Assessment of drying rates and moisture contents of raw and treated *Telfairia occidentalis* stem fibers

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Abstract
This study investigated the drying rates and moisture contents of raw and treated *Telfairia occidentalis* stem fibers. The stems of *Telfairia occidentalis* were retted in water for three days before the extraction of the fibers. The extracted fibers were washed, chemically treated, and oven-dried. The raw and the treated fibers were oven-dried at three distinct drying temperatures, 50°, 70°, and 90° C, and the moisture content was determined at an interval of 20 minutes till a constant weight was attained. The results showed that the drying rates for the raw fibers were 3.995, 4.721, and 8.732 %hr. for 50°, 70°, and 90° C, respectively. While that of the treated fibers were 9.111, 10.009, and 10.50 %hr. for 50°, 70°, and 90° C, respectively. The results showed the drying rate increased as a result of an increase in the drying temperature in both the untreated and the treated fiber samples. The findings revealed that the treated fibers have higher drying rate than the untreated fibers. This study concludes that a moderate oven drying temperature at 90°C is satisfactory for the successful drying of the *Telfairia occidentalis* in order to enhance its functional performance.

1. Introduction

The move towards sustainable development has increased the search for available, renewable, abundant, and eco-friendly resources that can successfully replace partly or wholly synthetic materials. Among the various natural fibers explored, plant-based fibers have gained significant attention due to their biodegradability, renewability, eco-friendliness, low cost, and abundance [1]; [2]; [3]; [4]; [5]; [6]; [7]; [8]; [9].

The major compositions of natural plant fibers are cellulose, hemicellulose, and lignin, with minor percentages of pectin, wax, and water-soluble substances [10]; [11]. The compositions may differ with the growing condition, soil type, region, and test methods even for the same kind of fiber [10]; [12]; [13]. In Nigeria, there are many varieties of natural plant fibers, which include: plantain, *miscanthus*, coir, bamboo, pineapple leaf, jute, sisal, hemp, kenaf, *Telfairia occidentalis*, corn, among others. Among the various sources of lignocellulosic fibers, *Telfairia occidentalis* is receiving great interest due to its renewable nature, abundance, eco-friendly, and favorable composition.

Telifairia occidentalis, also known as "ugu" in Nigeria, is a tropical vine grown in West Africa primarily for its edible leaves and seeds. While the leaves and seeds of the Fluted Pumpkin are well-known for their nutritional and medicinal benefits, the stem of the plant has often been overlooked as agricultural wastes [14]; [15]. Recent research, however, suggests that the stems of the *Telifairia occidentalis* contain valuable fibers that can be extracted and utilized in various industrial applications [16]; [17]. Literature research revealed that several tons of stem wastes are produced daily in market places and in homes all over Nigeria, but they are dumped as waste [17].

Despite the numerous benefits of *Telifairia occidentalis* and its potential application as reinforcement material in polymer composite, the industrial use of *Telifairia occidentalis* and other natural plant fibers in their natural forms for polymer composite application, is hampered by few setbacks. Previous studies have identified the major setbacks in the use of natural fibers in their natural forms to include: poor fiber-matrix adhesion, poor wettability, water absorption, moisture absorption [18]; [19]. The challenges are overcome via chemical treatments of the natural fibers [18]. Chemical treatments of the fibers, such as mercerization, acetylation, salinization, benzolation, have been found to enhance the compatibility between natural fibers and polymer matrix, improve fiber-matrix interfacial bonding, improve wettability, reduce moisture absorption, and increase the mechanical properties of the composites [20]; [21]**;** [12], [22]; [23]; [8].

Telfairia occidentalis fibers, like other natural fibers, are wet after extraction process due to water retting, hence, drying process which is a process of removing moisture from a material, typically by the application of

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heat, is highly needed to reduce the moisture content of the fibers. Drying is a fundamental natural fibers preprocessing that directly affects storage stability, moisture content, biological durability, shelf life, and fiber usability [24]; [25]; [26]. Insufficient or uncontrolled drying is capable of promoting microbial degradation, surface contamination, and non-uniform moisture distribution, thereby reducing the material quality and limiting downstream processing performance [11]; [26]. Hence, determining the optimal drying temperatures for natural fibers can enhance the mechanical properties of the fibers, improving the strength, durability, ductility, and rigidity of the fibers [27]; [28]. The influence of drying temperatures (40°C and 90°C) on the properties of Columbian banana fibers [28]. The result showed that 90o C oven drying temperature improved most of the properties compared to 40oC. Similar results were that experimentally investigated the drying kinetics of banana fiber at drying temperatures of 60°, 75°, and 90°C [29]. The effects of effects of drying temperatures (40° and 90° C) on the properties of Columbian coir fibers and interfacial adhesion with polylactic acid [25]. The results showed that drying at 90 oC significantly enhanced the fiber stiffness. The influence of drying temperatures (70, 100, and 130 ^{o}C) on the coconut fiber, and found that drying temperature at 70 ^{o}C was satisfactory, providing natural fiber-reinforced composites with good tensile strength, combined with good ductility [27].

Acquiring an in-depth understanding of and refining the moisture-related characteristics of *Telfairia occidentalis* are essential for improving their functional uses. This can be achieved through determination of the optimal drying temperature, moisture content and drying rate of the fibers. Hence, this study aims at assessing the drying rates and moisture contents of raw and treated *Telfairia occidentalis* stem fibers. The objectives of this study are: (1) to determine the optimum temperature for the drying of *Telfairia occidentalis*, (2) to determine the moisture content of raw and treated *Telfairia occidentalis*, (3) to determine the drying rates of raw and treated *Telfairia occidentalis,* and (4) to compare the effects of the surface modification on the moisture contents and the drying rates of *Telfairia occidentalis.*

2. Material and Method

2.1. Material

The material used in this study was *Telfairia occidentalis* stem fiber. *Telfairia occidentals'* stems are readily available, renewable, eco-friendly and in abundance. *Telfaira occidentalis* stems used were residues or agricultural wastes left after vegetables had been taken from *Telfairia occidentalis*. The stems were obtained from Southeast Nigeria. Both the raw and treated *Telfaira occidentalis* fibers were used in this study.

Sodium hydroxide (NaOH) and acetic acid were the reagents used in this study for the chemical treatment of the extracted fibers. The reagents were got from Bridgehead Market, Onitsha, Anambra State, Nigeria. NaOH was used for the mercerization treatment of the extracted fiber. Acetic acid was used to neutralize the NaOH used in the mercerization of the fiber. The minimum purity for all the chemicals used is 99%.

2.2. Preparation of Samples

The stems of *Telfairia occidentalis* (Figure 1) gathered were cut in small sizes, washed to remove dirt, and retted in water at room temperature for 3 days. The fibers were manually extracted from the stems of the *Telfairia occidentalis* after 3 days. The extracted fibers were thoroughly washed with clean water and sun dried for 24 hours.

The extracted fibers were subjected to chemical treatment using sodium hydroxide and acetic acid. The essence of the chemical treatment was the remove unwanted hemicellulose, lignin, pectin, and other impurities [12]. The extracted fibers were treated with 2% NaOH solution in water for 2 hours. The 2% of NaOH was prepared by dissolving 20 g of NaOH pellets in 1000 ml of water. Dilute acetic acid was used to neutralize the fibers treated with NaOH. The water to acetic acid ratio used was 90:10 [12]; [8]; [9]. After the mercerization and the neutralization processes, the treated fibers were washed with distilled water till pH 7 was attained. The treated fibers were first sun dried for 24 hours.

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Figure 1. *Telfairia occidentalis* Stems

2.3. Drying Rate and Moisture Contents Tests of *Telfairia occidentalis* Stem Fibers

In order to access the drying rate and the moisture content of both the untreated and the treated *Telfairia occidentalis* fibers in this study, a laboratory oven (model-AISET YLD-200) was used. The experiment was conducted at three distinct temperatures: 50°C, 70°C, and 90°C. Three sets of samples (A, B, and C) each for the raw fiber and the treated fibers were prepared and used for the experiments. Sample A was dried at 50°C, Sample B was dried at 70°C, and Sample C was dried at 90°C. The initial weights of the Samples were recorded before the drying process began.

Each fiber sample was then placed in the oven, which was pre-set to the specified temperature. At each temperature setting, the Sample was subjected to 20-minute drying interval. After each interval, the Sample was removed from the oven, and the weight was immediately measured using Ming Heng Electronic Digital precision scale (model: MH-887). This process was repeated until the fibers reached a constant weight (equilibrium moisture content), indicating that moisture had been removed. All Samples were subjected to the same drying process. Figure 2 shown a weighing of fibers during the oven drying process.



Figure 2. Weighing of Fibers during the Oven Drying Process

The moisture content at each interval was determined by comparing the initial weight of the fibers with their weight after each drying interval. This allowed for the calculation of the drying rate at each temperature setting. Moisture content, which is the amount of water present in a material, typically expressed as a percentage of the material's total weight as shown in Equation (1).

$$Moisture\ content\ = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \quad (1)$$

The drying rate, as shown by Equation (2), refers to the amount of moisture removed from a material per unit of time. It is typically expressed as kg of water evaporated per kg of dry material per hour or as a percentage per hour (Morton, 2008).

$$Drying\ rate = \frac{Initial\ moisure\ content - final\ moisture\ content}{Time} \quad (2)$$

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The drying rate constant k, was determined using Equation (3) and Equation (4):

$$K = -\frac{\ln MR}{t} \quad (3)$$

$$MR = \frac{M - M_e}{M_i - M_e} \quad (4)$$

Where:
Where MR is moisture ratio,
M_i is initial moisture content,
M_e is equilibrium moisture content,
M is moisture content at time t and
K is drying constant

3. Results and Discussion

3.1. Moisture Contents and Drying Rates of *Telfairia occidentalis* Stem Fibers

The results of the moisture contents and the drying rates experiment for both untreated and treated *Telfairia occidentalis* fibers assessed at different oven drying temperatures of 50°C, 70°C, and 90°C are presented graphically in this section.

3.1.1. Moisture Contents and Drying Rates of the Untreated *Telfairia occidentalis* Fibers

Figure 3 shows the moisture contents of the untreated *Telfairia occidentalis* fiber at 50°C (Sample A) measured over a period of 360 minutes at an interval of 20 minutes. The moisture content decreases with increase in the drying time till it got to 340 minutes. The moisture content began to decrease from 95.32% at 20 minutes to 71.4% at 340 and 360 minutes. The equilibrium moisture content of the untreated fiber at 50°C oven drying temperature, as can be seen from the figure, is 71.4%. The drying rate and drying constant of the fiber were computed from the moisture contents results shown in Figure 3 using equations (3) and 4, respectively. The drying rate for the 50°C oven drying temperature, as shown in Table 1, is 3.995 %/hr., while the drying constant is 1.118 hr^{-1}.

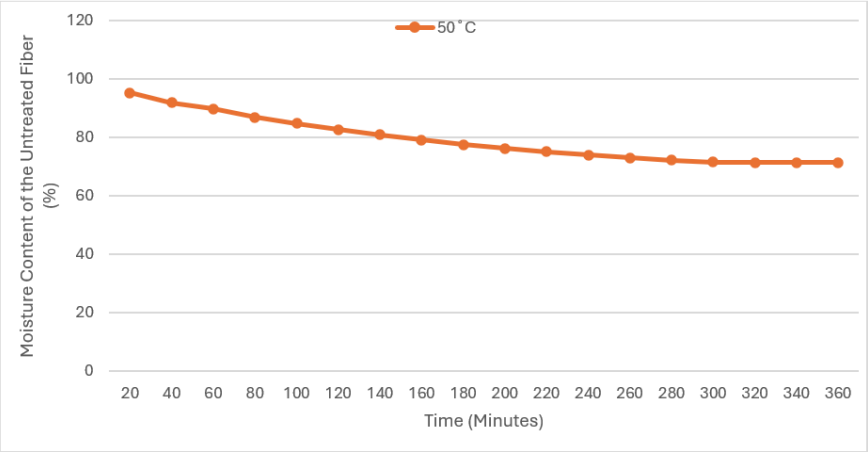

Figure 3. Moisture Contents of the Untreated Fiber at 50°C Oven Drying Temperature (Sample A_u)

Table 1. Drying Rate of the Untreated *Telfairia occidentalis* Fibers

Sample	Drying Temperature	Drying Rate (%/hr.)	MR	Drying Constant, K (hr^{-1})
Sample A	50	3.995	0.1143	1.118
Sample B	70	4.721	0.0323	4.531
Sample C	90	8.732	0.0225	5.181

Figure 4 shows the moisture contents of the untreated *Telfairia occidentalis* fiber at 70°C (Sample B) measured over a period of 260 minutes at an interval of 20 minutes. The moisture content deceased from 92.29% at 20 minutes to 71.85% at 240 and 260 minutes. The equilibrium moisture content of the untreated fiber at 70°C oven drying temperature, as can be seen from the figure, is 71.85%. The drying rate for the 70°C oven drying temperature, as shown in Table 1, is 4.721 %/hr., while the drying constant is 4.531 hr^{-1}.

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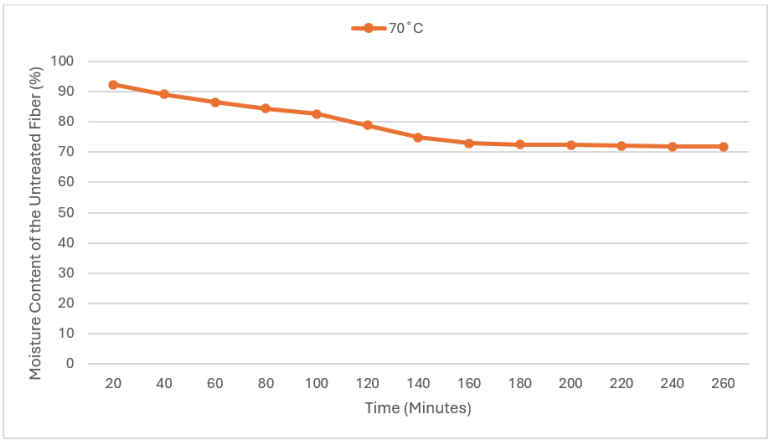

Figure 4. Moisture Content of the Untreated Fiber at 70°C (Sample B_u)

The moisture contents of 90°C (Sample C) oven drying temperature examined over a period of 260 minutes are as depicted in Figure 5. The moisture content deceased from 88.75% at 20 minutes to 50.94% at 240 and 260 minutes. The equilibrium moisture content of the untreated fiber at 90°C oven drying temperature, as can be seen from the figure, is 50.94%. The drying rate for the 90°C oven drying temperature, as shown in Table 1, is 8.732 %/hr., while the drying constant is 5.181 hr^{-1}.

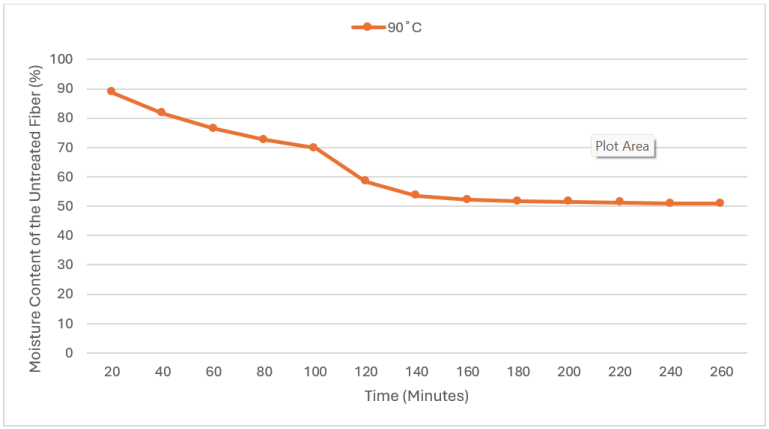

Figure 5. The Moisture Content of Untreated Fiber at 90°C (Sample C_u)

3.1.2. Moisture Contents and Drying Rates of the Treated Fibers

Figure 6 shows the moisture contents of the treated *Telfairia occidentalis* fiber at 50°C (Sample A) measured over a period of 360 minutes at an interval of 20 minutes. The moisture content deceased from 71.43% at 20 minutes to 31.54% at 240 to 360 minutes. The equilibrium moisture content of the treated fiber at 50°C oven drying temperature, as can be seen from the figure, is 31.54%. The drying rate for the 50°C oven drying temperature, as shown in Table 2, is 9.111 %/hr., while the drying constant is 2.320 hr^{-1}.

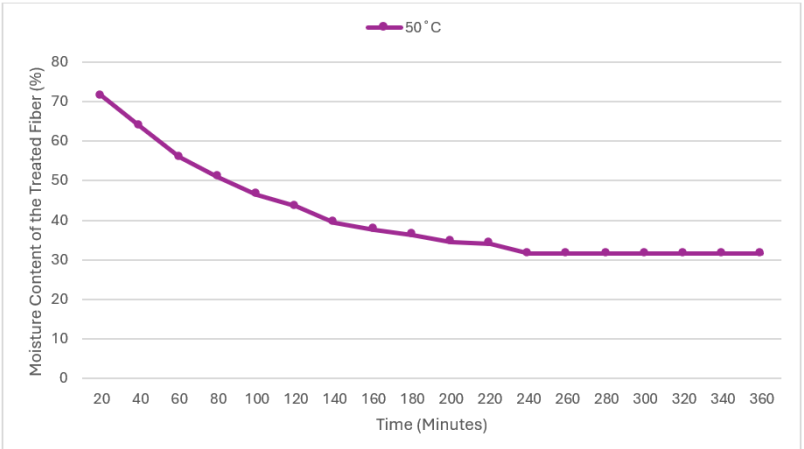

Figure 6. The Moisture Contents of the Treated Fiber at 50°C (Sample A_t)

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Table 2. Drying Rate of the Treated *Telfairia occidentalis* Fibers

Sample	Drying Temperature	Drying Rate (%/hr.)	MR	Drying Constant, K (hr^{-1})
Sample A	50	9.111	0.1959	2.320
Sample B	70	10.009	0.1195	3.220
Sample C	90	10.500	0.0755	3.277

Figure 7 shows the experimental results of the moisture contents of the treated *Telfairia occidentalis* fiber at 70°C (Sample B) measured over a period of 260 minutes at an interval of 20 minutes. The moisture content deceased from 74.63% at 20 minutes to 41.30% at 180 to 260 minutes. The equilibrium moisture content of the treated fiber at 70°C oven drying temperature, as can be seen from the figure, is 41.30%. The drying rate for the 70°C oven drying temperature, as shown in Table 2, is 10.009 %/hr., while the drying constant is 3.220 hr^{-1}.

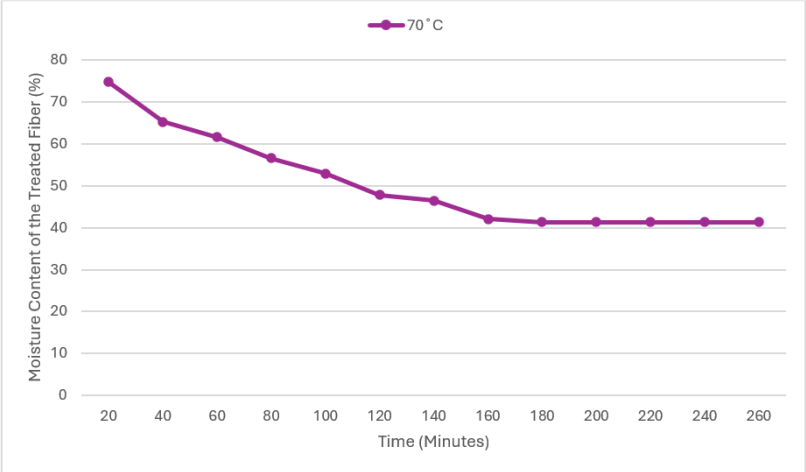

Figure 7. Moisture Contents of the Treated Fiber at 70°C (Sample B_t)

The experimental results for the moisture contents of 90°C (Sample C) oven drying temperature observed over a period of 260 minutes are as shown in Figure 8. The moisture content deceased from 69.29% at 20 minutes to 37.79% at 160 to 260 minutes. The equilibrium moisture content of the treated fiber at 90°C oven drying temperature, as can be seen from the figure, is 37.79%. The drying rate for the 90°C oven drying temperature, as shown in Table 2, is 10.50 %/hr., while the drying constant is 3.277 hr^{-1}.

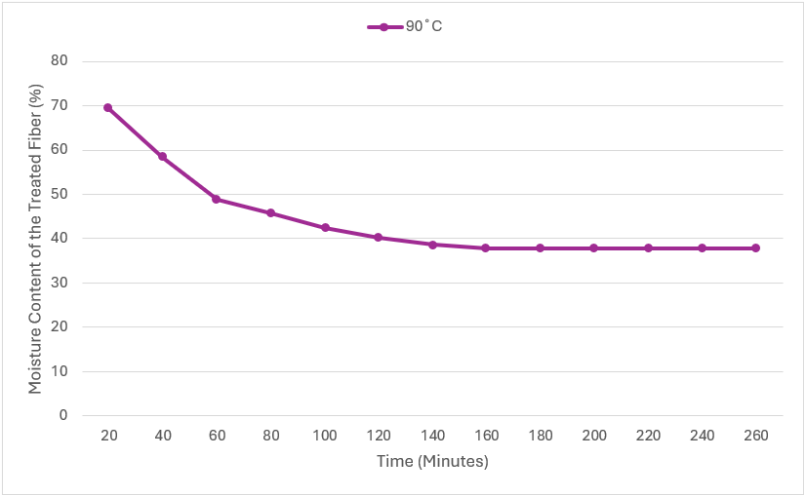

Figure 8. Moisture Contents of the Treated Fiber at 90°C (Sample C_t)

3.1.3. Comparison of the Drying Rates and Equilibrium Moisture Contents of the Untreated and the Treated Fibers

Figure 9 shows the comparison of the experimental results of drying rates of the untreated and treated *Telfairia occidentalis* fibers at 50°C, 70°C, and 90°C oven drying temperatures. It can be deduced from the figure that the drying rate of the fiber increases with increase in the temperature for both the untreated and treated natural fibers. In each case, the sample dried with 90°C oven drying temperature has the highest drying rate while the sample dried with 50°C has the lowest drying rate. At 90°C, the weight loss was most pronounced,

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indicating that heat plays a key role in the drying process by evaporating water content more quickly. This confirms that higher temperatures significantly accelerate the drying process of the natural fibers. However, care must be taken, as excessively high oven drying temperature can degrade the cellulose, leading to reduction in the mechanical and structural properties of natural fibers [27].

It can also be seen from the figure that the treated samples have higher drying rates than the untreated samples in each of the oven drying temperatures. This implies that chemical treatment increases the natural fiber drying rate. This can be attributed to the removal of lignin, hemicellulose, and other non-cellulosic components during the alkali treatment [25]. Hence, removing the hydroxyl group in the fiber, which is responsible for moisture absorption and retention. The Chemical treatment opened up the fiber structure, allowing moisture to evaporate from the fiber more readily.

Reduced Equilibrium Moisture Content (EMC) in treated bio-fibers indicates lowered hydrophilicity, enhancing moisture resistance critical for sustainable bio-composites and green construction materials. Such material innovations complement broader ecological management strategies, including sustainable agroforestry [30], tropical forest conservation [31], and advanced environmental monitoring [32]; [33]. Together, these developments promote eco-friendly material utilization and environmental preservation across diverse industrial and natural ecosystems.

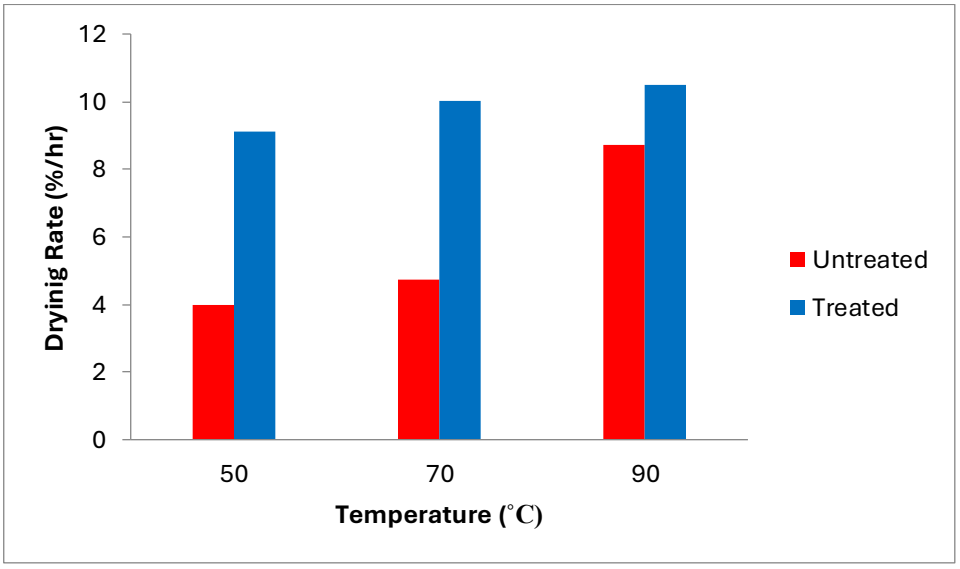

Figure 9. Comparison of the Drying Rates of the Untreated and the Treated Fibers

4. Conclusion

The assessment of the drying rates and moisture contents of the raw and treated *Telfairia occidentalis* stem fibers has been experimentally carried out in this study. Different oven drying temperatures of 50°C, 70°C, and 90°C were used in the experiments. The results revealed that:

a. Natural fibers can be successfully extracted from the stems of *Telfairia occidentalis*.

b. The drying rate was higher for the treated fibers, with rates of 9.111%/hr at 50°C, 10.009%/hr at 70°C, and 10.5%/hr at 90°C compared to the untreated fiber which at 50°C, was 3.995%/hr, increasing to 4.721%/hr at 70°C, and reaching a maximum of 8.732%/hr at 90°C.

c. The equilibrium moisture content of the treated fiber is less than the untreated fiber. For the untreated fiber, the EMC for 50°C was 71.35% (at 360 minutes); the EMC for 70°C was 71.85% (at 260 minutes) and that of 90°C was 50.94% (at 260 minutes). For the treated fiber, the EMC for 50°C was 31.54 % (at 360 minutes), the EMC for 70°C was 41.30% (at 260 minutes) and that of 90°C was 37.79% (260 minutes).

d. The optimum temperature for the drying of *Telfairia occidentalis* is 90°C.

e. Chemical treatment improves the drying rates and moisture contents of natural fibers.

This study concludes that a moderate oven drying temperature at 90°C is required for the successful drying of the *Telfairia occidentalis* in order to enhance its functional uses.

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Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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