The Feasibility of Varying Banana Fiber Thickness as Insulation in a Cookstove to Improve Carbon Emissions and Boiling Time of Water

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Abstract: This study aims to utilize banana fibers as insulation to provide a cleaner, safer cookstove for those living beyond the poverty line. The researchers will collect portions of banana tree species Musa acuminata × balbisiana and obtain fibers to be used as insulation for the cookstove for a total of 4 cookstove setups. Boiling Time of Water (BTW) and CO emissions percentage is tested to identify which cookstove is the most efficient using One-Way MANOVA, Mean and Standard Deviation. The results show an increase in Carbon Monoxide levels and an increase in BTW as the Thickness of Banana Fiber Insulation (TBFI) increases. Therefore, the hypothesis is denied, and TBFI affects its insulation properties. Consequently, banana fibers are not efficient thermal insulators for cookstoves.

Key Words: banana fibers; insulation; cookstove; emissions.

1. INTRODUCTION

Study shows that families living in poverty (earning 163 Philippine Pesos or less/day) cannot afford appliances with the proper health and environmental benefits (ADB, 2015). Many households do not possess a cookstove to cook their daily meals, resulting in families cooking on an open fire or a substandard cookstove. "The typical cooking fire produces about 400 cigarettes' worth of smoke an hour, and prolonged exposure is associated with respiratory infections, eye damage, heart and lung disease, and lung cancer" (National Geographic, 2017). Most fatalities related to fires do not occur due to burns but instead inhaling toxic gases produced during combustion. Results from Manohar's study (2016) conclude that banana fibers gathered from the trunk of a banana tree have better insulation properties than a standard unsustainable insulator.

1.1 Statement of the Problem

An improved cookstove system utilizing various thicknesses of banana fiber insulation is tested by the researchers' as a potential alternative to conventional cookstoves to 1) determine whether the banana fiber acts as a quality insulator for the cookstoves, and 2) whether the percentage of CO particles and the boiling time of water is affected by the insulator in any way.

The research questions are as follows:

1. What is the percentage of Carbon Monoxide (CO) and the boiling time of water using a cookstove with varying banana fiber thicknesses as insulation?
2. Is there a significant difference between the percentage of Carbon Monoxide (CO) and the boiling time of water among the four setups?

2. METHODOLOGY

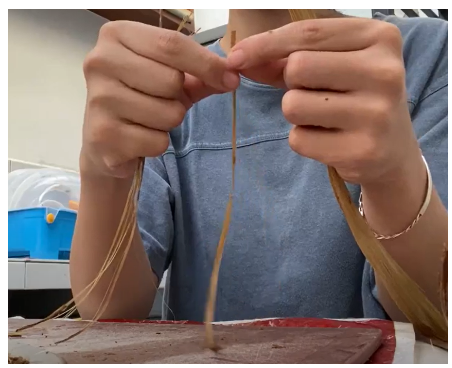
2.1 Research Design

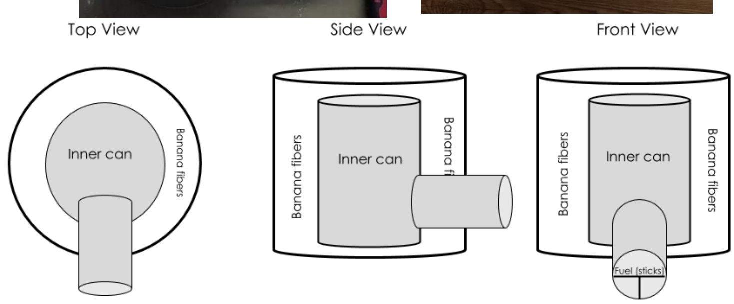
The research design of this study is causal-comparative. The researchers examined the independent variables (thickness of banana fiber insulation) and how it was affected by the dependent variables (CO emissions percentage and boiling time of water) and studied the cause and effect relationships between variables.

2.2 Before Experimentation

The researchers submitted a letter of request to conduct a study to the head of the Research Department. Also, the team completed an ethics checklist to ensure the safety and ethical standpoint of this research.

Banana fibers were gathered through the banana plant Musa acuminata × balbisiana. “Tuxing”, a Filipino method, was utilized to extract the banana fibers. The banana fibers acted as a thermal insulator in the study. The clean cookstove required one 15.5 cm × 10 cm empty metal cans (originally coffee cans) as the cookstove’s body. An additional tin can (20 cm × 7 cm, 20 cm × 9 cm, 20 cm × 11 cm) was placed inside the outer body. The banana fibers were placed in between the two metal cans to serve as the insulator. Lastly, a small can (17.5 cm × 11 cm) was horizontally placed on the side of the body to act as the fuel holder and to allow oxygen flow. Four cookstoves were created in total, each with different thicknesses of banana fiber insulation (0 mm of banana fibers, 20 mm, 30 mm, 45 mm). 7 ounces of dried charcoal acted as the fuel for the cookstoves. In addition to the cookstoves, the researchers used an automotive-grade exhaust analyzer to detect and measure the different gases emitted. The toxicity of the smoke being released is determined by the percentage of CO with the amount of the gas particles being directly proportional to the toxicity of the smoke. A percentage of gas is given by the emission analyzer during the test.





2.3 Data Gathering Procedure

The automotive-grade exhaust analyzer was placed in the fuel chamber of the cookstove prior to the Water Boiling Test (WBT). This was to ensure the machine had time to read the CO released while the WBT was ongoing. Two (2) cups of room temperature water were placed in a pot and onto the stovetop while the charcoal was lit. A thermometer was placed inside the pot and the stopwatch started. The WBT determined the boiling times of water per setup. The stopwatch stopped (seconds) once the temperature reached 100 degrees celsius. Both the smoke emissions test and the WBT were performed six times per set up to ensure correct data. The charcoal was switched each trial to ensure data was consistent.

Once all the data was collected, the experimentation location was cleaned and the researchers continued on with their data analysis.

2.4 Data Analysis

The data analysis portion of the study was conducted on SPSS Version 4. The mean and standard deviation was used to determine the percentage of CO and the boiling time of water with cookstoves containing varying thicknesses of banana fiber insulation. Secondly, one-way Manova was used to determine whether there was a significant difference between the percentage of CO and the boiling time of water among the four setups.

3. RESULTS AND DISCUSSION

Research Question 1. What is the percentage of Carbon Monoxide (CO) and boiling time of water using a cookstove with varying banana fiber thicknesses as insulation?

	Setup	Mean	Std. Deviation	N
CO	00 mm TBFI	.0767	.01366	6
	20 mm TBFI	.1633	.03327	6
	30 mm TBFI	.1950	.02811	6
	45 mm TBFI	.0883	.01941	6
	Total	.1308	.05587	24
Boiling Time	00 mm TBFI	26.3767	1.72718	6
	20 mm TBFI	32.5817	1.18749	6
	30 mm TBFI	37.6300	2.14297	6
	45 mm TBFI	43.6600	2.67159	6
	Total	35.0621	6.76712	24

TBFI – Thickness of Banana Fiber Insulation

Table 1. Results of setups

Table 1 shows the results of four (4) setups with varying banana fiber insulation. Six (6) trials were conducted for each setup. For the percentage of CO, the 30 mm of banana fiber insulation had the highest measurement (M = .1950, SD = .2811) followed by 20 mm (M = .1633, SD = .0333), 0 mm (M = 0.767, SD = 0.137), and 45 mm (M = .0883, SD = .0194) respectively. For the boiling time of water, the 45 mm thick banana fiber insulation had the longest boiling time (M = 43.6600, SD = 2.6716) followed by 30 mm (M = 37.5817, SD = 2.1430), 20 mm (M = 32.5817, SD = 1.1875), and 00 mm (M = 26.3767, SD = 1.7272) respectively.

The researchers have observed that as the thickness increases, so does the boiling time. This trend was also observable for the percentage of Carbon Monoxide; however after the 30mm setup, there was a decrease. Concerning the boiling time, the trend suggests that a smaller insulation thickness would translate to a shorter boiling time. Therefore, we can say that the less banana fiber insulation, the more thermally efficient the cookstove is. Possible factors contributing to the unexpected findings are a lid, the small size of the stove, material of cans, burning of banana fibers, and length of the combustion chamber.

Research Question 2. Is there a significant difference between the percentage of Carbon Monoxide (CO) and the boiling time of water among the three setups?

Box's Test of Equality of Covariance Matrices			Shapiro-Wilk Test		
			Statistic	df	Sig.
Box's M	12.090	Standardized Residual for Percentage of CO	.958	24	.394
F	1.098	Standardized Residual for Boiling Time of Water	.950	24	.277
df1	9				
df2	4583.923				
Sig.	.360				

Table 2. Test of Equality of Variances and Normality

Table 2 shows the Box's Test, and the assumption on the equality of variance is satisfied, $p > 0.05$. The normality of the standardized residuals was examined using Shapiro-Wilk Test and found that the residuals follow a multivariate normal distribution ($p > 0.05$). Hence, Wilks' Lambda Test was used to determine if there is a significant difference in the CO percentage and the boiling time of water among the cookstoves with different thicknesses of banana fiber insulation.

Table 3. Multivariate Tests and Test Between-Subject

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared[d]
TBFI	Wilks' Lambda	.012	52.244[b]	6.000	38.000	.000	.892

	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared[d]
TBFI	Percentage of CO	.411	1	.411	667.995	.000	.829
	Boiling Time of Water	29504.392	1	29504.392	7319.825	.000	.923

a. *Partial eta squared can be cited as a measure of effect size: f^2 is Cohen's effect size: .02 = small, .15 = moderate, .35 = large.*

Effects

Table 3 presents the difference between the percentage of CO and boiling time of water of the cookstove with different thicknesses of banana fiber insulation. Results were as follows, $F(6, 38) = 52.244$, $p < 0.05$. Wilks' Lambda and partial η^2 were found to identify whether the thickness of banana fiber insulation had a large effect on the CO levels and boiling time of the cookstove. The results were as follows, Wilks' Lambda = 0.012, partial η^2= 0.892. Specifically, Table 5 showed that the differences in the thickness of banana fiber insulation had the strongest effect on the boiling time of water (partial η^2= 0.923), then CO (partial η^2= 0.829).

ble	(I) Setup	(J) Setup	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
ıana	00 mm TBF	20 mm TBFI	-.087*	.014	.000	-.117	-.057
		30 mm TBFI	-.118*	.014	.000	-.148	-.088
		45 mm TBFI	-.012	.014	.425	-.042	.018
	20 mm TBFI	30 mm TBFI	-.032*	.014	.039	-.062	-.002
		45 mm TBFI	.075*	.014	.000	.045	.105
	30 mm TBF	45 mm TBFI	.107*	.014	.000	.077	.137
	00 mm TBFI	20 mm TBFI	-6.205*	1.159	.000	-8.623	-3.787
		30 mm TBFI	-11.253*	1.159	.000	-13.671	-8.835
		45 mm TBFI	-17.283*	1.159	.000	-19.701	-14.865
	20 mm TBFI	30 mm TBFI	-5.048*	1.159	.000	-7.466	-2.630
		45 mm TBFI	-11.078*	1.159	.000	-13.496	-8.660
	30 mm TBFI	45 mm TBFI	-6.030*	1.159	.000	-8.448	-3.612

ed marginal means
rence is significant at the .05 level.
multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 4. Pairwise Comparisons

In table 4, the percentage of CO is significantly different between 00 mm TBFI and 20 mm TBFI and 00 mm and 30 mm TBFI ($p < 0.05$). There was also a significant difference in the percentage of CO among 20 mm TBFI and 45 mm TBFI and 30 mm TBFI and 45 mm TBFI ($p < 0.05$). This is to say that the TBFI made a significant difference in the percentage of CO between the 00 mm TBFI and 20 mm TBFI, 00 mm TBFI and 30 mm TBFI, 20 mm TBFI and 45 mm TBFI, and 30 mm TBFI and 45 mm TBFI. There is no significant difference in the percentage of CO between 00 mm TBFI and 45 mm TBFI and 20 mm TBFI and 30 mm TBFI ($p > 0.05$). The TBFI did not have a significant effect on the percentage of CO between the two pairs of setups. The BTW had a significant difference between all setups ($p < 0.05$), meaning that the TBFI significantly affected the BTW between each setup.

Based on the data gathered from the experimentation, the researchers have found varying percentages of carbon monoxide and boiling times from each setup. Table 3 shows that there is a significant difference between the two dependent variables, namely the boiling time and percentage of Carbon Monoxide with different thicknesses of banana fiber insulation. The study also found that the banana fiber thicknesses had a substantial effect on the percentage of Carbon Monoxide and boiling time. Table 4 shows that all but one pair (0mm and 45mm) have a significant difference when it comes to Carbon Monoxide since $p > .05$. Possible reasons for the unexpected findings are the burning of banana fibers, length of the combustion chamber, the possibility of absorption of gases by banana fibers, and moisture content of the fuel.

4. CONCLUSIONS

The first objective of the study is to identify the percentage of Carbon Monoxide (CO) and boiling time of water with varying banana fiber thicknesses as insulation. This means that as the thickness increases, so does the boiling time. This trend was also observable for the percentage of Carbon Monoxide; however after the 30mm setup, there was a decrease. With the boiling time, the trend suggests that a smaller insulation thickness would translate to a shorter boiling time. Therefore, one can assume that the less banana fiber insulation, the more thermally efficient the cookstove is. A study (Quist, Jones, Lewis, 2016) collected data that shows that the presence of a lid resulted in higher heat which connects to a quicker boiling time.

The researchers have observed that throughout the experiments' progression, particularly the 30mm setup, the banana fibers slowly began to burn, which may have decreased the insulation properties. The length of the combustion chamber, the area in which there is ventilated air, may have contributed to the 45mm setups drop in mean since it had the shortest chamber. The researchers have recognized that air circulation is significant as this allows for a more efficient and safer cookstove. Kshirsagar & Kalamkar (2014) found that cookstoves with fan-based air circulation emits 30% less carbon monoxide and consumes 37% less fuel which could be used as a basis for more improved cookstove designs of future studies. A separate can was attached to the cookstove's side to serve as an exhaust for the fumes which was also where the Automotive Gas Analyzer was placed. The same cans were used for each setup meaning the 45mm setup had the shortest can extending outward. Since the 45mm setup had the shortest exhaust can, this may have allowed for the Carbon Monoxide to escape and become undetected by the Automotive Gas Analyzer. A previous study by Mensah et al. (2020) stated that cookstoves with secondary air supply produced the lowest particulate matter emissions. Since the 45mm setup has the largest secondary air supply or exhaust hole, it may have caused a lower percentage of emissions. These findings indicate that the setups with the greatest to least Carbon Monoxide Emissions are the following: 30mm, 20mm, 45mm, 0mm. Therefore, the researchers have found a cookstove safer without the banana fiber insulation since it has the lowest Carbon Monoxide Emissions.

The second objective of the study is determining whether there is a significant difference between the percentage of Carbon Monoxide (CO) and the boiling time of water between the four setups. Based on the data gathered from the experimentation, the researchers have found varying percentages of carbon monoxide and boiling times from each setup. Table 2 shows that there is a significant difference between the two dependent variables, namely the boiling time and percentage of Carbon Monoxide with different thicknesses of banana fiber insulation.

In summary, the results do not support the theoretical framework: banana fiber insulation does not help thermal efficiency and does not reduce CO emissions. As the banana fiber gets thicker, the percentage of CO emissions increases, and the time it takes to boil water increases. However, there was an unexpected decrease in the percentage of CO emissions when the 45 mm banana fibers were tested, and it had no significant difference on the 0 mm banana fibers. The researchers had to gather data under a time constraint, and there was also a lack of available materials for the data gathering. Eight trials per setup were the supposed amount to be conducted to ensure the accuracy of the results; however only six trials of each setup were carried out. Moreover, the material used to make the cookstoves were metal cans, which only a few studies have done. Researchers pursuing the same study can use the paper's findings to create a better cookstove. Communities that use cookstoves as a medium to cook their meals can disregard using banana fibers as an insulator since it does not make a cookstove more thermally efficient and produce less CO.

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