature and air circulation control system, this machine ensures fiber drying without damaging its natural structure. Equipped with IoT-integrated humidity parameters and temperature control, this technology allows real-time monitoring during the drying process. This development is expected to answer the unique challenges faced by Indonesian MSMEs in processing water hyacinth content. By optimizing drying time and quality consistency, this machine increases production efficiency and end product quality for the water hyacinth-based craft industry.

2. Methods

Drying plays a critical role in lignocellulosic fiber processing, as moisture reduction influences fiber flexibility, surface condition, and resistance to biological degradation [12,16]. For natural fibers intended for craft and textile-related applications, controlled drying conditions are essential to preserve fiber integrity and ensure consistent quality prior to further processing such as weaving or dyeing [17]. Accordingly, the design of the proposed drying system prioritizes stable thermal conditions and uniform air circulation to facilitate controlled moisture removal while maintaining the structural characteristics of lignocellulosic water hyacinth fibers.

This study employs the Research and Development (R&D) approach to design, create, and test a research-based product [38]. The R&D method in developing a dryer machine was based on research on making dryer machines for other fibers that had been conducted previously by Efendi et al. [39] and Pavan and Avinash [40] and generated in the flowchart shown in Figure 1.

Figure 1. Flowchart of Development Stages for Dryer Machine.

2.1. Problem Definition

Drying water hyacinth fibers using manual methods has many disadvantages as explained in the previous section. To thoroughly understand the problem, researchers conduct a survey with 48 respondents in Walahar Village, Karawang Regency, West Java Province, Republic of Indonesia.

Table 2 shows the demographics of the respondents collected. Researchers collected data by distributing the questionnaire. Respondents were selected who were aged 18 years or over, owned a water hyacinth fiber craft business, and/or worked as water hyacinth craftsmen in Walahar Village.

Table 2. Respondents Demographic.

Characteristics	Category	Amount	Percentage
Gender	Female	29	60.4%
	Male	19	39.6%
Age	18 – 27 years old	5	10.4%
	28 – 37 years old	23	47.9%
	38 – 47 years old	13	27.1%
	48 – 57 years old	6	12.5%
	≥ 58 years old	1	2.1%
Experience as a Water Hyacinth Craftsman	< 3 years	15	31.3%
	3 – 6 years	14	29.2%
	6 – 9 years	8	16.7%
	9 – 12 years	5	10.4%
	> 12 years	6	12.5%

At this stage, the type of questionnaire designed with a three-point Likert scale is distributed to know the responses of respondents regarding the manual method drying process. The questionnaire is based on two aspects, including satisfaction with manual drying methods and drying technology needs with three options such as satisfied, doubtful, and not satisfied for satisfaction aspect. Then, for drying technology needs, three options including yes, doubtful, and no.

The satisfactory survey of the current manual drying method shown in Figure 2(left) indicates 56.3% unsatisfied craftsmen, 33.3% satisfied, and 10.4% neutral responses. This indicates that only 1/3 of respondents are satisfied with the manual drying method. Moreover, during the face-to-face interviews. most fiber craftsmen in Walahar stated problems with the manual drying method including drying using manual methods takes a long time, unstable weather conditions, dirt or mold sticking to it, and ergonomic problems. The survey on the need for the new technology in drying machines results shown in Figure 2(right), there were 81.3% of respondents stated that they needed fiber drying technology, in respect to only 2.1% unnecessary to utilize technology and 16.7% neutral responses. The results of this survey prove that most of the craftsmen at the research location think that technology can make it easier for them to dry water hyacinths. Based on the results of these two surveys, it can be concluded that craftsmen are not satisfied with manual drying and think that technology is needed to make their work easier.

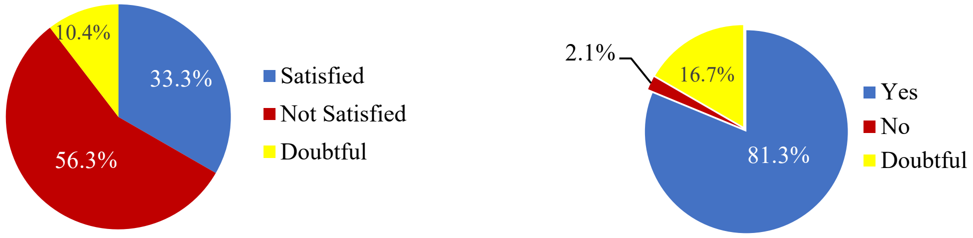

Figure 2. Satisfaction Survey with Manual Drying Methods (Left); and Survey of Drying Technology Needs at Research Locations (Right).

2.2. Literature Review and Studies

In developing a dryer machine to dry water hyacinth fibers, researchers consider the research steps and components that will be used based on references from previous research. The dryer machine technology to be developed must meet several criteria such as better quality and quality control, lower costs (operation, maintenance, and capital), and shorter processing times than current conditions [31]. Apart from that, researchers also analyzed shortcomings in previous research to eliminate ineffective steps or components for machine development. Although these references are not case studies for creating water hyacinth dryers, but for other materials, these references are very

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important to consider. A summary of the references used by researchers to compile the steps and components of the drying machine prototype is shown in Table 3.

Table 3. Dryer Machine Specifications.

No	Description	Specification	Reference
1	Research Stages	Five Stages (Problem definition, literature review and studies, design, manufacturing, testing)	[39,40]
2	Machine Shape	Rotary	[32,33]
3	Heat Source	LPG Cylinder	[29,41,42]
4	Machine Material	Mild Steel	[28,29]
5	Electrical Energy Sources	Grid	[29,30]
6	Mechanical Drive	Motor, V-Belt, and Pulley	[32,40,43]
7	Capacity	10,000 grams	[44]
8	Thermometer	Analog thermometer	[29,30]
9	Color	Green	Water hyacinth's color
10	Control	Electrical Panel	[31]
11	Burner / Stove	One Gas Burner / Stove	[31]

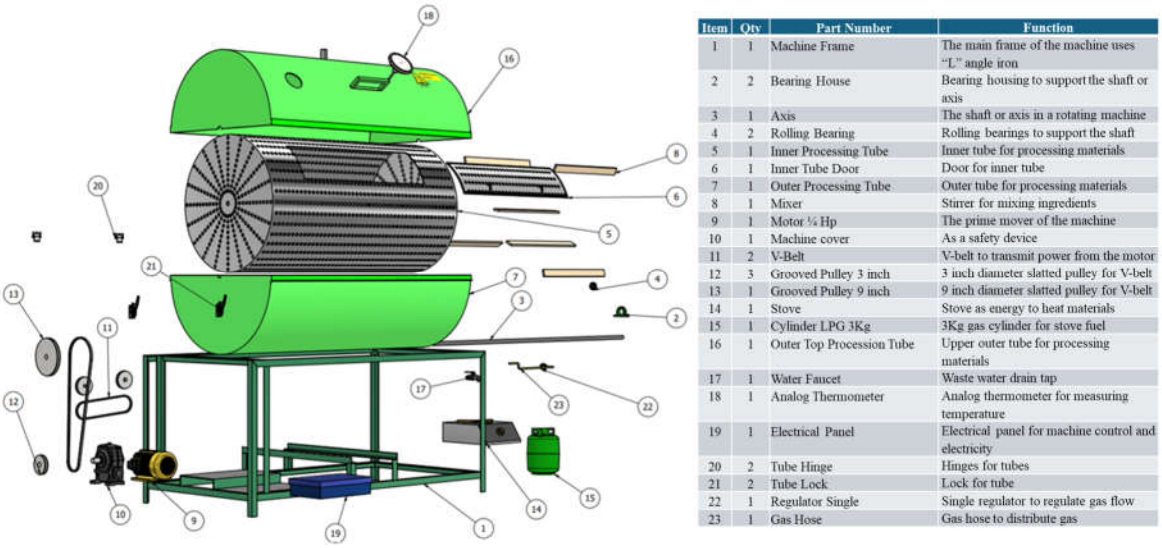
2.3. Design

The prototype dryer machine is then in the design stage consisting of hardware design and software design.

2.3.1. Hardware Design

Hardware in this machine is a physical component of a dryer consisting of mechanical, structural, and electrical system parts that form the main framework and function of the machine. These elements include the machine frame, drive motor, heating system, fan, sensor, and other supporting components that work together to produce an efficient and effective drying process according to predetermined specifications.

The principles of hardware design for the prototype refer to the specifications presented in Table 3. In the hardware design, the machine is drawn using the Autodesk Inventor application. Making hardware designs includes two-dimensional and three-dimensional drawings. Two-dimensional drawings are used for machine manufacturing execution and three-dimensional drawings are used for machine visualization. The hardware components of the water hyacinth dryer machine are presented in the detailed design shown in Figure 3, with a comprehensive description of each component and its respective function provided.



Item	Qty	Part Number	Function
1	1	Machine Frame	The main frame of the machine uses "L" angle iron
2	2	Bearing House	Bearing housing to support the shaft or axis
3	1	Axis	The shaft or axis in a rotating machine
4	2	Rolling Bearing	Rolling bearings to support the shaft
5	1	Inner Processing Tube	Inner tube for processing materials
6	1	Inner Tube Door	Door for inner tube
7	1	Outer Processing Tube	Outer tube for processing materials
8	1	Mixer	Stirrer for mixing ingredients
9	1	Motor ¼ Hp	The prime mover of the machine
10	1	Machine cover	As a safety device
11	2	V-Belt	V-belt to transmit power from the motor
12	3	Grooved Pulley 3 inch	3 inch diameter slatted pulley for V-belt
13	1	Grooved Pulley 9 inch	9 inch diameter slatted pulley for V-belt
14	1	Stove	Stove as energy to heat materials
15	1	Cylinder LPG 3Kg	3Kg gas cylinder for stove fuel
16	1	Outer Top Procession Tube	Upper outer tube for processing materials
17	1	Water Faucet	Waste water drain tap
18	1	Analog Thermometer	Analog thermometer for measuring temperature
19	1	Electrical Panel	Electrical panel for machine control and electricity
20	2	Tube Hinge	Hinges for tubes
21	2	Tube Lock	Lock for tube
22	1	Regulator Single	Single regulator to regulate gas flow
23	1	Gas Hose	Gas hose to distribute gas

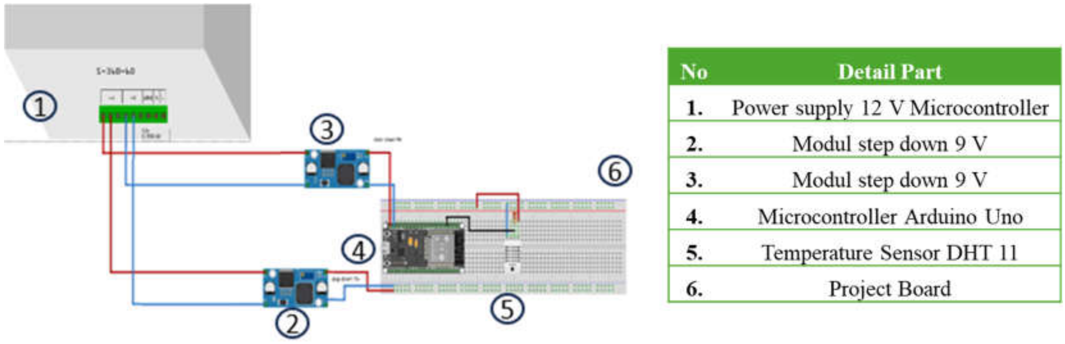
Figure 3. 3D Hardware Design of Water Hyacinth Dryer Machine.

2.3.2. Software Design

The software on this machine is a collection of programs and instructions that control the operation of the dryer. The software acts as the machine's brain that processes data from sensors, sets operating times, controls temperature and humidity, and coordinates hardware functions. Through a graphical user interface (GUI), the software allows the operator to monitor the condition of the machine, set drying parameters, and obtain real-time data on the ongoing process, thereby increasing the efficiency and ease of operation of the machine.

At the software design stage, programming is done using the Arduino IDE application, which is connected to a Graphical User Interface (GUI) system. This GUI system contains a program to read the time, temperature, and humidity of the dryer machine. The GUI interface helps in interfacing the device with the microcontroller so that it can be integrated as expected. Once the programming process is complete, the software for the electronic system working circuit is designed.

This stage includes assembling the electronic components of the device, such as the ESP 32 microcontroller, power supply, and DHT 22 temperature sensor. It is important to pay attention to the connections and circuit paths during the assembly process, as any errors can cause the data to be unreadable and the system to be damaged due to a circuit short circuit. To avoid errors in the circuit, it is necessary to first create a circuit design using the Thinkercad web, as shown in Figure 4 and the explanation of the software components for the prototype dryer machine is also provided.



No	Detail Part
1.	Power supply 12 V Microcontroller
2.	Modul step down 9 V
3.	Modul step down 9 V
4.	Microcontroller Arduino Uno
5.	Temperature Sensor DHT 11
6.	Project Board

Figure 4. Software Design of Dryer Machine.

2.4. Manufacturing

The manufacturing process of the water hyacinth drying machine involves the assembly of hardware components and the integration of software systems into the machine structure. This stage is conducted systematically and is divided into four main sub-stages, those were cutting and forming the frame, welding and joining, assembling the drive and heating system, and installing a microcontroller-based control system. In this process, various equipment is used, such as a 13mm 600W electric drill for drilling the frame, a plate bending machine for forming metal materials, a 400W grinding machine with a 4-inch blade to smooth the surface, and SMAW and MIG welding machines to unite the components. Precision measurements are carried out using angle rulers, magnetic squares, markers, and meters so that the machine structure is stable and functions optimally.

2.4.1. Measuring and Cutting

The first sub-stage is measuring and cutting iron plates and "L" angle irons to be used as production containers and machine frames shown in Figure 5a.

2.4.2. Welding

The second sub-stage is the welding sub-stage to connect the iron components such as plates and frames shown in Figure 5b.

2.4.3. Drilling and Painting

The third is the drilling and painting sub-stage shown in Figure 5c. Drilling is performed on the outer processing tube and frame to facilitate the installation of bearings. Bearings are put in place to minimize friction between moving parts on the machine, such as shafts and motors. Additionally, painting activities involve painting the plates and frames with green anti-rust iron paint.

2.4.4. Assembling

The final sub-stage is the assembling as shown in Figure 5d. This activity is started by assembling the pulley, v-belt, shaft, and electric motor into a unit as a transmission to rotate the tube. Then, the second assembling activity is conducted on the LPG cylinder, gas hose, and stove as the heat source. The last assembly activity is the electrical panel assembly.

(a) **(b)** **(c)** **(d)**

Figure 5. Manufacturing Process of Water Hyacinth Dryer Machine.

After the manufacturing and assembly processes have been completed, the complete appearance of the dryer machine prototype can be seen in Figure 6.

Figure 6. Final Product of dryer machine.

2.5. Testing

Researching with several references, several performance indicators will be considered in testing the prototype dryer machine. The overall performance indicators of the machine are assessed by comparing the results of the manual method with the results of the drying machine, so that the increase in efficiency and quality obtained by the machine can be identified. The properties of the dryer, such as heat distribution, air circulation, holding capacity, and energy consumption, directly affect the five performance indicators above. Measurement with the right measuring instrument ensures that the results obtained are more accurate and reliable for evaluating machine performance, as shown in Table 4. In addition, measurements with measuring tools are useful to ensure the results obtained are more accurate.

Table 4. List of Testing Items for Performance Test.

No	Testing Items	Measuring Tools	References
1	Drying Time and Temperature	Stopwatch and Machine Timer	[14,45,46]
2	Drying Temperature	Analog Thermometer and Temperature Sensor	[47,48]
3	Fiber Moisture Content	Moisture Meter	[14,49,50]
4	Fiber Productivity	Digital Weighing Scale	[51,52]
5	Fiber Quality	Visual Observation	[53,54]

To evaluate the moisture content, the sample weight was measured with the digital scales, and the Moisture Content (MC) was calculated at different durations using the initial MC and the weight as shown in the following Equation 1 [45].

$$MC = 100(-\frac{\mathrm{IW}}{\mathrm{Wt}}\left(1-\frac{\mathrm{IMC}}{100}\right)) \tag{1}$$

where MC is moisture content, IW is the initial weight of the sample, Wt is the weight of the sample at a time t, and IMC is the initial mc of the sample expressed on a wet basis. The water hyacinth drying time can be declared complete if the water hyacinth moisture content has been reduced to <10% [15,55].

The mathematical equation for the relationship between drying time and temperature was examined to determine the efficacy of adjusting the drying temperature [46]. For this purpose, a model was created using Equation 2 [45].

$$MR = \frac{\mathrm{Mt}}{\mathrm{Mo}} = \exp[-k(t-to)] \tag{2}$$

where MR is moisture ratio, M_t is moisture content when dry based on time, M_o is initial moisture content on a dry basis time t_o, k is drying rate (h^{-1}), $(t - t_o)$ is the duration of drying time (h).

To evaluate the performance of the drying machine, a comparative testing approach was employed, contrasting its operation with the conventional manual drying method. This comparison facilitated the identification of improvements in efficiency and product quality attributable to the mechanized system. Key design attributes of the dryer, namely heat distribution, air circulation, holding capacity, and energy consumption were analyzed, as these factors directly influence the five performance indicators summarized in Table 1.

Temperature measurements of the drying process were obtained using a calibrated IoT-based DHT22 temperature and humidity sensor. Real-time data collection was conducted through a data logging system, enabling continuous monitoring. The recorded data were further analyzed using statistical and mathematical modeling software, based on Equations 1 and 2. All parameters were measured in triplicate at predetermined time intervals to ensure data validity and reliability. The integration of software-based monitoring and analysis provided a robust framework for objectively and quantitatively assessing the drying machine’s performance in terms of efficiency and output quality.

3. Results

3.1. Drying Time

Drying time is the time the drying method requires to dry the water hyacinth stem until it can be used as a basic material for handicrafts or when it has a moisture content below 10%. Using direct sunlight can be used as a manual method as seen in Figure 7(a) and 7(b). Drying in this method can be conducted on mats, wood, grass, or soil. However, this method requires a very long drying time. When conditions are sunny, the time needed to dry the water hyacinth stems is around 4 days or 5,760 minutes. This duration will be even longer during the rainy season. The ineffectiveness and inefficiency of drying using manual methods is an opportunity to create technology that can shorten drying time. In this study, the use of a dryer machine to produce dried water hyacinth can be seen in Figure 7(c) and 7(d). In Figure 7(c) there is water hyacinth before being put into the machine and in Figure 7(d) there is water hyacinth that has been dried.


(a) (b) (c) (d)

Figure 7. Manual drying method, (a) Before drying; (b) After drying and Drying using Machine, (c) Before drying; (d) After drying.

To evaluate the technology that has been developed, trials and evaluations were conducted on drying water hyacinth. Evaluation is conducted by comparing the drying results between the manual method and the dryer machine based on several observed parameters. This comparison aims to assess the extent to which the developed tool can work optimally, efficiently, and superior to conventional methods. Table 5 shows the comparison results of drying using the two methods. The water hyacinth stems used are divided into two weights, namely 5kg and 10kg.

Table 5. Water Hyacinth Drying Time.

Load of Water Hyacinth (kg)	Manual Method* (Mins)	Dryer Machine (Mins)
5	5,760	200
10	5,760	280

*: Drying using the manual method requires the same process time without considering the quantity.

According to the result, the manual method takes four days or 5,760 minutes to produce dried water hyacinth suitable for crafting, with capacity having no impact on the drying process. On the other hand, a dryer machine is capable of more rapid processing. It takes 200 minutes to process 5kg of water hyacinth and 280 minutes for 10kg. Processing 10kg of wet water hyacinth using the machine can be finished faster because it utilizes the maximum capacity of the machine.

3.2. Drying Temperature

Drying time is directly related to the temperature of the process. Temperature measurements were conducted during the drying process to determine the maximum temperature achievable using the manual method and prototype dryer machines. In Figure 8, it is shown that the manual method, which utilizes sunlight for heat, maintains a stable temperature of around 32-35 degrees Celsius in sunny conditions.

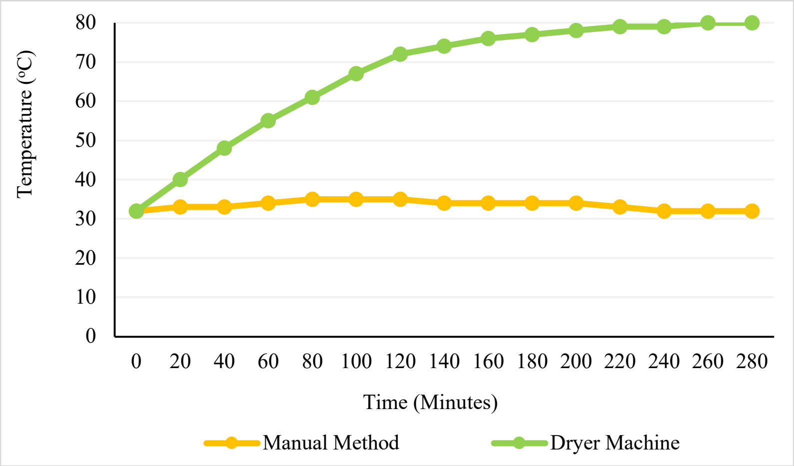


Figure 8. Drying Temperature.

On the other hand, dryer machine can produce higher temperatures. After 20 minutes of operation, the temperature produced by this machine exceeded those of the manual method. The temperatures of this machine reach the maximum after 120-280 minutes of operation. At these minutes, the temperature stabilizes at its peak around 72°C - 80°C , indicating that this is when the machine reaches optimal drying temperature.

The temperature measurements are conducted using an analog thermometer. The dryer machine is equipped with a DHT22 temperature sensor that can measure temperature and display it on an LCD. For the example, in 280-minute temperature, when comparing its readings to those of an analog thermometer, the sensor showed a temperature of 79.7°C while the thermometer displayed 80°C, resulting in a difference of 0.3°C.

3.3. Fiber Moisture Content Analysis

The wet water hyacinth stems contain moisture content of ± 95%. Drying water hyacinth using sunlight with an average radiation temperature of 28 – 35°C has an average decrease in moisture content of 20.75% in one day. The initial specimen of water hyacinth before drying had a moisture content of 95%, after drying for 4 days the water hyacinth specimen had a moisture content of 12%. Based on the results of checking with a moisture meter, a drastic decrease occurred from day 0 to day 1.

On the other hand, drying using a dryer machine is more effective. Referring to the results of checking water hyacinth content which are visualized in Figure 9, with a load of 5kg of material, a dryer machine can produce dry water hyacinth in 200 minutes. Meanwhile, with a load of 10 kg of material or full capacity, dry water hyacinth can be produced in 280 minutes. A drastic decrease occurred during the drying process from 80 minutes to 160 minutes. Water hyacinth experienced a weight loss of 94.5% after the drying process using a dryer machine was conducted. The results of checking with a moisture meter and calculations show that the implementation of a dryer machine has been able to reduce the water hyacinth content to less than 10%. The drying process was considered complete when the moisture content reached around 8-10%, which is suitable for lignocellulosic fiber applications.

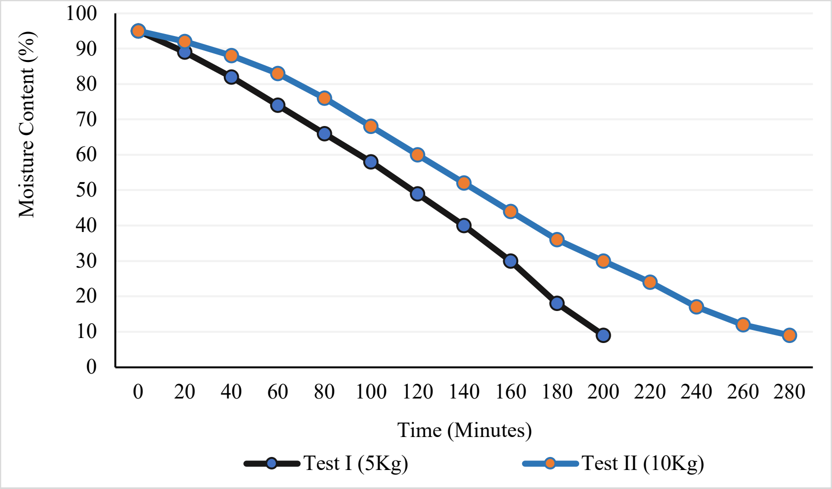


Figure 9. Moisture Content Reduction Using Dryer Machine.

For lignocellulosic fibers like water hyacinth, 9% is optimal because excessively low moisture content is detrimental to fiber quality, particularly when it falls below approximately 7%. At such low moisture levels, fibers lose internal bound water that acts as a plasticizing agent within the cellulose structure, resulting in reduced flexibility and increased rigidity. Consequently, the fibers become brittle and more susceptible to fracture during mechanical handling and weaving processes. Previous studies have demonstrated that cotton fibers processed at low moisture content exhibit reduced strength, increased fiber damage, and higher breakage rates, with optimal processing typically occurring above 6–7% moisture content. Furthermore, insufficient moisture leads to fiber fracture characteristics associated with brittle failure and deterioration of mechanical performance during processing. Therefore, maintaining moisture content above this threshold is essential to preserve flexibility, structural integrity, and overall usability of natural fibers in downstream applications such as handicrafts and textile production [56,57].

3.4. Fiber Productivity

In the test conducted, the average production time for water hyacinth with manual drying method typically takes four days. To compare the productivity of drying with the manual method and dryer machine, the four days were used as consideration. This test aims to compare the amount of water hyacinth that can be processed and dried within the same time duration. During the test, the weather conditions in four days were sunny all day and night, with no rain and no drizzle. If the conditions are rainy season, drying using the manual method will take more than four days.

In this study, each drying cycle was conducted using a loading capacity of 10 kg of wet water hyacinth, which corresponds to the designed capacity of the dryer machine. With a drying duration of 280 minutes per cycle, the system requires a total operating time of 1120 minutes to complete four consecutive cycles within a 24-hour period. This operational setting results in a daily processing capacity of 40 kg of raw water hyacinth material. The remaining time of 320 minutes is allocated for break, loading and unloading between cycles, system cooling, and routine inspection. This operational pattern demonstrates that the dryer machine can operate in a near-continuous manner while maintaining stable performance. Then, also reflects practical and feasible working conditions small-scale craft industries that rely on batch-based processing systems.

As shown in Figure 10, the Y-axis depicts the amount of water hyacinth fiber in kilograms (kg), both in wet and dry conditions. This axis is used to measure the volume of water hyacinth processed and produced from two drying methods, namely manual and using a dryer machine, at three different time periods such as 4 days, 30 days, 90 days, and 180 days. Productivity in this context is determined based on the ratio between the amount of dry water hyacinth produced to a certain processing time and condition. By comparing the amount of dry output obtained at the same time, it can be analyzed which method is more efficient.

The test results, visualized in Figure 10, show that within 4 days, the manual drying method can process 160 kg of water hyacinth and produce 9.1 kg of dried material suitable for crafts. In comparison, the dryer machine can process the same amount (160 kg) and produce 8.8 kg of dried water hyacinth. Although the resulting dry mass from the dryer machine appears slightly lower, this difference is attributed to the lower final moisture content achieved by the machine. The controlled drying system reduces the moisture content to approximately 9%, whereas manual sun drying typically retains around 12% moisture, resulting in a higher apparent weight due to residual water. Therefore, the dryer machine provides more effective moisture removal and produces fibers with lower moisture content and improved quality, even though the final mass is slightly lower.

If production process comparisons are conducted over a short period, such as four days, the differences in production output are negligible. However, extending the observation period to a longer duration reveals more pronounced differences in production outcomes. As shown in Figure 10, the results of a month or 30-day experimental trial highlight these disparities. Over the trial period, six days experienced rainfall during daytime hours, rendering manual drying infeasible on those occasions and restricting the processing to only 900 kilograms of wet water hyacinth. Conversely, the drying process utilizing a dryer machine remained operational despite the rainy conditions, enabling the processing of a greater volume of wet water hyacinth, amounting to 1,200 kilograms. Moreover, the dryer machine produced 66.3 kilograms of dried water hyacinth over the 30-day period, compared to only 51.19 kilograms achieved through manual drying.

Productivity testing was extended to a longer duration of 90 days and 180 days, equivalent to three and six months. The unpredictable weather conditions during this period led to irregularities in the drying process and fluctuations in water hyacinth productivity. In contrast, the production process utilizing a dryer machine maintained consistent performance. As illustrated in Figure 10, the production volumes achieved through manual drying, and the dryer machine revealed a substantial disparity. Based on this, within 180 days, manual drying can only process approximately 4400 kg of wet water hyacinth, whereas the dryer machine is capable of processing up to 7200 kg under continuous operation. This results in significantly higher dried output from the machine compared to the manual method. These findings highlight that the primary advantage of the dryer machine lies not only in faster drying time but also in its ability to sustain continuous and weather-independent operation, leading to substantially higher overall productivity in long-term applications.

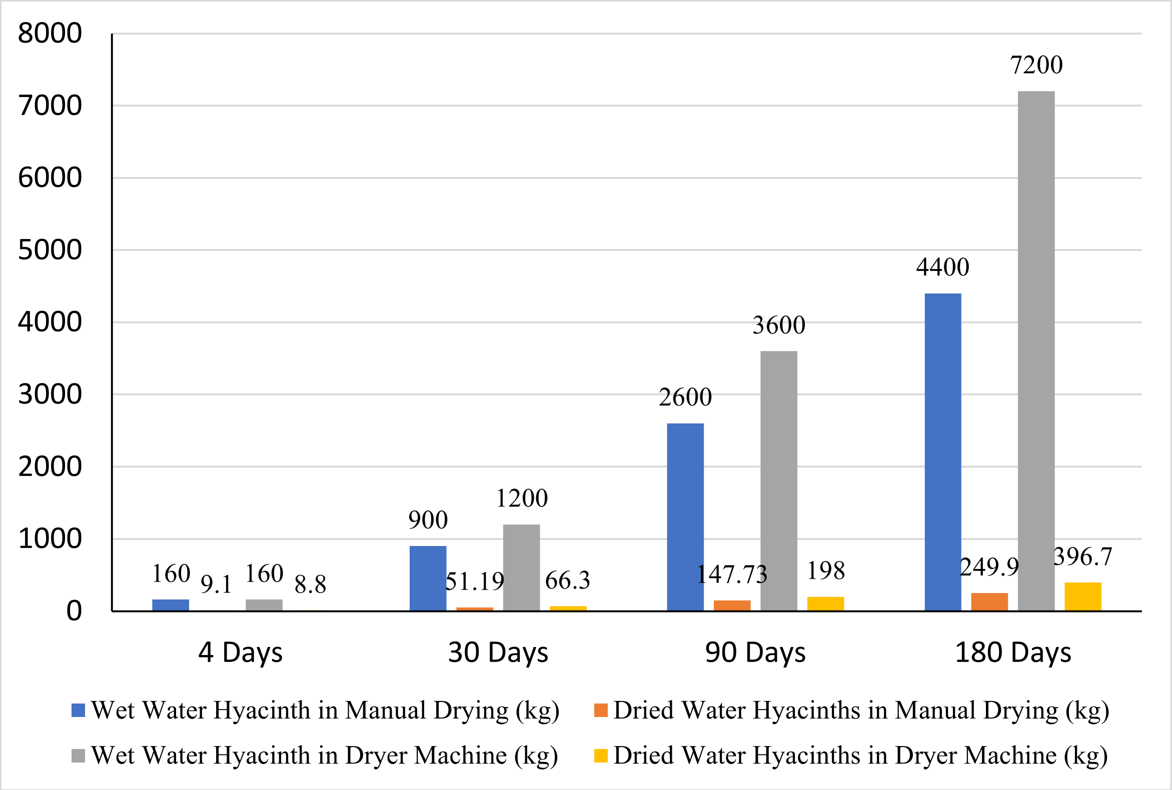


Figure 10. Productivity Comparison on trial for 4 days, 30 days, 90 days, and 180 days.

Based on the graphic in Figure 10., although the amount of dried material produced by the dryer machine appears slightly lower than that obtained through manual drying during the initial four-day period, this difference is primarily attributed to the lower final moisture content achieved by the machine. The drying system reduces the moisture content to 9%, whereas manual sun drying typically reaches around 12%, resulting in a slightly higher final weight due to retained moisture. Furthermore, over short operational periods, the difference in productivity between the two methods remains relatively small. However, over extended periods, the advantages of the drying machine become more significant due to its consistent operation and independence from weather conditions, leading to higher overall productivity.

3.5. Fiber Quality Analysis

Water hyacinth experiences changes in texture and color after drying. The water hyacinth stem has a stiff texture and is green, but after it goes through the drying stage, its texture becomes more flexible and less stiff, and its color changes to a slightly brown hue. These changes in texture and color are caused by the reduced moisture content of the water hyacinth after it has been dried. In Figure 11 there is documentation of the differences between water hyacinths dried using the manual method and water hyacinths dried by machine.

In terms of quality, the use of a dryer machine produces clean water hyacinth fibers without any dirt or dust stuck to the stems as seen in Figure 11b. Meanwhile, when drying using the manual method, several samples of water hyacinth stems had a dark color and looked a bit dirty as seen in Figure 11a. This result is worse than drying using a machine that produces fiber without mold or dirt, and the quality of the water hyacinth produced has a brighter color and a clean surface. Drying using the manual method results in the water hyacinth being easily exposed to dust, dirt, and mold, which is a factor in reducing the quality of the fiber.

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(a) (b)

Figure 11. Results of Dried Water Hyacinth, (a) Using Manual Method; (b) Using Dryer Machine.

Dried water hyacinth stems that are dirty and damaged because they are filled with dust or mold cannot be used to make crafts because water hyacinth is very difficult to color. After separating the unusable dried water hyacinth from the usable dried water hyacinth, researchers found that approximately 0.84 kg of unusable dried water hyacinth was obtained from the 9.1 kg of dried water hyacinth produced during manual drying. This means that about 9.2% of the dried water hyacinth cannot be used or further processed into crafts. However, zero or no unusable dried water hyacinth was found in the material processed using a dryer machine. Zero unusable dried water hyacinth saves raw material losses and minimizes financial losses for craftsmen. As depicted in the graph in Figure 12, the data shows that using machines successfully eliminates the threat of external dust and dirt during the drying process.

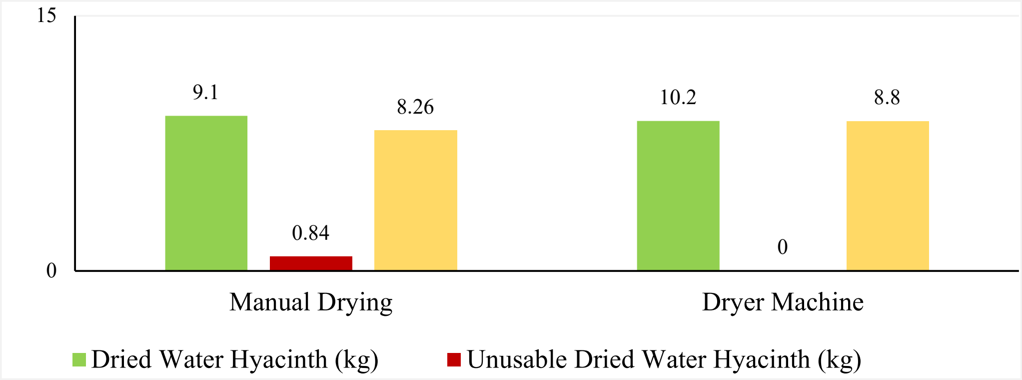

Figure 12. Analysis of Unusable Dried Water Hyacinth in 4 Days of Production.

Moreover, the Y-axis in Figure 12 shows the weight of dried water hyacinth (in kilograms), which is divided into three categories, namely dried water hyacinth (usable dried water hyacinth) shown in light green, unusable dried water hyacinth (unusable dried water hyacinth due to damage) shown in red, and total of fiber that can be used shown in purple. This figure shows the productivity of the two drying methods. Productivity is determined based on the amount of dried water hyacinth that is suitable for use and can be processed into crafts. In the manual method, out of a total of 9.1 kg of dried water hyacinth, 0.84 kg cannot be used. In contrast, the use of a drying machine produces 8.8 kg of dried water hyacinth without any unusable material, indicating higher efficiency in maintaining material quality.

The improvements observed in fiber cleanliness, flexibility, and color uniformity can be directly attributed to controlled moisture reduction during the drying process. In lignocellulosic fibers, excessive or uneven drying may lead to surface contamination, discoloration, and partial structural degradation, reducing material suitability for craft applications [17,53]. The controlled drying environment provided by the developed system minimizes exposure to dust and biological contaminants, thereby preserving fiber surface quality and enhancing usability for downstream craft processing.

3.6. Implications for Lignocellulosic Fiber Processing in Small-Scale Industries

From a lignocellulosic materials perspective, the results of this study demonstrate that drying constitutes a decisive preprocessing stage in enabling the utilization of invasive biomass resources such as water hyacinth. By significantly reducing drying time while maintaining fiber quality, the proposed system addresses a key processing bottleneck commonly encountered in small-scale industries that rely on manual drying techniques. Similar observations have been reported in studies on other lignocellulosic materials, where controlled drying enhances process continuity, reduces biological degradation, and improves material consistency [16,17]. The findings of this study therefore support the broader applicability of controlled drying technologies in decentralized lignocellulosic biomass processing systems.

Furthermore, the practical utilization of dried water hyacinth fibers is clearly demonstrated in the form of handcrafted products, as illustrated in Figure 13. The figure presents a variety of finished goods produced by local craftsmen, including woven bags, storage baskets, containers, and decorative household items. These products reflect the successful transformation of lignocellulosic water hyacinth fibers into value-added applications with satisfactory structural strength, flexibility, and aesthetic quality.

Figure 13. Handcrafted Products Made from Dried Water Hyacinth Fibers.

The ability of the fibers to be manually woven into diverse shapes without significant breakage indicates that the drying process has preserved the mechanical integrity and workability of the material. This highlights the importance of achieving an optimal moisture content that balances sufficient dryness with retained flexibility for craft processing. Additionally, these handcrafted products demonstrate strong market potential, as similar water hyacinth-based goods are widely distributed not only in domestic markets but also in international export markets.

From a sustainability perspective, the utilization of water hyacinth fibers for handicraft production represents an environmentally beneficial approach by converting an invasive aquatic plant into economically valuable products. This contributes to a circular economy model, where biomass waste is effectively repurposed into functional and marketable goods, supporting both environmental management and local economic development [58].

4. Conclusions

This study confirms that drying is a critical preprocessing step in the utilization of lignocellulosic water hyacinth fibers. The developed drying system effectively reduces moisture content, enhances fiber quality, and improves processing efficiency, thereby enabling consistent material utilization for small scale craft industries. By overcoming the limitations of traditional sun drying methods, the proposed approach supports the sustainable processing of lignocellulosic biomass and contributes to the expanded utilization of invasive plant resources as value added natural fibers.

This research survey showed that 56.3% of craftsmen in Walahar Area, Karawang, Indonesia, were dissatisfied with manual drying methods in drying water hyacinth fibers. Besides, 81.3% of these craftsmen expressed a need for fiber-drying technology to dry water hyacinth. In addition, the main issues with manual drying methods include long processing times, weather conditions, ergonomic concerns, and the amount of dust that sticks to the fiber. Based on the survey results, the dryer machine was developed to help craftsmen increase fiber productivity and quality. The dryer machine was created with a product development approach that takes similar past research as a reference. The stages of this research include identifying user needs, machine component & concept studies, design, manufacturing, and testing with user response & feedback.

To determine the performance of the drying machine, performance testing was carried out through five main indicators, including drying time, drying temperature, fiber moisture content, productivity, and fiber quality. Each indicator was measured using a specific measuring instrument and compared with a manual method as a reference. This approach allows for an objective evaluation of the speed, efficiency, and quality of the drying results. The results of each test are described separately to show the difference in performance between the traditional method and the developed machine technology. The result of performance test showed that the dryer machine can process 10 kilograms of water hyacinth in 280 minutes, which is significantly faster than the manual method which takes 4 days in sunny condition. Furthermore, the dryer machine can dry the fibers of water hyacinth to a moisture content of less than 10%, surpassing the manual method's capability of reaching only 12%. The dryer machine can also produce a maximum heat of 80°C, which is higher than the constant drying temperature of 32-35°C for the manual method. Additionally, the dryer machine yields high-quality dried water hyacinth, while the manual method results in approximately 9.2% of the dried material being unsuitable due to dirty and damage.

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References

1. Asmara, T.; Djaja, S.D.; Syutrisno, E.; Krisnandar, I. Geographical Indication Legal Protection Efforts of Non-Rattan Wood Forest Product as Indonesia Natural Wealth. *Multicult. Educ.* **2021**, *7*, 80–85.
2. Rozikin, M.; Wijaya, A.F.; Riyadi, B.S. Sustainable Development: Disaster Risk Reduction of Forest and Land Fire in Indonesia. *Int. J. Membr. Sci. Technol.* **2023**, *10*, 329–339.
3. Surya, B.; Syafri, S.; Sahban, H.; Sakti, H.H. Natural Resource Conservation Based on Community Economic Empowerment: Perspectives on Watershed Management and Slum Settlement in Makassar City, South Sulawesi, Indonesia. *Sustainability* **2020**, *9*, 104.
4. Rakotoarisoa, T.F.; Ritcher, T.; Rakotondramanana, H.; Contreas, J.M. Turning a Problem into Profit: Using Water Hyacinth (*Eichhornia crassipes*) for Making Handicrafts at Lake Alaotra, Madagascar. *Econ. Bot.* **2016**, *70*, 365–379.
5. Tobias, V.D.; Conrad, J.L.; Mahardja, B.; Khanna, S. Impacts of Water Hyacinth Treatment on Water Quality in a Tidal Estuarine Environment. *Biol. Invasions* **2019**, *21*, 3479–3490.
6. Ayanda, O.I.; Ajayi, T.; Asuwaju, F.P. *Eichhornia crassipes* (Mart.) Solms: Uses, Challenges, Threats, and Prospects. *Sci. World J.* **2020**, *2020*, 3452172.
7. Wainger, L.A.; Harms, N.E.; Magen, C.; Liang, D.; Nesslage, G.M.; McMurray, A.M.; Cofrancesco, A.F. Evidence-Based Economic Analysis Demonstrates that Ecosystem Service Benefits of Water Hyacinth Management Greatly Exceed Research and Control Costs. *PeerJ* **2018**, *6*, e4824.
8. Mack, R.; Smith, M. Invasive Plants as Catalysts for the Spread of Human Parasites. *NeoBiota* **2011**, *9*, 13–29.
9. Ayana, B. Economic Importance, Impacts and Possible Mitigation Measures of Aquatic Water Hyacinth (*Eichhornia crassipes* Martius) in Ethiopia. *J. Environ. Earth Sci.* **2021**, *11*, 1–11.
10. Gonzalez, R. Eco-Development of Biocomposites from Water Hyacinth: A Sustainable Integral Design Proposal for Xochimilco, Mexico City. *Int. J. Des. Soc. Change Sustain. Innov. Entrep.* **2022**, *3*, 67–82.
11. Prabhu, A.V. Biogas Production from Anaerobic Co-Digestion of *Prosopis juliflora* Pods with Water Hyacinth, Dry Leaves, and Cow Manure. *J. Energy Sources Part A Recover. Util. Environ. Eff.* **2019**, 1–13.
12. Fengel, D.; Wegener, G. *Wood: Chemistry, Ultrastructure, Reactions*; Walter de Gruyter: Berlin, Germany, 1984.
13. Sjöström, E. *Wood Chemistry: Fundamentals and Applications*; Academic Press: London, UK, 1993.
14. Akendo, I.C.O.; Gumbe, L.O.; Gitau, A.N. Dewatering and Drying Characteristics of Water Hyacinth (*Eichhornia crassipes*) Petiole. Part II: Drying Characteristics. *CIGR J.* **2008**, *7*.
15. Nasution, I.S.; Satriyo, P.; Raaini, M. Monitoring and Performance of Stem Stalk Water Hyacinth Drying Using Modified Greenhouse Dryer. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1116*.
16. Mujumdar, A.S.; Law, C.L. Drying Technology: Trends and Applications in Postharvest Processing. *Food Bioprocess Technol.* **2010**, *3*, 853–852.
17. Rowell, R.M. *Handbook of Wood Chemistry and Wood Composites*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2012.
18. Kompas. Eceng Gondok, Dibuat Jadi Tas, Sandal, hingga Gazebo. Available online: https://lifestyle.kompas.com/read/2021/02/16/082334020/eceng-gondok-dibuat-jadi-tas-sandal-hingga-gazebo?page=all (accessed on 28 December 2025).
19. Farhan, F. Dari Gulma Eceng Gondok Jadi Goodybag hingga Menembus Pasar Rusia. Available online: https://regional.kompas.com/read/2019/01/11/16000001/dari-gulma-eceng-gondok-jadi-goodybag-hingga-menembus-pasar-rusia?page=all (accessed on 22 January 2026).
20. Prahestiwi, E.R.; Sadikin, A.; Saripah, L. Society's Entrepreneurship during the Pandemic through Water Hyacinth Handicraft in Walaharklari Village, West Java. *Spektrum J. Pendidik. Luar Sekolah* **2021**, *9*, 276–277.
21. Sauqii, D.A. Bangunan Irigasi Bendung Walahar, Kabupaten Karawang. Available online: https://www.researchgate.net/publication/375746323_Bangunan_Irigasi_Bendung_Walahar_Kabupaten_Karawang (accessed on 30 December 2025).
22. Berita Satu. Olah Eceng Gondok Hasilkan Ratusan Juta. Available online: https://www.beritasatu.com/ekonomi/211844/olah-eceng-gondok-hasilkan-ratusan-juta (accessed on 6 May 2026).

23. Diskominfo Karawang. From Weeds to Crafts to Russia. Available online: https://diskominfo.karawangkab.go.id/berita/dari-gulma-menjadi-kerajinan-tangan-hingga-menembus-rusia (accessed on 26 January 2026).
24. Tribun News. Ridho Sulap Eceng Gondok Jadi Barang Kerajinan yang Hasilkan Ratusan Juta Rupiah Tiap Bulan. Available online: https://www.tribunnews.com/regional/2017/02/23/ridho-sulap-enceng-gondok-jadi-barang-kerajinan-yang-hasilkan-ratusan-juta-rupiah-tiap-bulan (accessed on 26 January 2026).
25. Kompas. Dari Gulma Eceng Gondok Jadi Goodybag hingga Menembus Pasar Rusia. Available online: https://pemilu.kompas.com/read/2019/01/11/16000001/dari-gulma-eceng-gondok-jadi-goodybag-hingga-menembus-pasar-rusia (accessed on 12 February 2026).
26. Syahrir, R. Socio-Economic Impacts and Sustainability of Mining: A Case Study of Historical Tin Mining in Singkep Island, Indonesia. *Extr. Ind. Soc.* **2020**, *1*.
27. Niroka, P.; Panprayun, G.; Peeerakiatkhajohn, P. Performance of a Solar Greenhouse Dryer for Water Hyacinth. *Int. Energy J.* **2022**, *22*, 167–176.
28. Ilechie, C.O.; Aibangbee, G.; Ogblechi, S.; Abikoye, S. Development and Performance Evaluation of a Multipurpose Dryer. *Adv. Mater. Res.* **2011**, *367*, 745–752.
29. Saparudin, M.A.; Setiawan, R.J.; Budi, E.; Puspito, A.; Fauzi, I. Design and Manufacture of Bamboo Handicraft Dryer Machine Based on LPG Gas. *Tadulako Sci. Technol. J.* **2021**, *2*, 1–9.
30. Jessica, J.E.E.; Felipe, G.M.J.; Jose, P.S.F.; Eduardo, O.S.L.; Fabian, F.L.G. Influence of the Thermal Conductivity of Air on the Moisture Homogeneity of a Tray Dryer. *Int. J. Heat Technol.* **2019**, *37*, 322–326.
31. Argo, B.D.; Sandra, S.; Ubaidillah, U. Mathematical Modeling on the Thin Layer Drying Kinetics of Cassava Chips in a Multipurpose Convective-Type Tray Dryer Heated by a Gas Burner. *J. Mech. Sci. Technol.* **2018**, *32*, 3427–3435.
32. Gomez-de la Cruz, F.J.; *et al.* New Experimental Rotary Dryer of Olive Stone: Design, Control and Modeling. *Waste Biomass Valorization* **2018**, *9*, 443–449.
33. Delele, M.A.; Weigler, F.; Mellmann, J. Advances in the Application of a Rotary Dryer for Drying of Agricultural Products: A Review. *Dry. Technol.* **2015**, *33*, 541–558.
34. Go, A.; Das, S.K.; Srzednicki, G.; Driscoll, R.H. Modeling of Moisture and Temperature Changes of Wheat during Drying in a Triangular Spouted Bed Dryer. *Dry. Technol.* **2007**, *25*, 575–580.
35. Niksiar, A.; Sohrabi, M.; Rahimi, A. A Model for the Dynamics of Spouted Bed Dryers. *Dry. Technol.* **2013**, *31*, 295–307.
36. Holowaty, S.A.; Schmalko, M.E.; Schvezov, C.E. Modeling of a Double Pass Belt Conveyor Dryer of Yerba Mate. *Dry. Technol.* **2020**, *40*, 938–947.
37. Lutfy, O.F.; Selamat, H.; Mohd Noor, S.B. Intelligent Modeling and Control of a Conveyor Belt Grain Dryer Using a Simplified Type 2 Neuro-Fuzzy Controller. *Dry. Technol.* **2015**, *33*, 1210–1222.
38. Ma’ruf, K.; Candra, R.K.; Setiawan, R.J.; Azizah, N.; Khosyiati, N.E. Sustainable Microplastic Filter Development for River Conservation: A Case Study in Yogyakarta. In Proceedings of the International Conference on Decision Aid Sciences and Applications, *Manama, Bahrain*, **2024**.
39. Efendi, A.; Nugraha, A.; Baharta, R. Manufacturing of Electrical Dryer Machine for Food and Fruit Products. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *692*, 012006.
40. Pavan, D.; Avinash, S. Design and Development of Multipurpose Cooling and Drying Machine. *Mater. Today Proc.* **2021**, *45*, 424–428.
41. Setyawan, E.Y.; *et al.* Performance of Turmeric Dryer Cabinets with LPG Fuel Using Temperature Control and Air Speed. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *420*, 012044.
42. Tortoe, C.; Ampah, J.; Anokor, P.T.; Buckman, E.S.; Nketia, S. Fabrication and Performance Evaluation of a Wooden Cabinet Dryer for Value Addition of Fruits for Micro-, Small and Medium-Scale Enterprises (MSMEs). *Ghana J. Agric. Sci.* **2023**, *58*, 12–21.
43. Pandit, S.V.; Shinde, J.G.; Kadam, S.J. Design and Development of Raisins Drying Machine. *Iconic Res. Eng. J.* **2018**, *2*, 47–52.
44. Ibrahim, M.N.; Sarker, M.S.; Aziz, A.B.; Salleh, M. Drying Performance and Overall Energy Requisite of Industrial Inclined Bed Paddy Drying in Malaysia. *J. Eng. Sci. Technol.* **2014**, *9*, 398–409.

45. Rotz, C.A.; Sprott, D.J. Drying Rates, Losses and Fuel Requirements for Mowing and Conditioning Alfalfa. *Trans. ASAE* **1984**, *27*, 715–720.
46. Llobodanin, L.G.; Billiris, A. Effect of the Drying Air Conditions on the Drying Rate and Milling Quality of a Long-Grain Rice Variety. *Food Sci. Technol.* **2023**, *43*, 65722.
47. Mburu, J.K.; Gumbe, L.O.; Some, D.K. Dewatering and Drying Characteristics of Coffee Pulp. II: Drying Characteristics. *Kenya Coffee* **1995**, *60*, 2003–2008.
48. Liu, J.; Liu, Y.; Li, X.; Zhu, J.; Wang, X.; Ma, L. Drying Characteristics, Quality Changes, Parameter Optimization and Flavor Analysis for Microwave Vacuum Drying of Garlic (*Allium sativum* L.) Slices. *LWT* **2023**, *173*, 1–11.
49. Zhang, Q.; Li, Y.; Puri, M.; Manbeck, H.B. Elastoplastic Constitutive Equation Parameter and Load Response of Wheat en-Masse—Part II: Constitutive Equation Parameter Dependence on Initial Density and Moisture Content. *Trans. ASAE* **1989**, *32*, 203–209.
50. Shammi, S.; Hossen, M.; Mamun, M.; Soeb, M. Temporal and Spatial Representation of Temperature and Moisture in Drying Chamber and Its Impact on Vertical Vacuum Dehumidifying Rice Seed Dryer Performance. *J. Agric. Food Res.* **2022**, *10*, 100424.
51. Ma'ruf, K.; Setiawan, R.J.; Chen, Y.T. Enhanced Sustainable Drying Technology: Performance of Solar-Powered Hybrid Dryer for Natural Fiber Processing. In Proceedings of the 5th International Symposium on Materials and Electrical Engineering (ISMEE), *Bandung*, *Indonesia*, **2025**.
52. Gerken, M.; Hülsbeck, M.; Ostermann, T.; Hack, A. Validating the FIBER Scale to Measure Family Firm Heterogeneity—A Replication Study with Extension. *J. Fam. Bus. Strateg.* **2022**, *13*, 100497.
53. dos Santos, G.L.; *et al.* Fiber Quality of Colored Cotton as a Function of Potassium Fertilization in the Semi-Arid Region. *J. Nat. Fibers* **2024**, *21*.
54. Kuramoto, K.; *et al.* Visual Colour Fastness Assessments for Multi-Coloured Fabrics. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *254*, 142014.
55. Casas, E.V.; Raqid, J.G.; Yaptenco, K.F.; Peralta, E.K. Optimized Drying Parameters of Water Hyacinths (*Eichhornia crassipes* L.). *Sci. Diliman* **2012**, *24*, 28–49.
56. Byler, R.K. Historical Review on the Effect of Moisture Content and the Addition of Moisture to Seed Cotton before Ginning on Fiber Length. *J. Cotton Sci.* **2006**, *10*, 300–310.
57. Cao, J.; Cheng, L.; Zhang, L.; Liu, X.; Xu, H. Further Studies of Mechanical Damage on Machine-Harvested Cotton Fiber via Coupling Effect of Moisture Regains and Low Temperature. *J. Nat. Fibers* **2024**, *21*, 2309913.
58. Popola. Effects of Water Hyacinth on Water Quality in Water Obtained from Pandam Lake, Pandam Game Reserve, Plateau State, Nigeria. *Int. J. Pure Appl. Sci.* **2020**, *19*, 162–173.