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# Thermal Energy Storage Potential of Banana Stem and Peel: Comparing Heat Conductivity at Room Temperature Post-Oven Drying

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**ABSTRACT**

Bananas, a globally consumed staple, generate substantial agricultural waste, particularly peels and pseudostems, which account for over 60 % of the biomass. This waste presents an opportunity for value-added applications, especially in fire safety and thermal-resistant materials. In this study, dried banana pseudostems and peels were analysed for their thermal properties using Newton's Law of Cooling. Key findings revealed that banana pseudostem outperformed the peel in thermal resistance, attributed to its higher lignin and cellulose content, which enhance insulation. These properties suggest that banana by-products hold significant potential for sustainable, thermally resistant materials, addressing fire safety challenges in regions like Malaysia. This research underscores the dual environmental and functional benefits of repurposing banana waste, aligning with sustainable development goals and promoting eco-friendly innovations.

## 1. Introduction

Globally, bananas (Musaceae family) are a crucial fruit crop known for their superior nutritional value compared to other common tropical fruits, and both ripe and unripe bananas are edible [1]. In 2017, Malaysia is reported to be planting bananas across 35,000 hectares of plantations, producing 350000 tonnes [2]. Commonly only for the majority of the crops, pulp of the banana are consumed whereas the peel and stems are discarded as wastes. In fact, the banana pulp ratio to the whole banana portion is only less than 40 % of the total banana weight [3]. Indicatively, more than 60 % becomes waste, which can conclude up to 20000 tonnes of banana waste. In order to avoid them from becoming by-products or unused wastes, it is better to repurpose banana stem and peel for other applications.

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Commercial farming also exhibits maximum use of banana peel as animal feedstocks and natural fertilizers [4]. However, more alternatives can be implemented into daily use besides farming sectors. Research trends also indicated that banana peel can be developed into advanced materials as fillers for plastics and other composites [5]. Singh reviewed multiple applications of banana fiber-reinforced composites suited for various industries including construction, automotive, packaging, aerospace and medical. Hence, banana can be implemented as composites of thermosets, thermoplastics, cements and biodegradables [6]. This indicates that banana has more potential in diverse applications besides being just another nutritious edible fruit.

Malaysia exhibits a variety of industries whereas construction is blooming in every state. In 2018, fire statistics in Malaysia revealed that there were 6,626 incidents involving structural fires, resulting in 97 fatalities and total financial losses amounting to RM3.3 billion [7]. Fire-related accidents might occur due to construction errors and fire safety equipment lacking in most buildings [8]. To counter this issue, government can provide a cheap and readily accessible material that can withstand heat. Studies reported that banana fibre already exhibit excellent thermal properties including thermal stability [9], thermal conductivity [10] and char formation [11]. Banana peel composite's thermal retardancy was also evaluated by Kong in 2022, where the LOI value is higher value of 31.5 % with addition of MCAPP. Therefore, exhibiting self-extinguishing and anti-dripping properties [12]. These findings accentuates the potential of thermal properties for banana fibre.

In fact, banana is known to be constituent of variety of natural polymers including lignin, cellulose and hemicellulose, pectin and starch [13]. Furthermore, lignin and cellulose are known to exhibit excellent thermal resistance based on previous studies [10,14-16]. Nonetheless, these constituents are different based on different banana. Thus, pseudostem is known to have high composition of cellulose and lignin at 65 and 16 % respectively [17]. Comparatively, banana peel is known to have lower cellulose and lignin at 30 and 12 % respectively.

Table 1 reiterates the ratio of material present based on each banana parts [18]. Thus, it can be deduced the variance in these natural polymer content would contribute to varying thermal properties.

**Table 1**
Summary of polymeric content inside banana part

| Banana part | Material abundance to whole content (%) | | References |
|---|---|---|---|
| Natural polymer | Neck (Psuedostem) | Peel | |
| Cellulose | 65 | 16 | [17] |
| Lignin | 30 | 12 | [18] |

Despite the increasing exploration of natural substance in composite materials, limited studies focus specifically on the thermal conductivity properties of banana peel powder, leaving a critical gap in understanding its potential as a sustainable and thermally efficient material for industrial applications. This study aimed to use Newton's cooling law to evaluate the thermal performance and latent heat based on the cooling effect by the room temperature on dried banana parts. It is hypothesized that banana psuedostem will exhibit higher temperature resistance, and lower cooling effect due to abundance of lignin and cellulose.

## 2. Materials and Methods

### 2.1 Sample Preparation

### 2.1.1 Extraction from banana waste

The bananas (Musa acuminata) wastes used in this research were bought from a local market in Serdang, Selangor, Malaysia. As illustrated in Figure 1, banana peels and banana necks (psuedostem) were segregated after cutting them respectively. Both banana parts were cleaned with probiotic based soap and removed out of any soil and dirt, and then they were carefully separated from the fruit's edible part.

**Fig. 1.** Banana peels (left) and banana necks (right)

### 2.1.2 Oven drying

In accordance with a prior oven drying experiment of various studies, banana peels were dried for 24 hours at 80 in an oven of lab H2.3 building at the aerospace engineering department residing in Faculty of Engineering, Universiti Putra Malaysia. Previous drying methods were compared to be ideal at this conditions based previous study [19]. To prevent the peels from being overlapped, the banana peels were arranged as dispersal equally and maximising water content removal process.

A universal oven (UF-110, Memmert, Germany) (Figure 2) was used for the microwave drying process. The banana peels were put in the microwave oven on top of a stainless baking tray as shown in Figure 3. Next, the banana peel were shrunk in size and dried out and was carried on to the grinding process. This step was also repeated for banana neck parts where it was dried in the same oven following the completion of drying for banana peel parts.

**Fig. 2.** Mehmert universal oven

**Fig. 3.** Banana peel arrangement on a tray

### 2.1.3 Grinding dried banana parts

After the drying process, the banana peels were collected into a beaker and transferred into a Heavy Duty Blender of 2L size (Kenwood, Britain) (Figure 4) with 1800 W. The process of grinding was to crush dried banana parts into small sizes of powder particles as depicted. Banana peels have higher percentage of yield per banana fruit compared to banana neck. Hence, their volume ratio was higher per banana fruit and the banana neck (psuedostem) was only obtained from the banana waste, not the trunk of banana tree. By referring to Figure 5, at the end of grinding process there were two types of powder produced including banana neck and banana peel powder.

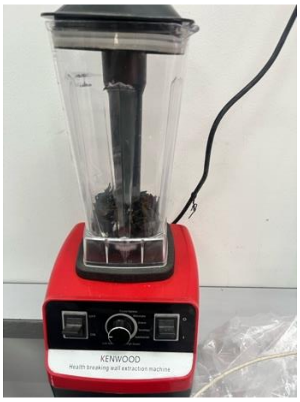

**Fig. 4.** Heavy duty blender with dried banana peels

**Fig. 5.** Powder produced after grinding

## 2.2 Reheating in Oven and Temperature Monitor Experiment

### 2.2.1 Simultaneous heating of banana powders

After obtaining the powder for peel and neck, 40 g were weighed *via* gravimetric balance to maintain the same mass. Then, these powders segregated into beakers for oven heating procedure. In their respective beakers, they were heated inside a universal oven at 80 °C for 2 hours. Directly, the beakers were then removed from the oven and underwent temperature monitor experiment. Figure 6 emphasizes how the arrangement of the powders were, in the oven dry for heating experiment.

**Fig. 6**. Beaker of banana powders; Neck (left) and peel (right)

### *2.2.2 Measuring temperature and experiment repetition*

As soon as the beaker was placed out of the oven, a needle probe thermometer (Thermometer TP-300) (Figure 7) was placed into the beaker for measurement of initial temperature post-heating. Then, temperature was recorded again for every 5 minutes to monitor the cooling effect of room temperature towards each banana powder.

**Fig. 7.** TP-300 probe thermometer with 150 mm length

Steps in section 2.2.1 and 2.2.2 was repeated twice to gather more data and ensure data consistency across different days that may be affected by various environmental conditions. For cooling effect to be measured, the room temperature was also recorded at 32.0°C on Day 1, 30.5°C for Day 2 and 30.8 °C for Day 3. Room temperature acted as a control variable as heated powders reverted back to normal temperature.

## *2.3 Thermal Analysis Based on Temperature Decay*

### *2.3.1 Newton’s cooling law*

Newton’s cooling law stated that “The rate of change of the temperature of a warming/cooling body is proportional to the difference between the temperature of the body and the surrounding temperature”. Eq. (1) is the basis of Newton’s cooling law. Let y = $T(t)$, temperature at described time it will be derived into Eq. (2), which directly implies the cooling rate of the respect material for this experiment [20].

$$\frac{dy}{dt} = -k(y = a) \tag{1}$$

$$T(t) = T_0 + (T_f - T_0)e^{-kt} \tag{2}$$

Where, *t* is time, $T_0$ is initial temperature, $T_f$ is the room temperature, *k* is the cooling constant of the material at the current environmental conditions.

Temperature decay can be defined as cooling effect as the temperature between two mediums reach thermal equilibrium based on these equations. The results of the temperature monitor were further discussed in Section 3.1.

## **3. Results and Discussion**

### *3.1 Temperature Decay Data*

Decay of the temperature (*T*) versus time (*t*) when both powders are placed out of the oven is presented in Table 2. This data summarizes the temperature profile of respective banana part for each day and powder. In general, each powder experiences cooling effect as temperature decreases with time. During initial temperature monitored where *t* is 0, Peel D3 exhibit the highest, followed by Peel D2, Neck D3, Neck D2, Neck D1 and Peel D1.

Across the three days of experiment, data suggests that banana peel measure the initial highest temperature compared to banana neck. This may imply that peel has better heat convection towards external medium. This data reflects from previous study which emphasizes that higher initial temperature can indicate lower specific heat capacity, enabling higher temperature initial but faster temperature drop as time progresses [21].

**Table 2**
Temperature monitor of peel and neck across 3 days experiment and time

| | T (°C) | | | | | |
|---|---|---|---|---|---|---|
| | Day 1 | | Day 2 | | Day 3 | |
| t (min) | Peel D1 | Neck D1 | Peel D2 | Neck D2 | Peel D3 | Neck D3 |
| 0 | 56.4 | 56.9 | 57.6 | 57.4 | 58 | 57.6 |
| 5 | 46.7 | 47.1 | 50.1 | 50.6 | 49.4 | 50.6 |
| 10 | 41.8 | 42.5 | 44.5 | 45.3 | 44.7 | 46.5 |
| 15 | 38.9 | 39.6 | 40.3 | 41.4 | 38.8 | 40.6 |
| 5 | 37.3 | 38.1 | 37.8 | 38.8 | 36.3 | 37 |
| 10 | 36.1 | 36.7 | 35.6 | 36.1 | 34.1 | 34.7 |
| 15 | 35.4 | 36.1 | 34.3 | 35.3 | 32.8 | 33.4 |
| 20 | 34.7 | 35.4 | 33.4 | 34.2 | 31.9 | 32.4 |
| 25 | 34.4 | 35.1 | 32.7 | 33.5 | 31.4 | 31.9 |
| 30 | 33.9 | 34.6 | 32.3 | 33.1 | 31 | 31.4 |
| 35 | 33.6 | 34.2 | 31.8 | 32.5 | 30.9 | 31 |
| 40 | 33.1 | 33.8 | 31.5 | 32.2 | 30.8 | 30.9 |
| 45 | 32.9 | 33.5 | 31.2 | 31.9 | 30.8 | 30.9 |
| 50 | 32.3 | 33.3 | 31 | 31.7 | 30.8 | 30.8 |
| 55 | 32.2 | 33.1 | 30.7 | 31.4 | 30.8 | 30.8 |
| 60 | 32.1 | 32.8 | 30.6 | 31.6 | 30.8 | 30.8 |
| 65 | 32.1 | 32.7 | 30.5 | 31.2 | 30.8 | 30.8 |
| 70 | 32.1 | 32.6 | 30.5 | 30.9 | 30.8 | 30.8 |
| 75 | 32.1 | 32.5 | 30.5 | 30.7 | 30.8 | 30.8 |
| 80 | 32.0 | 32.4 | 30.5 | 30.5 | 30.8 | 30.8 |
| 85 | 32.0 | 32.3 | 30.5 | 30.5 | 30.8 | 30.8 |
| 90 | 32.0 | 32.2 | 30.5 | 30.5 | 30.8 | 30.8 |
| 95 | 32.0 | 32.1 | 30.5 | 30.5 | 30.8 | 30.8 |
| 100 | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |
| 105 | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |
| 110 | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |
| 115 | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |
| 120 | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |

### *3.2 Temperature Decay Data*

Depiction of thermal decay when each powder was subjected to room temperature can be referred in Figure 8. There are 6-line graphs in Figure 8A where each line represents temperature profile for respective banana powder and days. Data from Table 2 was reiterated into graph form in Figure 8 (A-D).

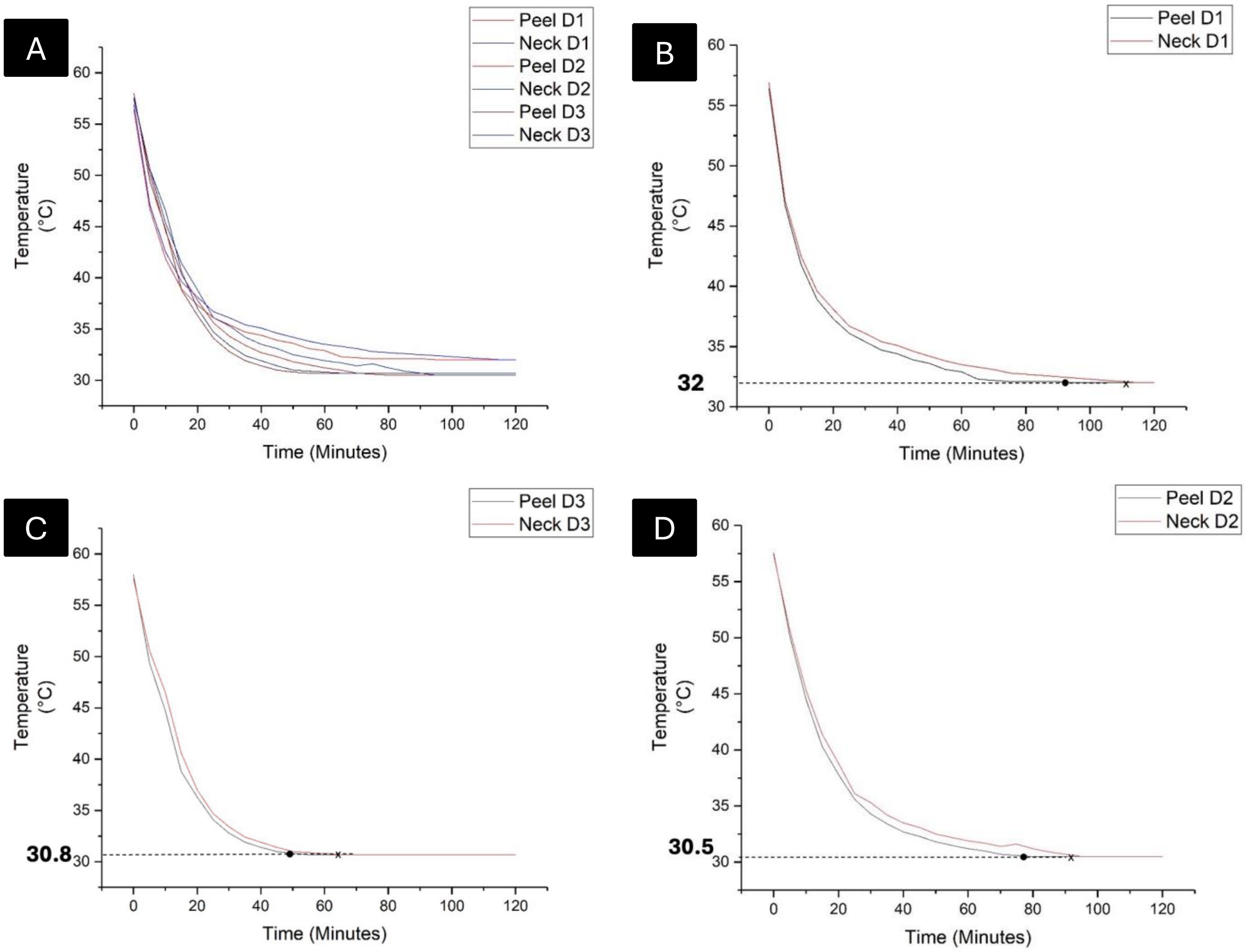

**Fig. 8.** (A) Summary of temperature decay across two banana powders and three days; (B) Day 1 of temperature decay for peel and neck; (C) Day 2 of temperature decay for peel and neck and (D) Day 1 of temperature decay for peel and neck

Exponential plot across all four graphs in the figures indicated a decreasing slope as temperature decreases against time. When each of the powder is removed from the oven, the temperature reading decreases exponentially. This indicated there is a net heat transfer flow from each of the powders into the surrounding air. Besides, Day 1 had the highest room temperature of 32 °C followed by Day 3 (30.8 °C) and Day 2 (30.5 °C). All graphs also indicated that all samples achieved thermal equilibrium temperature of the powders that matches the room temperature at the end of the sampling time and temperature.

Based on the second law of thermodynamics, heat can only transfer from a hotter material to cooler material [22]. In this case, the heated powders have higher temperature than the surrounding temperature. This temperature difference enabled heat to be transferred from each of the powder into the surrounding air. The exponential slope of temperature decrease can be inferred by the decreasing rate of heat transfer, as lesser molecules being transferred kinetically *via* heat convection [21]. Hence, air surrounding the room involves kinetically active molecules and the energy dissipates as the heat transfers from the heated powder into the air.

As illustrated in Figures 8B, 8C and 8D, temperature drops gradually until it reached a constant temperature reading. Temperature remained constant at 32°C where Peel D1 reaches earlier at the 80-minute mark, compared to Neck D1 (100-minute mark). For Day 2, both powders reached constant temperature of 30.5°C but peel reaches earlier at 65-minute mark, compared to neck, at 80-minute mark. The powders reached a stable temperature of 30.8 °C on Day 3 while peel approaches only at 40-minute mark and neck at 50-minute mark. Consistently across the three days, neck experience slower exponential of cooling effect compared to peel. Hence, neck may indicate slower heat transfer than peel.

Both peel and neck powders approached room temperature reading which was 32°C on Day 1. This pattern also reflects on Day 2, which recorded 30.5°C, both powders reach exact same temperature. For Day 3, room temperature was achieved for both neck and peel powders. Due to lack of equipment accessibilities, only temperature is recorded as benchmark for room conditions. When involving air as surrounding, there are also several other factors that may affect the rate of heat transfer flow including air velocity, relative humidity and median radiant temperature [23].

### *3.3 Heat Convection Analysis via Newton's Cooling Law*

According to Newton's law of cooling, an object's rate of heat loss is proportional to the temperature difference between it and its surroundings (T). The Eq. (1) for *T(t)* is dq/dt = $kA(T_f - T_0)$, where k is a constant and A represents the area of heat exchange. This equation suggests that temperature decreases exponentially with time. Based on Eq. (2), we can rearrange the formula to obtain the cooling constant and all the other values are available from the experiment. Eq. (3) is derived from Eq. (2), whereby the cooling constant, *k* can represent the respective cooling rates of distinct banana powders or days.

$$k = -ln \frac{(T(t) - T_0)}{T_f - T_0} \tag{3}$$

The final temperature was expected to be the room temperature, which are specific to each day. $T_f$ for Day 1, Day 2 and Day 3 was 32.0, 30.5 and 30.8 °C respectively. $T_0$ is the initial recorded temperature of powder directly after being removed from the oven which referred to first recorded temperature of each powder.

Based on Table 3, cooling constant, *k* is estimated to be the highest from Peel D3, followed by Neck D3, Peel D1, Peel D2, Neck D1 and Neck D2. This trend indicated that the room temperature difference of the day heavily affects the cooling rate of respective powders. For Day 1, Peel D1 had higher cooling rate than Neck D1 which was at 1.2 % difference in cooling constant. Consecutively, identical pattern for percentage difference was depicted for Day 2 (1.19 %) and Day 3 (1.29 %) samples with which peel experienced higher cooling rate than the neck. Consistent experiment data on three frequencies stipulate that neck had slower cooling rate than peel. Studies also have indicated that repeating experiments of different days will increase the accuracy and data consistency for thermal analysis [24,25].

**Table 3**
Various temperature *vs* types of powders at different days

| Experiment | Day 1 | | Day 2 | | Day 3 | |
|---|---|---|---|---|---|---|
| Graph Plot | Peel D1 | Neck D1 | Peel D2 | Neck D2 | Peel D3 | Neck D3 |
| Tf, room temperature ,(°C) | 32.0 | 32.0 | 30.5 | 30.5 | 30.8 | 30.8 |
| T(t) current temperature, (°C) | 36.1 | 36.7 | 35.6 | 36.1 | 34.1 | 34.7 |
| To, initial temperature ,(°C) | 56.4 | 56.9 | 57.6 | 57.4 | 58 | 57.6 |
| *t* (minute) | 10 | 10 | 10 | 10 | 10 | 10 |
| *k* (cooling constant) | 2.119 | 2.093 | 2.094 | 2.069 | 2.173 | 2.145 |

## 4. Conclusions

Based on the thermal analysis and temperature monitor performed, it can be deduced that in dry form banana neck has lower cooling constant than banana peel. Hence, the higher the cooling constant, the faster the temperature decreases in respect to time. This might suggest that banana neck exhibit latent heat and thermal resistance. Furthermore, studies indicate cellulose and lignin content is higher in neck than peel, explaining the higher thermal capacity of neck. Thus, banana neck (psuedostem) has higher potential in being an energy storage material for future development and research.

Despite two distinct banana part (neck and peel) powders measured at 40 g, the cooling effect is distinct as proven by the temperature analysis *via* graph and cooling constant based on Newton's cooling law. Previous studies have conducted thermal decay experiment based on Newton's Cooling Law including water-based setups and simulations [26,27]. This study has proven that thermal equilibrium with thermal decay is aligned with this law and calculation.

Though the experimental setup is affected by other several factors including air velocity and humidity, another minor complication is that the probe thermometer measures about few seconds after the powder is removed from the oven. Thermal equilibrium must occur nearly instantly, which limits the test to be most accurate, as temperature is not measured directly thereafter.

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## References

[1] Kumar, Nishant, Akash Ved, Ritu Rani Yadav, and Om Prakash. "A comprehensive review on phytochemical, nutritional, and therapeutic importance of Musa." *International Journal of Current Research and Review* 13 (2021): 114-124. https://doi.org/10.31782/IJCRR.2021.13901

[2] Gobilik, Januarius, Mattunjan Md Epin, Hamdy Roslie, David Benjamen Lintua, Kenneth Rodrigues, Suzan Benedick, and Abdul Hamid Ahmad. "Growth, Yield and Economic Potential of Cavendish Banana Planted in Oil Palm Gaps." *Transactions on Science and Technology* 9, no. 2 (2022): 43-52.

[3] Vishala, Jangam, and Gurpreet Singh. "A review on product development through pulp and peel of banana." *Plant Archives* 21, no. 1 (2021): 693-698. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.104

[4] Padam, Birdie Scott, Hoe Seng Tin, Fook Yee Chye, and Mohd Ismail Abdullah. "Banana by-products: an under-utilized renewable food biomass with great potential." *Journal of food science and technology* 51 (2014): 3527-3545, https://doi.org/10.1007/s13197-012-0861-2

[5] Chaudhari, Chetan Prakash, Kiran Bhole, and Jayram Gholave. "Review on banana fibre-reinforced composites." *Advances in Manufacturing Processes: Select Proceedings of RAM 2020* (2021): 359-379. https://doi.org/10.1007/978-981-15-9117-4_27

[6] Singh, Shresht, Nithesh Naik, Nilakshman Sooriyaperakasam, Tejas Iyer, Chirag Agarwal, Jeswanthi Tirupathi, and Mahmood Al Abdali. "A comprehensive review of banana fiber-reinforced composites: properties, processing and applications." *Journal of Computers, Mechanical and Management* 1, no. 2 (2022): 22-33. https://doi.org/10.57159/gadl.jcmm.1.2.22011

[7] “Fire Safety Regulations: A Comparative Study of Malaysia and England and Wales.” Accessed: Nov. 12, 2024. [Online]. Available: https://www.buildingengineer.org.uk/intelligence/fire-safety-regulations-comparative-study-malaysia-and-england-and-wales

[8] Muhamad Salleh, Naziah, Nuzaihan Aras Agus Salim, Mastura Jaafar, Mohd Zailan Sulieman, and Andrew Ebekozien. "Fire safety management of public buildings: a systematic review of hospital buildings in Asia." *Property Management* 38, no. 4 (2020): 497-511. https://doi.org/10.1108/PM-12-2019-0069

[9] Biswal, Manoranjan, Smita Mohanty, and Sanjay K. Nayak. "Thermal stability and flammability of banana-fiber-reinforced polypropylene nanocomposites." *Journal of applied polymer science* 125, no. S2 (2012): E432-E443, https://doi.org/10.1002/app.35246

[10] Muthukumar, K., R. V. Sabariraj, S. Dinesh Kumar, and T. Sathish. "Investigation of thermal conductivity and thermal resistance analysis on different combination of natural fiber composites of banana, pineapple and jute." *Materials Today: Proceedings* 21 (2020): 976-980. https://doi.org/10.1016/j.matpr.2019.09.140

[11] Te, Wei Zun, Kavinesh Nair Manor Muhanin, Yu-Ming Chu, Anurita Selvarajoo, Ajit Singh, Shams Forruque Ahmed, Dai-Viet N. Vo, and Pau Loke Show. "RETRACTED: Optimization of Pyrolysis Parameters for Production of Biochar From Banana Peels: Evaluation of Biochar Application on the Growth of Ipomoea aquatica." *Frontiers in Energy Research* 8 (2021): 637846. https://doi.org/10.3389/fenrg.2020.637846

[12] Kong, Fanbei, Baisheng Nie, Chao Han, Dan Zhao, Yanan Hou, and Yuxuan Xu. "Flame retardancy and thermal property of environment-friendly poly (lactic acid) composites based on banana peel powder." *Materials* 15, no. 17 (2022): 5977. https://doi.org/10.3390/ma15175977

[13] Kayisu, Kalenga, LAMARTINE F. HOOD, and Peter J. Vansoest. "Characterization of starch and fiber of banana fruit." *Journal of food science* 46, no. 6 (1981): 1885-1890, https://doi.org/10.1111/j.1365-2621.1981.tb04511.x

[14] El Moustaqim, Mehdi, Abderrahmane El Kaihal, Maryam El Marouani, Samir Men-La-Yakhaf, Mhamed Taibi, Saloua Sebbahi, Souad El Hajjaji, and Fatima Kifani-Sahban. "Thermal and thermomechanical analyses of lignin." *Sustainable chemistry and pharmacy* 9 (2018): 63-68. https://doi.org/10.1016/j.scp.2018.06.002

[15] Silviya, E. K., G. Unnikrishnan, S. Varghese, and J. T. Guthrie. "Thermal and mechanical characterization of EVA/banana fiber-derived cellulose composites." *Journal of applied polymer science* 125, no. 1 (2012): 786-792. https://doi.org/10.1002/app.35140

[16] Manohar, Krishpersad. "Experimentally determined apparent thermal conductivity of banana fibre." *International Journal of Innovative Research in Science, Engineering and Technology* 5, no. 8 (2016): 14317-14323. https://doi.org/10.15680/IJIRSET.2016.0508003

[17] Nascimento, Rosa EA, Mónica Carvalheira, João G. Crespo, and Luísa A. Neves. "Extraction and Characterization of Cellulose Obtained from Banana Plant Pseudostem." *Clean Technologies* 5, no. 3 (2023): 1028-1043. https://doi.org/10.3390/cleantechnol5030052

[18] Tadesse, Melkie Getnet, Esubalew Kasaw, and Jörn Felix Lübben. "Valorization of banana peel using carbonization: potential use in the sustainable manufacturing of flexible supercapacitors." *Micromachines* 14, no. 2 (2023): 330. https://doi.org/10.3390/mi14020330

[19] Anuar, Mohd Shamsul, Suraya Mohd Tahir, Muhammad Irfan Najeeb, and So’bah Ahmad. "Banana (Musa acuminata) peel drying and powder characteristics obtained through shade and microwave drying processes." *Advances in Materials and Processing Technologies* 5, no. 2 (2019): 181-190. https://doi.org/10.1080/2374068X.2018.1545201

[20] Davidzon, Michael I. "Newton’s law of cooling and its interpretation." *International journal of heat and mass transfer* 55, no. 21-22 (2012): 5397-5402. https://doi.org/10.1016/j.ijheatmasstransfer.2012.03.035

[21] Ghassemi, Majid, Majid Kamvar, and Robert Steinberger-Wilckens. *Fundamentals of heat and fluid flow in high temperature fuel cells*. Academic Press, 2020. https://doi.org/10.1016/B978-0-12-815753-4.00005-1

[22] Boltzmann, Ludwig. "The second law of thermodynamics." In *Theoretical physics and philosophical problems: selected writings*, pp. 13-32. Dordrecht: Springer Netherlands, 1974. https://doi.org/10.1007/978-94-010-2091-6_2

[23] Yang, Yuxin, Junmeng Lyu, Heng Du, Zhiwei Lian, Weiwei Liu, Lin Duanmu, Yongchao Zhai et al. "Main effects and interactions of multiple key factors related to thermal perception." *Science of the Total Environment* 918 (2024): 170683. https://doi.org/10.1016/j.scitotenv.2024.170683

[24] National Academies of Sciences, Policy, Global Affairs, Board on Research Data, Information, Division on Engineering, Physical Sciences, Committee on Applied, Theoretical Statistics, Board on Mathematical Sciences and Analytics, 2019. *Reproducibility and replicability in science*. National Academies Press. https://doi.org/10.17226/25303

[25] Nosek, Brian A., Tom E. Hardwicke, Hannah Moshontz, Aurélien Allard, Katherine S. Corker, Anna Dreber, Fiona Fidler et al. "Replicability, robustness, and reproducibility in psychological science." *Annual review of psychology* 73, no. 1 (2022): 719-748. https://doi.org/10.31234/osf.io/ksfvq

[26] Wibowo, Edy, Naily Ulya, Mohammad Rakha Farizi, and Nurwulan Fitriyanti. "Derivation of Newton's law of cooling and heating: Heating the water then cooling it down naturally to the room temperature." *Momentum: Physics Education Journal* 7, no. 1 (2023): 78-92. https://doi.org/10.21067/mpej.v7i1.6889

[27] Xiao, Hui, Zhimin Dong, Rui Long, Kun Yang, and Fang Yuan. "A study on the mechanism of convective heat transfer enhancement based on heat convection velocity analysis." *Energies* 12, no. 21 (2019): 4175. https://doi.org/10.3390/en12214175