5th African International Conference on Industrial Engineering and Operations Management, Johannesburg/Pretoria, South Africa, April 23 - 25, 2024
Publisher: IEOM Society International, USA
Published: April 23, 2024 DOI: 10.46254/AF05.20240256

A Brewing Solution: Utilizing Spent Coffee Grounds As An Alternative Biomass Fuel

Gerald M. Araco, Francis Miguel C. Flores, Andre Louis C. Ollica, Ralph Daniel C. Paglinawan, and Damirson A. Co, MSIE, PIE (co-author)
Department of Industrial Engineering
University of Santo Tomas
España Blvd., Sampaloc, Manila, Philippines 1008
gerald.araco.eng@ust.edu.ph, francismiguel.flores.eng@ust.edu.ph, andrelouis.ollica.eng@ust.edu.ph, ralph.paglinawan.eng@ust.edu.ph
daco@ust.edu.ph

Abstract

In response to the global demand for sustainable energy, researchers explore biomass fuels like Spent Coffee Grounds (SCGs) as eco-friendly alternatives. This study compares SCG fuel pellets with commercial ones for thermal properties, aiming to establish SCGs as viable biomass fuel alternatives. SCGs, sourced from Arabica coffee ground waste, undergo pelletization using an industrial pelletizer with starch as a binding agent. The study measures moisture content, ash content, and calorific value through laboratory experiments. Statistical analyses using T-test reveal significant differences in moisture and ash content between SCG Fuel Pellets and commercial counterparts, with no significant difference in calorific value. SCG Fuel pellets excel in moisture and ash content, making them viable alternatives. The study recommends further research on the industrial performance and scalability of SCG fuel pellets. This research contributes valuable insights into repurposing coffee production waste, offering an environmentally friendly alternative. It supports efforts to diversify the world's energy portfolio and mitigate the environmental impact of conventional fuel sources.

Keywords
Spent Coffee Grounds, Biomass Fuel, Palletization, Thermal Properties, T-Test

1. Introduction
The escalating global exchange of materials, integral to manufacturing processes (Banton 2023), invariably results in substantial waste production across diverse manufacturing scales (Southern Waste and Recycling, 2021). This waste, defined as discarded material without further use, poses environmental threats when deposited in landfills (Christenson et al. 2000). As a response, enhancing resource efficiency and minimizing landfill waste has become imperative for sustainable practices (Hamedani et al. 2022). In the field of sustainability, there is a growing emphasis on transforming waste materials, such as Spent Coffee Grounds (SCG), into valuable products (Lühmann 2020).

Coffee, the second most globally consumed beverage after tea (Scully et al.2016), significantly contributes to waste generation, particularly in the form of SCG (Zuorro & Lavecchia 2012). Despite attempts to repurpose SCG, a substantial portion still finds its way into landfills, with only 25% being repurposed for agricultural products (Kanniah, 2020). Notably, the Philippines, the second-largest consumer of coffee in Asia, is poised to witness a 4.4% year-on-year increase in coffee consumption by 2025 (Cigaral, 2023). This surge in coffee consumption not only exacerbates the global waste issue but also demands innovative solutions for which it could have functional uses (Tiseo 2023).

Simultaneously, the quest for alternative energy sources gains prominence in meeting escalating energy demands while mitigating environmental repercussions (Colantoni et al. 2021). Biomass resources, including SCG, have emerged as substitutes for fossil fuels, particularly in the production of ethanol and fuel pellets (Kondamudi, 2008). SCG pellets exhibit favorable characteristics, such as low ash content, high fuel cell content, and high specific heat of combustion (Smirnov et al. 2022). However, optimizing boiler efficiency proves challenging, necessitating the incorporation of binding agents like sawdust (Nosek et al.2020; Limousy 2013). Alternative binding agents, such as starch, adhere to industry standards, ensuring the quality of SCG fuel pellets (Kristanto & Wijaya 2018). Environmental life cycle assessments underscore the potential of SCG fuel pellets in climate change mitigation and waste reduction (Hamedani et al. 2022).

This research proposes a novel solution involving the utilization of SCG in fuel pellets, to compare its properties—moisture content, ash content, combustion efficiency, and calorific value—against a commercially procured brand of fuel pellets. By employing cornstarch as a binding agent, readily available in the Philippines, the study seeks to evaluate the economic viability of SCG pellets relative to traditional biomass fuels, with a particular emphasis on their potential as alternative biomass sources in various industries.

1.1 Objectives

The primary aim of this research is to conduct a comparative analysis between fuel pellets derived from Spent Coffee Grounds (SCG) and commercially purchased biomass fuel pellets, focusing on key parameters (i.e. thermal properties) such as moisture content, ash content, and calorific value.

2. Literature Review

The adverse environmental impact of fossil fuels, notably coal, is unequivocal, emitting harmful pollutants such as sulfur dioxide (SO2), nitrogen oxide (NOx), particulate matter (PM), and carbon dioxide (CO2). In 2019, coal consumption accounted for a staggering 80.8% of global energy consumption, significantly contributing to climate change and posing severe health risks. The consequences include compromised air quality, leading to respiratory and cardiovascular diseases and premature deaths, as exemplified by the Philippines with nearly 27,000 deaths annually and economic losses of 1.9% of GDP (Greenpeace Southeast Asia 2020). Fossil fuel production and consumption have also led to environmental issues like acid rain, eutrophication, groundwater contamination, and the generation of 300 million tons of plastic waste annually (Fossil Fuels and Climate Change: The Facts 2022).

Spent coffee grounds (SCG) emerge as a potential biomass fuel source due to their rich composition in organic compounds and minerals. Studies highlight the presence of polysaccharides, polyphenols, and amino acids, making SCG suitable for diverse applications, ranging from the food industry to alternative fuel sources. The potential of SCG lies not only in waste reduction but also in its contribution to renewable energy solutions (Cruz 2012; Vega et al., 2015; Colantoni et al. 2021).

palletization serves as a transformative process, converting SCG into fuel pellets that offer a renewable and clean-burning alternative. Analogous to wood pellets, these compressed particles provide a carbon-neutral energy source, contributing to home heating, industrial processes, and electricity generation. Wood pellets, the most commercially available form, demonstrate advantages such as lower ash residues, and reduced debris, and dust, making them a superior alternative to traditional methods (Jones & Harper, n.d.).

While SCG shows promise as a biomass fuel, there are environmental concerns, particularly in emissions during the drying and pelletization processes. The open-air drying approach is recommended to minimize the overall impact on the environment. Pure SCG pellets may emit higher levels of NOx and exhibit reduced combustion efficiency, emphasizing the need to combine SCG with other materials for improved performance. Striking a balance between harnessing the potential of SCG and mitigating environmental impact remains a critical aspect of its utilization (Energy Reports 2022; Kristanto et al. 2018).

Exploring the economic feasibility of SCG as biomass fuel reveals promising prospects, considering its abundance and low cost. Factors such as location, collection, transportation, and conversion technologies play vital roles in determining economic performance. SCG's potential for diverse value-added products positions it as a profitable commodity for various industries, ranging from biofuels to adsorbents and bioactive chemicals (Kookos 2018; Utilization of Spent Coffee Grounds - "A Profitable Coffee Waste," 2023).

Innovations in SCG utilization extend across various applications, including refuse-derived fuel, biomethane production, biochar creation, sustainable dye, and energy storage materials. The diversification of SCG into different products underscores its versatility and potential contributions to multiple industries (Johnson et al.2022; Kim et al. 2020; Limousy et al. 2017).

Practical insights from studies emphasize the significance of the drying process in influencing SCG properties. Solar drying stands out as an advantageous method, balancing low energy requirements with quality dried SCG. The combustion efficiency challenges of SCG can be addressed through the incorporation of binding agents, such as starch, demonstrating the importance of optimizing composition for acceptable standards (Colantoni et al.2021; Kristanto & Wijaya 2018).

Relevant policies, such as the Renewable Energy Act of 2008 in the Philippines, actively promote the use of biomass fuels and renewable energy sources (Republic Act No. 9513, 2008). These policies aim to reduce harmful emissions and encourage the development of renewable energy systems at national and local levels. The regulatory framework plays a pivotal role in shaping the trajectory of SCG utilization in renewable energy systems.

Despite the potential of SCG as a renewable energy source, several challenges must be addressed for successful integration. Feedstock availability, technological constraints, environmental impact, and policy/regulatory constraints represent barriers that require careful consideration. These challenges, altogether, emphasize the complexity of transitioning to renewable energy sources and highlight the need for comprehensive solutions (European Biomass Industry Association 2009).

In conclusion, SCG has emerged as a promising biomass fuel and offers a sustainable solution to waste management while addressing economic and environmental concerns. The ongoing research and development in this field can contribute to a more efficient and environmentally friendly use of coffee waste, fostering a greener and sustainable future. As the study progresses, a comparative analysis of SCG pellets against commercially available biomass fuel pellets will provide valuable insights into their performance metrics, shaping the trajectory of SCG in the renewable energy landscape.

3. Methods

This study employed a quantitative comparative research design, comparing two groups of biomass fuel pellets: (1) SCG pellets and (2) a commercially procured brand of wood fuel pellets, across specific thermal properties to determine differences and ascertain the former's compliance with energy industry standards (i.e. whether or not it is a capable biomass fuel). The experimental comparative analysis imposed specific conditions to observe the impact on dependent variables (thermal properties). The selection of this research design stemmed from the need for an objective comparison, considering the abundant production of spent coffee grounds, a by-product of one of the most consumed beverages, coffee. Specifically, the comparison focused on three thermal properties: moisture content, ash content, and calorific value, aiming to evaluate the suitability of SCGs as a viable biomass fuel alternative.

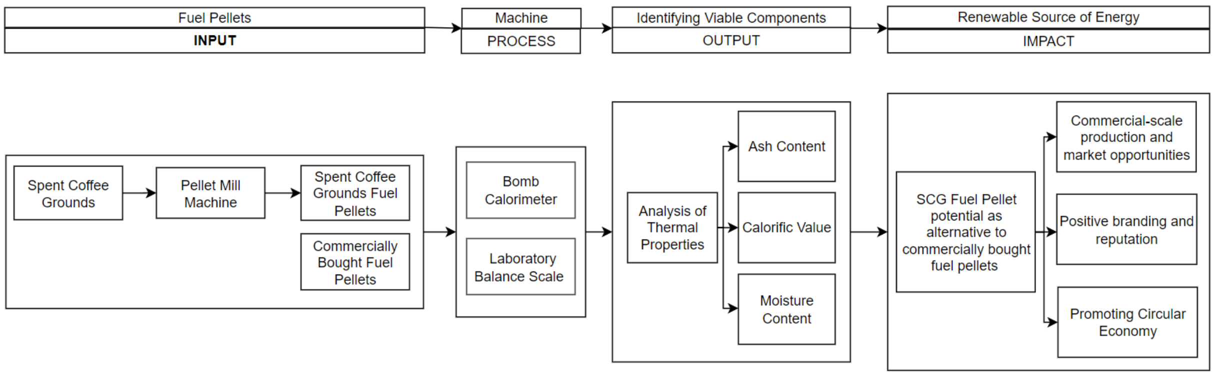

Figure 1. Conceptual Framework

In the conceptual framework presented in Figure 1, a comparative analysis was conducted between fuel pellets derived from spent coffee grounds and commercially available ones. The study began with the pelletization of spent coffee grounds using a pellet mill machine, resulting in the production of spent coffee ground fuel pellets for comparison. Both sets of pellets underwent combustion in a designated chamber prior to analysis. The researchers employed three key analytical tools: a calorimeter to determine calorific values, a laboratory balance scale to measure pellet mass for evaluating changes such as ash content and moisture loss. Three thermal properties were scrutinized: ash content to detect inorganic impurities, calorific value analysis for energy potential, and moisture content for efficient combustion. Additionally, the impact of both fuel pellets was assessed across three dimensions: enhancing branding for environmentally conscious companies, identifying commercial-scale production viability, and promoting a circular economy by repurposing coffee waste.

4. Data Collection

The study was conducted at the Department of Science and Technology - Industrial Technology Development Institute, General Santos Avenue, Bicutan, Taguig City, Philippines. Spent coffee grounds were sourced from various coffee shops, and testing was carried out at the University of Santo Tomas - Chemical Engineering Laboratory. Sample size calculations were performed using G*Power software, resulting in a total of 42 batches collected, each comprising 21 batches per group of fuel samples. This necessitated collecting at least 2.1kg of material per variable due to laboratory equipment limitations. The independent variables were spent coffee ground fuel pellets and commercially bought fuel pellets, produced through pelletization and online purchase, respectively. These variables were compared to assess the superiority or inferiority of spent coffee grounds. Dependent variables included moisture content, ash content, and calorific value. Instruments such as weighing scales, bomb calorimeters, and sample cups were used for measurements. Data gathering procedures involved acquiring samples, pelletizing spent coffee grounds, drying fuel pellets, and assessing physical and thermal properties. Moisture content was determined using a formula, while calorific value and ash content were measured using calorimeters and weighing scales, respectively. The procedure was repeated for all 42 batches of fuel pellets. Statistical analysis, including independent samples t-tests conducted via SPSS, was employed to evaluate significant differences between the physical and chemical properties of the two types of fuel pellets. Results were interpreted accordingly to draw conclusions.

5. Results and Discussion

5.1 Numerical Results

The results of the moisture content analysis are presented in Tables 1 and 2. The moisture content of the SCG Fuel Pellet has a higher value due to it being moist compared to the commercially available Fuel pellets that are drier, which means that it has lower moisture content. A lower moisture content is better for efficient burning while producing less pollution. In this aspect, the moisture content of commercially available fuel pellets is seen to have a better outcome.

Moisture Content (%)= (Initial Wet Weight - Final Dry Weight / Initial Wet Weight) x 100

Equation 1. Moisture Content Formula

Table 1. Moisture Content of SCG Fuel Pellets

Sample	Initial Wet Weight (g)	Final Dry Weight (g)	Moisture Content (%)
1	70.87	47.32	33.23%
2	70.68	47.25	33.15%
3	70.13	48.57	30.74%
4	70.24	46.38	33.97%
5	70.27	47.17	32.87%
6	70.16	47.45	32.37%
7	70.74	48.53	31.40%
8	70.25	47.46	32.44%
9	70.23	48.15	31.44%
10	70.31	47.54	32.39%
11	70.25	46.21	34.22%
12	70.12	47.55	32.19%
13	70.21	47.89	31.79%
14	70.89	48.26	31.92%
15	70.28	46.67	33.59%
16	70.15	47.78	31.89%
17	70.34	48.29	31.35%
18	70.78	47.59	32.76%
19	70.22	48.03	31.60%
20	70.42	48.20	31.55%
21	70.38	47.27	32.84%

Table 2. Moisture Content of Commercially-Available Fuel Pellets

Sample	Initial Wet Weight (g)	Final Dry Weight (g)	Moisture Content (%)
1	71.41	73.12	2.39%
2	71.35	74.38	4.25%
3	71.11	74.21	4.36%
4	69.89	71.28	1.99%
5	71.23	72.17	1.32%
6	69.78	72.26	3.55%
7	71.38	73.09	2.40%
8	71.12	74.27	4.43%
9	71.09	74.32	4.54%
10	71.39	74.12	3.82%
11	70.18	72.38	3.13%
12	70.08	73.21	4.47%
13	71.16	72.01	1.19%
14	71.13	74.56	4.82%

15	71.39	73.28	2.65%
16	70.18	73.27	4.40%
17	72.1	74.26	3.00%
18	71.41	74.12	3.79%
19	71.23	73.31	2.92%
20	71.38	72.03	0.91%
21	72.26	74.54	3.16%

The ash content analysis results for both variables are presented in Tables 3 and 4. The ash content of the SCG Fuel Pellet is lower than that of the commercially available fuel pellets. In this context, the SCG fuel pellets are deemed the superior option because of their lower ash content, which implies significantly cleaner burning and better overall performance.

Ash Content (%) = (Weight of Ash/Weight of Sample) x 100
Equation 2. Ash Content Formula

Table 3. Ash Content of Commercially-Available Fuel Pellets

Sample	Initial Weight (g)	Ash Weight (g)	Ash Content (%)
1	0.7682	0.0190	2.47%
2	0.8748	0.0290	3.32%
3	1.0238	0.0250	2.44%
4	1.0238	0.0098	0.96%
5	0.9219	0.0145	1.57%
6	0.7349	0.0150	2.04%
7	0.8345	0.0139	1.67%
8	0.8541	0.0141	1.65%
9	0.8388	0.0046	0.55%
10	1.1670	0.0128	1.10%
11	1.0016	0.0115	1.15%
12	1.1415	0.0172	1.51%
13	1.0939	0.0094	0.86%
14	1.1018	0.0228	2.07%
15	1.1551	0.0224	1.94%
16	1.1164	0.0195	1.75%
17	0.9240	0.0130	1.41%
18	1.0492	0.0238	2.27%
19	1.0087	0.0125	1.24%
20	0.9095	0.0142	1.56%
21	0.9801	0.0091	0.93%

Table 4. Ash Content of Commercially-Available Fuel Pellets

Sample	Initial Weight (g)	Ash Weight (g)	Ash Content (%)

1	0.9135	0.0175	1.92%
2	0.874	0.0388	4.44%
3	1.102	0.0249	2.26%
4	0.8841	0.0129	1.46%
5	0.8004	0.0127	1.59%
6	1.071	0.0097	0.91%
7	0.8666	0.0116	1.34%
8	0.9097	0.0516	5.67%
9	0.872	0.0274	3.14%
10	0.9286	0.0431	4.64%

Tables 5 and 6 show the calorific value of each sample for SCG Fuel Pellets and Commercially available pellets. The calorific value of the SCG Fuel Pellet has a higher value compared to the commercially available Fuel Pellets. Where the SCG Fuel Pellets could be a preferred choice for heating or energy production purposes due to its ability to generate more energy per unit.

CV = Heat Produced/Amount of Fuel Pellets

Equation 3. Calorific Value Formula

Table 5. Calorific Value of SCG Fuel Pellets

Sample	Change in Temperature (°C)	Mass of water (g)	Specific Heat of water (J/g°C)	Ground Weight (g)	Calorific Value (MJ/kg)
1	4	2000	4.184	0.7682	43.5720
2	2.3	2000	4.184	0.8748	22.0009
3	2.7	2000	4.184	1.0238	22.0684
4	2.7	2000	4.184	1.0238	22.0684
5	2.4	2000	4.184	0.9219	21.7846
6	5.3	2000	4.184	0.7349	60.3489
7	7.2	2000	4.184	0.8345	72.1984
8	5.3	2000	4.184	0.8541	51.9265
9	2.2	2000	4.184	0.8388	21.9475
10	2.7	2000	4.184	1.1670	19.3604
11	4.1	2000	4.184	1.0016	34.2540
12	2.6	2000	4.184	1.1415	19.0598
13	2.7	2000	4.184	1.0939	20.6542
14	2.8	2000	4.184	1.1018	21.2656
15	5	2000	4.184	1.1551	36.2220
16	2.2	2000	4.184	1.1164	16.4901
17	3.6	2000	4.184	0.9240	32.6026
18	3.7	2000	4.184	1.0492	29.5097
19	4	2000	4.184	1.0087	33.1833

20	3.9	2000	4.184	0.9095	35.8826
21	2.8	2000	4.184	0.9801	23.9061

Table 6. Calorific Value of Commercially-Available Fuel Pellets

Sample	Change in Temperature (°C)	Mass of water (g)	Specific Heat of water (J/g°C)	Ground Weight (g)	Calorific Value (MJ/kg)
1	1.8	2000	4.184	0.9135	16.4887
2	2.4	2000	4.184	0.874	22.9785
3	3	2000	4.184	1.102	22.7804
4	2.5	2000	4.184	0.8841	23.6625
5	1.8	2000	4.184	0.8004	18.8186
6	3.2	2000	4.184	1.071	25.0024
7	4	2000	4.184	0.8666	38.6245
8	3.1	2000	4.184	0.9097	28.5158
9	3.1	2000	4.184	0.872	29.7486
10	3.3	2000	4.184	0.9286	29.7377
11	1.8	2000	4.184	0.9135	16.4887

5.2 Statistical Results

Table 7. Group Statistics: Moisture Content, Ash Content, and Calorific Values

	SCG vs CA	N	Mean	Std. Deviation	Std. Error Mean
Moisture Content	SCG Fuel Pellets	21	0.3237	0.0092	0.0020
	Commercially Available Fuel Pellets	21	0.0321	0.0119	0.0026
Ash Content	SCG Fuel Pellets	21	0.0164	0.0065	0.0014
	Commercially Available Fuel Pellets	10	0.0274	0.0165	0.0052
Calorific Value	SCG Fuel Pellets	21	31.4431	14.7815	3.2256
	Commercially Available Fuel Pellets	10	25.6358	6.3280	2.0011

Table 7 shows the group statistics results of the Statistical T-test for moisture content, ash content, and calorific value of the two fuel pellet types. Based on the data, the moisture content for spent coffee grounds has a mean of 0.3237 and a standard deviation of 0.0092. Meanwhile, the commercially available fuel pellets have a mean of 0.032138 and a standard deviation of 0.11894. This substantial difference in moisture content suggests that SCG Fuel Pellets are significantly more moist than commercially available fuel pellets, potentially impacting their combustion efficiency and overall performance. For the ash content, the spent coffee grounds have a mean of 0.01641 and a standard deviation of 0.00653. Meanwhile, the commercially available fuel pellets have a mean of 0.02737 and a standard deviation of 0.01647. This suggests that SCG Fuel Pellets produce less ash residue post-combustion, indicating cleaner burning and better overall performance. Lastly, in terms of their calorific values, the spent coffee grounds have a mean of 31.4431 and a standard deviation of 14.7815. Meanwhile, the commercially available fuel pellets have a mean of 25.6358 and a standard deviation of 6.3280. This indicates that SCG Fuel Pellets can generate more energy compared to commercially available pellets. Therefore, SCG Fuel Pellets may be preferred for heating or energy production purposes due to their higher energy output.

5.3 Validation

The Dependent Variables Should Be Continuous

The dependent variables in the study were the moisture content, ash content, and calorific values. These variables can take any number of values; hence the values are continuous.

The Independent Variable Should Consist Of Two Or More Categorical Independent Groups

Moreover, the independent variables used in the study are all categorical variables which include the SCG fuel pellets and commercially available fuel pellets.

The Observations Should Have Independence.

The observations between these two pellet types are independent and had no relationship to each other.

There Should Be No Significant Outliers In Any Of The Independent Groups

The independent groups are observed using the visualization method to identify the significant outliers, such as the box and scatter plots (Bhandari,2022). Figures 2, 3, and 4 show the boxplot of each fuel pellet's moisture content, ash content, and calorific value. Both samples' moisture and ash content have no significant outliers except for their calorific values. Hence, the two properties are compliant, except for the calorific value, which will be utilized using a non-parametric Mann-Whitney U Test.

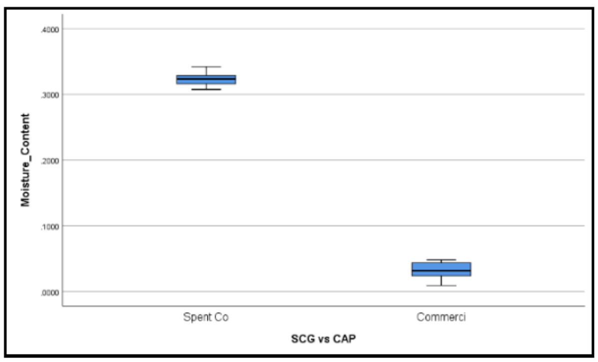

Figure 2. Moisture Content Box Plot

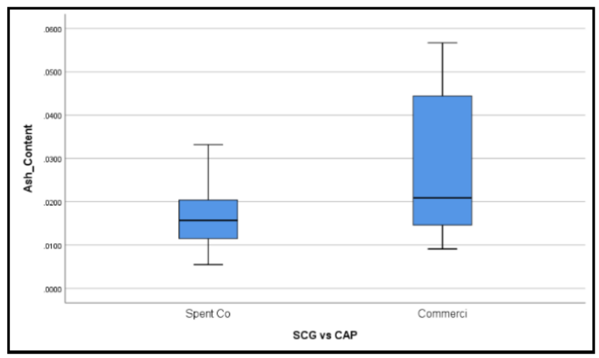

Figure 3. Ash Content Box Plot

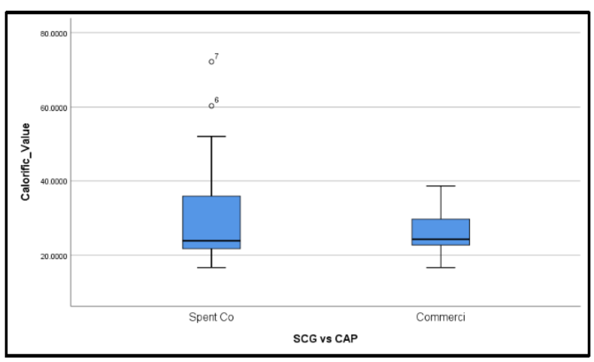

Figure 4. Calorific Value Box Plot

The Dependent Variables Should Be Approximately Normally Distributed For Each Category Of The Independent Variables

Table 8. Tests of Normality: Shapiro-Wilks Test

	SCG vs CA	Shapiro-Wilks Test		
		Statistic	**df**	**Sig.**
Moisture Content	SCG Fuel Pellets	0.971	21	0.761
	Commercially Available Fuel Pellets	0.930	21	0.140

Ash Content	SCG Fuel Pellets	0.968	21	0.677
	Commercially Available Fuel Pellets	0.889	10	0.165
Calorific Value	SCG Fuel Pellets	0.820	21	0.001
	Commercially Available Fuel Pellets	0.952	10	0.689

According to Beers (2022), a p-value less than 0.05 ($p < 0.05$) means that the null hypothesis should be rejected while having a p-value more significant than 0.05 ($p > 0.05$) would mean that the alternative hypothesis is weak and would not need to reject the null hypothesis. The Shapiro-Wilks test will determine if the data is normally distributed; a p-value of less than 0.05 would also be deemed to be not normally distributed. Table 8 shows that the p-value of moisture content of 0.761 and 0.140 for the SCG fuel pellets and commercially available pellets, respectively, shows that it is statistically significant and has a p-value greater than 0.05, which means it complies with the assumption. In addition, the p-values of 0.677 and 0.165 for the ash content of the two pellets are also greater than 0.05, which means the values for the moisture and ash content are normally distributed. Lastly, the p-value for the calorific value for commercially available pellets is 0.689, which is also greater than 0.05, while, for SCG pellets is 0.001, hence the data set for SCG Fuel pellets' calorific values are not normally distributed, hence Mann-Whitney U Test was employed for the statistical analysis of the calorific value.

There Should Be A Homogeneity Of Variances

Table 9. Levene's Test of Homogeneity

	SCG vs CA	**Levene's Test of Homogeneity**	
		F	**Sig.**
Moisture Content	Equal variances assumed	1.750	0.193
	Equal variances not assumed		
Ash Content	Equal variances assumed	4.203	0.049
	Equal variances not assumed		
Calorific Value	Equal variances assumed	18.393	0.000
	Equal variances not assumed		

The test of the different properties of the fuel pellets under Levene's Test for the assumption that the variances of the pellets are equal is shown in Table 9; Levene's Test for moisture content has a p-value of 0.193, indicating that the p-value is more significant than the alpha of 0.05. Hence, the non-significant, so equal variances will be assumed and do not violate this assumption. Meanwhile, the calorific value and ash content have a p-value of 0.049 and 0.00, respectively, which is less than the alpha–the test is significant, and equal variances are not assumed, which violates this assumption. For this matter, the study utilized the test under the equal variances not assumed.

5.4 Discussion

Statistical test assumptions were identified for both samples to check the compliance of the data for each test. The moisture content and ash content p-values were identified using the Independent Samples T-test, as the data are compliant in terms of the test assumptions. On the other hand, the calorific values were not compliant in terms of the assumptions for the Independent Samples T-test. Hence, the Mann-Whitney U Test was employed for the p-value of the said property.

Table 10. Table of Significant Values

Statistical Tests	Properties	Significant Values	
		SCG Fuel Pellets	Commercially Available Pellets
Independent Samples T-test	Moisture Content	p = 7.3575E-48	
	Ash Content	p = 0.0344185	
Mann-Whitney U Test	Calorific Value	p = 0.331271	

Table 10 shows the p-values between SCG fuel pellets and commercially available pellets regarding their moisture content, ash content, and calorific values. The p-value for the moisture content is lower than the alpha value of 0.05, which indicates that SCG Fuel pellets' moisture content is less than the mean moisture content of commercially available pellets. The ash content's p-value from the independent samples t-test resulted in a p-value of 0.0344185, which is also less than the alpha. Hence SCG Fuel pellets have statistically lower ash content than commercially available pellets. Lastly, the Mann-Whitney U Test for the calorific value provided a p-value of p = 0.331271, which is greater than the alpha value of 0.05; this indicates that the Commercially available fuel pellets have statistically higher calorific value than the SCG fuel pellets.

6. Conclusion

The statistical analysis revealed that SCG Fuel pellets have lower moisture and ash content compared to commercially available pellets, rejecting the null hypothesis. However, commercially available pellets exhibit a higher calorific value. Despite this difference, the appropriate conclusion to be made is that both types of pellets are viable as sustainable fuel sources. This finding highlights the potential for utilizing coffee waste as an alternative energy source. In conclusion, the study's unique research contribution lies in its comprehensive comparative analysis between spent coffee ground (SCG) fuel pellets and commercially available ones, shedding light on their distinct thermal properties and confirming the former's (SCG) potential as a sustainable energy source. This holistic approach offers valuable insights into the utilization of SCGs and advancements in biomass fuel technology.

References

Banton, Caroline. (2023, January 03). Raw Materials: Definition, Accounting, and Direct vs. Indirect. Retrieved from: https://www.investopedia.com/terms/r/rawmaterials.asp

Beers, B., P-Value: What It Is, How to Calculate It, and Why It Matters. From Investopedia:,2022. https://www.investopedia.com/terms/p/p-value.asp#:~:text=A%20p%2Dvalue%20less%20than,null%20hypothesis%20is%20not%20rejected.

Bhandari, P. (2021, February 16). Statistical Power and Why It Matters | A Simple Introduction. *Scribbr.* Retrieved from https://www.scribbr.com/statistics/statistical-power/

Christenson, S. C., & Cozzarelli, I. M. , The Norman Landfill environmental research site: what happens to the waste in landfills? US Geological Survey, 2000.

Cigaral, I. (2023). Filipino coffee drinkers to pump Southeast Asia's caffeine rush by 2025. Retrieved from https://www.philstar.com/business/2021/04/15/2090795/filipino-coffee-drinkers-pump-southeast-asias-caffeine-rush-2025"

Colantoni, A., Paris, E., Bianchini, L., Ferri, S., Marcantonio, V., Carnevale, M., … Gallucci, F. , Spent coffee ground characterization, pelletization test and emissions assessment in the combustion process. *Scientific Reports*, 11(1), 2021. doi:10.1038/s41598-021-84772-y

Cruz, R., Cardoso, M. M., Fernandes, L., Oliveira, M., Mendes, E., Baptista, P., ... & Casal, S., Espresso coffee residues: a valuable source of unextracted compounds. *Journal of Agricultural and Food Chemistry*, 60(32), 7777-7784, 2012.

(2009, June 3). European Biomass Industry Association. Retrieved March 17, 2024, from https://l.messenger.com/l.php?u=https%3A%2F%2Fwww.eubia.org%2Fcms%2Fwiki-biomass%2Fbiomass-resources%2Fchallenges-related-to-biomass%2F&h=AT3QktoW4owPY9sZLq_KEZgLFI_l8RHPQvfIYUycRjCMWVmkWD-oMbdl_TOyUASmi2QlA6i1yZugfhVB7AtbmDo1nnWEuNkyrDuYAaNiSrw9Avy-0lvFTC

Fossil fuels and climate change: the facts. (2022, February 18). ClientEarth. Retrieved May 18, 2023, from https://www.clientearth.org/latest/latest-updates/stories/fossil-fuels-and-climate-change-the-facts/

Hamedani, S. R., Colantoni, A., Bianchini, L., Carnevale, M., Paris, E., Villarini, M., & Gallucci, F. (2022). Environmental life cycle assessment of spent coffee ground pellet. *Energy Reports*, 8, 6976-6986.

Johnson, K., Liu, Y., & Lu, M. , A Review of Recent Advances in Spent Coffee Grounds Upcycle Technologies and Practices. *Frontiers in Chemical Engineering, 4, 31,2022.*

Kanniah, J. (2020). What Happens To Coffee Grounds After They're Used? Retrieved from https://perfectdailygrind.com/2020/09/what-happens-to-coffee-grounds-after-theyre-used/

Kim, Y., Lee, J., Yi, H., Fai Tsang, Y., & Kwon, E. E. (2018). Investigation into Role of CO2 in Two-Stage Pyrolysis of Spent Coffee Grounds. *Bioresource Technology*. doi:10.1016/j.biortech.2018.10.009

Kondamudi, N., Mohapatra, S. K., & Misra, M. (2008). Spent coffee grounds as a versatile source of green energy. *Journal of agricultural and food chemistry,* 56(24), 11757-11760,2008.

Kookos, I. K., Technoeconomic and environmental assessment of a process for biodiesel production from spent coffee grounds (SCGs). *Resources, Conservation and Recycling. 134, 156–164, 2018*. https://doi.org/10.1016/j.resconrec.2018.02.002

Kristanto, G. A., & Wijaya, H. (2018). Assessment of spent coffee ground (SCG) and coffee silverskin (CS) as refuse derived fuel (RDF). *IOP Conference Series: Earth and Environmental Science*, 195, 012056. doi:10.1088/1755-1315/195/1/012056

Limousy, L., Jeguirim, M., & Labaki, M., Energy applications of coffee processing by-products. *Handbook of Coffee Processing By-Products*, 323–367, 2017. doi:10.1016/b978-0-12-811290-8.00011-6

Limousy, L., Jeguirim, M., Dutournié, P., Kraiem, N., Lajili, M., & Said, R. , Gaseous products and particulate matter emissions of biomass residential boiler fired with spent coffee grounds pellets. *Fuel*, 107, 323-329, 2013.

Lühmann, M. (2020). Whose European bioeconomy? Relations of forces in the shaping of an updated EU bioeconomy strategy. *Environmental Development*, 100547. doi:10.1016/j.envdev.2020.100547

Nosek, R., Tun, M. M., & Juchelkova, D. (2020). Energy Utilization of Spent Coffee Grounds in the Form of Pellets. *Energies, 13(5)*, 1235. doi:10.3390/en13051235

Republic Act No. 9513. (2008, December 16). Official Gazette. Retrieved March 11, 2024, from https://www.officialgazette.gov.ph/2008/12/16/republic-act-no-9513/

Scully, D., Jaiswal, A., & Abu-Ghannam, N., An Investigation into Spent Coffee Waste as a Renewable Source of Bioactive Compounds and Industrially Important Sugars. *Bioengineering, 3(4)*, 33, 2016. doi:10.3390/bioengineering3040033

Smirnov, Y., Sverchkov, I., & Gabdullina, R., Biofuel pellets from spent coffee grounds. *Research, 2022. Square*. https://doi.org/10.21203/rs.3.rs-1551835/v1

Tiseo, Ian (2023, February 08). Global waste generation - statistics & facts. Statista. Retrieved from https://www.statista.com/topics/4983/waste-generation-worldwide/#:~:text=This%20is%20due%20to%20a,becoming%20a%20major%20issue%20worldwide.

Utilization of Spent Coffee Grounds - “A Profitable Coffee Waste”. (2023, April 27). *Food Infotech*. Retrieved May 19, 2023, from https://www.foodinfotech.com/utilization-of-spent-coffee-grounds-a-profitable-coffee-waste/

Campos-Vega, R., Loarca-Piña, G., Vergara-Castañeda, H. A., & Oomah, B. D., Spent coffee grounds: A review on current research and future prospects. *Trends in Food Science & Technology*, 45(1), 24–36,2025. doi:10.1016/j.tifs.2015.04.012

Zuorro, A., & Lavecchia, R. , Spent coffee grounds as a valuable source of phenolic compounds and bioenergy. *Journal of Cleaner Production*, 34, 49–56,2012. doi:10.1016/j.jclepro.2011.12.003

Biography

Gerald M. Araco is an Industrial Engineering student from the University of Santo Tomas.

Francis Miguel C. Flores is an Industrial Engineering student from the University of Santo Tomas.

Andre Louis C. Ollica is an Industrial Engineering student from the University of Santo Tomas.

Ralph Daniel C. Paglinawan is an Industrial Engineering student from the University of Santo Tomas.

Damirson A. Co, PIE, is an adjunct professor in the Department of Industrial Engineering at the University of Santo Tomas. He earned his Bachelor of Science degree in Industrial Engineering from the University of Santo Tomas and a Master of Science degree in Industrial Engineering Major in Production Systems from the University of the Philippines – Diliman.