Advanced and Sustainable Technologies (ASET) eISSN 2976-2294
*Volume 2, No 2, December 2023 [55-64]*

# Cracking the Code: Process Parameter Effects on *Khaya senegalensis* Energy Pellet Moisture Content

Ras Izzati Ismail[1*], Chu Yee Khor[1] and Alina Rahayu Mohamed[2]

[1]Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia
[2]Faculty of Chemical Engineering & Technology, Kompleks Pusat Pengajian Jejawi 3, Kawasan Perindustrian Jejawi, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia

Received 22 August 2023, Revised 22 September 2023, Accepted 25 September 2023

**ABSTRACT**

*The production of energy pellets from biomass sources holds immense potential for sustainable renewable energy generation. This study investigates the influence of key process parameters on the moisture content of energy pellets derived from Khaya senegalensis, a promising biomass feedstock in Malaysia. With a focus on unlocking the relationship between process variables and pellet moisture, a systematic experimental approach was adopted. The objective of this study is to investigate the effects of raw material moisture, feedstock particle size, compression pressure, and pelletization temperature on the manufactured biomass energy pellet's moisture content. By employing a comprehensive design of experiments and statistical analysis, the nuanced effects of these parameters are revealed on the moisture content of Khaya senegalensis energy pellets. The results illuminate the complex interplay between these process variables and the final moisture characteristics of the pellets. Understanding how these parameters impact moisture content is crucial for optimizing pellet quality, combustion efficiency, and storage stability. The study found a quadratic relationship between particle size, compression pressure, and pelletization temperature, indicating that larger particle sizes correlate with higher moisture content. Excessive pressure led to elevated levels while increasing temperature showed a decreasing trend. This research contributes valuable insights that advance the knowledge frontier of biomass pelletization, paving the way for enhanced utilization of Khaya senegalensis as a renewable energy resource.*

**Keywords:** Biomass, energy pellets, moisture content, pelletization process parameters, renewable energy.

## 1. INTRODUCTION

The growing demand for sustainable and eco-friendly energy sources has increased interest in biomass-derived energy pellets as a viable renewable energy option. Biomass pellets, compacted forms of organic materials, offer distinct advantages such as high energy density, ease of transport, and reduced greenhouse gas emissions compared to traditional fossil fuels. *Khaya senegalensis*, a prolific biomass resource, exhibits promising attributes for energy pellet production owing to its widespread availability, renewability, and potential to alleviate pressure on conventional energy sources. The rapid growth of *Khaya senegalensis*, introduced historically for road impoundment in Malaysia, has led to the frequent need for extensive trimming. This creates a challenge in efficiently managing vegetation growth and its associated maintenance efforts. However, rather than viewing this as a problem, it can be seen as an opportunity for sustainable biomass production. The fast growth of *Khaya senegalensis* provides a consistent source of biomass, ideal for energy pellet production. Converting trimmed vegetation into pellets aligns with circular economy principles, promoting renewable energy use and reducing

*Corresponding author: rasizzati@unimap.edu.my

environmental impact. This approach not only addresses an ecological issue but also creates economic opportunities and supports local economies through biomass processing and pellet manufacturing. However, the quality and performance of energy pellets are intricately linked with their moisture content, impacting combustion efficiency, storage stability, and transportation feasibility. Therefore, achieving optimal moisture content is a critical challenge in pellet production and understanding the influence of various process parameters on this attribute is paramount for refining the manufacturing process.

Therefore, the objective of this study was to investigate and analyze the influence of various key process parameters on the moisture content of energy pellets. Specifically, the study aimed to assess how variations in raw material moisture, feedstock particle size, compression pressure, and pelletization temperature affect the moisture content of energy pellets.

The study's scope encompasses laboratory-based experiments and statistical analyses conducted on energy pellets produced from *Khaya senegalensis* biomass, with variations in these parameters systematically explored. The study focused primarily on four key parameters (raw material moisture, feedstock particle size, compression pressure, and pelletization temperature). Other potentially influential variables, such as the type and composition of binders or additives, were not thoroughly investigated.

During the processing stage, the mechanical durability and combustion performance of wood pellets are influenced by temperature, pressure, and the interplay between these two primary variables [1–3]. One of the primary aims of this study is to investigate the impact of temperature and pressure on the quality characteristics of pellets made from *Khaya senegalensis* wood. The primary objective of this research is to investigate the correlation between process factors and the moisture content of energy pellets obtained from *Khaya senegalensis*. In order to better understand the details that control pellet moisture content and ultimately increase the effectiveness and viability of *Khaya senegalensis* energy pellets as a sustainable energy source, we want to rigorously investigate the effects of key process variables.

In this paper, we present a comprehensive exploration of the impact of raw material moisture, compression pressure, pelletization temperature and feedstock particle size on the moisture content of *Khaya senegalensis* energy pellets. The insights gained from this study are expected to contribute significantly to the field of biomass pelletization. By gaining a deeper understanding of the factors that influence pellet moisture content, we can optimize the process, ensuring the production of energy pellets with consistent and desirable properties [4]. Ultimately, this research bridges a crucial knowledge gap, enabling the sustainable utilization of *Khaya senegalensis* biomass as a renewable energy resource and advancing the frontiers of biomass energy technology.

## 2. MATERIAL AND METHODS

In this experiment, chipped khaya tree branches were processed into a powder using an IKA microfine grinder mill (Brand: IKA, Model: MF 10 BASIC). Subsequently, the sample underwent differentiation into several samples of varying particle sizes through the utilization of a sieve shaker in order to facilitate experimental applications. The experiment was carried out in a sequential manner, where each element was examined individually, with the biomass particle size being varied over five levels (0.1, 0.3, 0.5, 1, and 2 mm). The ground biomass feedstock was pelletized under consistent conditions of moisture content, pressure, temperature, and binder percentage, utilizing a Specac hydraulic single pellet press. A quantity of material weighing 1.0 g ± 0.005 was introduced into the 10 mm diameter. Following the application of a consistent force on the mould, the pressure was then relieved, leading to the removal of the mould from the chamber. Subsequently, the particle was expelled following the removal of the lower section of the mould. To mitigate potential harm to the pellet, the removal of the mould from the chamber was conducted with utmost care. The experiment was replicated three times.

Subsequently, the powdered khaya wood feedstock was prepared into five distinct levels of moisture content. The experiment was conducted in triplicate, with each replication focusing on one element at a time. The moisture content was varied across five levels (4%, 8%, 12%, 16%, and 20%) and determined using a moisture analyzer (Brand: AND, Model: MX-50) following the guidelines outlined in ASTM E871. In this instance, the feedstock was subjected to pelletization under controlled conditions, including consistent particle size, pressure, temperature, and binder concentration. The process of pelletization was conducted in accordance with the description provided in the preceding paragraph.

Then, the unprocessed khaya wood feedstock was subjected to pelletization at varying temperature levels. The experiment was conducted with three replications, each focusing on one element at a time. The factor in question had five levels, namely 25, 50, 75, 100, and 125 degrees Celsius.

Next, the experiment was extended to encompass five distinct pressure levels, specifically 1 Tonne (equivalent to 6.28 Megapascals), 2 Tonnes (equivalent to 12.5 Megapascals), 3 Tonnes (equivalent to 18.8 Megapascals), 4 Tonnes (equivalent to 25.1 Megapascals), and 5 Tonnes (equivalent to 31.4 Megapascals). Each pressure level was reproduced three times. The ground biomass underwent pelletization utilizing a Single Hot Press Hydraulic Machine, employing varying levels of pressure and temperature.

The moisture content of the manufactured khaya pellets were tested using a moisture analyzer (Brand: AND, Model: MX-50).

## 3. RESULTS AND DISCUSSION

In the field of energy pellet production, it is crucial to comprehend the complex correlation between process parameters and moisture content in order to enhance the quality and effectiveness of these fuel sources derived from biomass. This section explores the outcomes and the following discourse regarding the impacts of different process parameters on the moisture content of energy pellets. A thorough understanding of the dynamics of moisture content during the pelletization process is provided by revealing these intricate relationships. The findings of the study are important since they advance technical knowledge of the production of energy pellets. Additionally, these discoveries have important ramifications for improving the combustion efficiency, storage stability, and general performance of pellets within the context of producing renewable energy.

### 3.1 Moisture Content Variation by Particle Size

The moisture content of an energy pellet is typically considered a thermal property, as it relates to the amount of water present in the material and its ability to affect the combustion and energy release characteristics of the pellet. Moisture content can impact the heating value, combustion efficiency, and emissions of energy pellets and is typically measured as a percentage of the total weight of the pellet. While moisture content can be affected by mechanical factors such as the size and shape of the pellets, it is primarily a function of the environmental conditions (e.g. humidity) and storage conditions of the pellets, which can impact the amount of water absorbed or released by the material.

Based on the reported results depicted in Figure 1, there appears to be a clear increasing trend between feedstock particle size and moisture content in *Khaya senegalensis* fuel pellets.

Specifically, as the particle size increases from 0.15 mm to 2 mm, the moisture content of the resulting pellets also increases from 9.47% to 11.01%. A good $R^2$ equivalent to 0.97 was obtained in this case. This trend is consistent with the general understanding larger particles may be more difficult to dry effectively, which could contribute to higher moisture content in the resulting pellets. Very little was found in the literature on the question of the effect of particle size on pellets' moisture content.

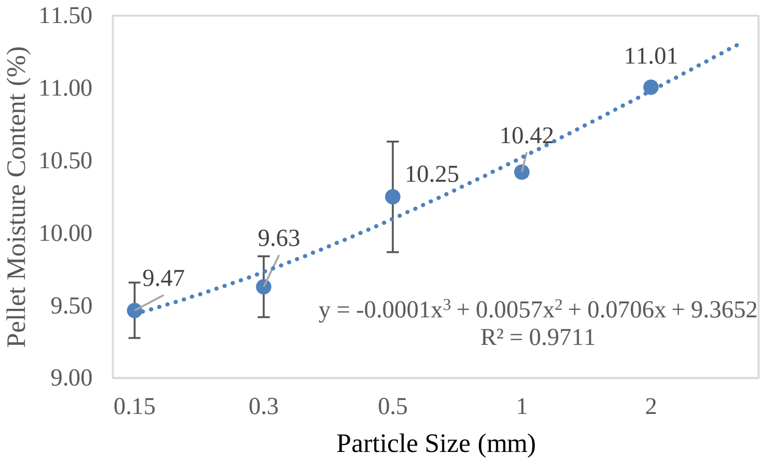


**Figure 1:** Moisture content behaviour in response to different particle size distributions during pelletization.

Smaller particle diameters might result in a greater rate of mass loss, particularly moisture, thereby reducing the pellets moisture content percentages [5]. In another study by [6], however, it was concluded that particle size distributions generally did not influence the pellet moisture content, moisture absorption during storage, abrasion resistance and thermochemical conversion time.

Following the increment of feedstock particle size, a significant increase ($P<0.05$) in the pellet moisture content was recorded in Table 1. According to these data, we can infer that ANOVA analysis has shown that there is a statistically significant difference between the particle size and pellet moisture content. The p-value of 1.22E-25 is substantially smaller than the standard significance level of 0.05, indicating that there is strong evidence to reject the null hypothesis. In summary, it appears that the statistical analysis has produced good evidence to support the conclusion that there is a considerable difference between the feedstock particle size and pellet moisture content. However, this outcome is contrary to that of [7], who found that the effect of particle size on pellet moisture is statistically insignificant in the pelletizing process at the same moisture content ($p < 0.05$).

**Table 1:** ANOVA analysis for pellets moisture content pelletized at different particle sizes.

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 657.73 | 1 | 657.73 | 1444.22 | 1.22E-25 | 4.195972 |
| Within Groups | 12.757 | 28 | 0.462 | | | |
| Total | 670.4791 | 29 | | | | |

By selecting optimal feedstock particle sizes and implementing effective drying and storage techniques, producers can help ensure that their energy pellets have consistent and desirable properties, including moisture content.

### 3.2 Energy Pellet Moisture Content Trends Across Feedstock Moisture Content

Figure 2 presents the resulting pellet moisture content in relation to variations in feedstock moisture content variation, revealing a range of 10.82% to 12.21%. Examining the trend closely, the following associations are observed: At 4% moisture content in the feedstock, the pellets exhibit a moisture content of 11.21%. Then, when the feedstock moisture content is 8%, the resulting pellets display a slightly higher moisture content of 11.25%. Notably, a feedstock moisture content of 12% yields pellets with a lower moisture content of 10.82%, indicating a significant decrease. In contrast, a feedstock moisture content of 16% leads to a slightly elevated moisture content of 11.56% in the resulting pellets. Lastly, at 20% moisture content in the feedstock, the pellets reach the highest moisture content in this treatment with a value of 12.21%.

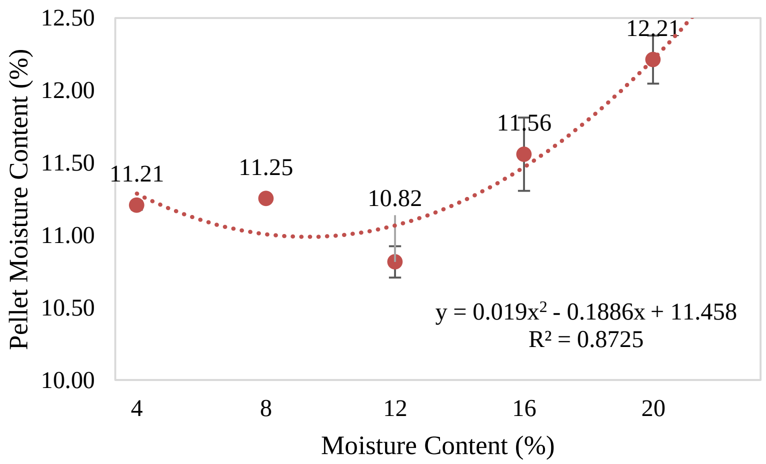


**Figure 2:** Graphical depiction of energy pellets moisture content trends exhibited by distinct moisture contents.

The observed variations in the moisture content of the resulting pellets can be explained by the interaction between the feedstock moisture content and the pelletization process. If the feedstock has a high moisture content, then the resulting pellets will also have a high moisture content, which can have a negative impact on their quality, transportation, and combustion [6]. When the feedstock moisture content is low, such as at 4% or 8%, the available moisture may be insufficient to facilitate proper binding and densification of the pellets. As a result, the pellets may retain a slightly higher moisture content to compensate for the limited moisture available during pellet formation. This explains why the moisture content of the pellets increases marginally at 4% and 8% feedstock moisture content.

Conversely, when the feedstock moisture content increases to 12% or 16%, there is an optimal range of moisture available during the pelletization process. This optimal moisture level promotes better binding and compaction of the feedstock particles, resulting in denser and more tightly formed pellets. In accordance with the present results, previous study by [8] have demonstrated that moisture content is a crucial process parameter that significantly impacts the quality of biomass fuel pellets. In the same paper, it was stated that the presence of water within the raw material serves as a binding agent for biomass particles by facilitating starch gelatinization, protein denaturation, and partial solubilization of certain chemical components during the densification process. This results in the reinforcement and enhancement of bonds between biomass particles, ultimately leading to an improvement in the overall integrity of biomass pellets [9]. Nevertheless, the surplus water that particles are unable to assimilate adheres to the biomass surface, hindering particle consolidation and diminishing pellet excellence [10]. This excess moisture, when not effectively incorporated into the biomass matrix, can hinder particle consolidation and ultimately diminish the overall quality of the pellets. When excess water remains on the surface of the biomass particles, it can create a barrier between the particles themselves, preventing them from coming into close contact and forming strong bonds. In pelletization, the goal is to achieve a dense and tightly compacted structure to produce high-quality pellets. However, excess moisture on the surface can act as a lubricant, reducing friction and inhibiting the formation of strong interparticle bonds. This can result in pellets that are less dense, less durable, and more prone to breakage [11]. As a consequence, the moisture content of the pellets decreases at 12% feedstock moisture content compared to the lower values.

However, at 16% feedstock moisture content, there may be a slight increase in moisture content, possibly due to factors like increased water absorption by the feedstock or variations in the pelletization process. At 20% feedstock moisture content, the excess moisture may lead to some loss or evaporation during the pelletization process. This can result in a slight decrease in the moisture content of the resulting pellets compared to the 16% feedstock moisture content.

These results suggest that increased levels of biomass moisture result in an increase in pellet moisture content, as anticipated. The moisture content of pellets is directly proportional to the initial moisture content of the biomass. Consequently, an increase in the initial moisture content of the biomass results in a higher pellet moisture content, leading to a decline in pellet quality. This is due to the fact that excessively high water content in pellets can have an adverse impact on the efficiency and temperature of combustion. We can gather that the moisture content is crucial because it affects both the combustion and physical performance of a densified product [12].

Interestingly, a marginal overlap can be observed between the error bar of the 12% feedstock moisture content and that of the 16% counterpart, suggesting that there may be a statistically significant difference in the moisture content of the pellets between these two feedstock moisture conditions. This indicates that the pelletization process is sensitive to variations in feedstock moisture content within this range.

### 3.3 Pelletization Temperature Effects on Pellet Moisture

The outcomes of the parametric examination of the effect of pelletization temperature on the moisture content of khaya pellets are presented in Figure 3. From the data, it is evident that there is a decreasing trend in moisture content as the temperature increases. This trend suggests that higher temperatures lead to a reduction in the moisture content of the *Khaya senegalensis* biofuel pellets. To assess the rate of change, we can calculate the differences in moisture content between consecutive temperature points. The moisture content decreased by 0.79% from 25°C to 50°C. It further decreased by 0.49% from 50°C to 75°C. The decrease from 75°C to 100°C was relatively smaller, at 0.18%. Finally, the moisture content decreased by 0.78% from 100°C to 125°C. The rate of change appears to be relatively larger between the lower temperature ranges (25-50°C and 50-75°C), indicating a more rapid reduction in moisture content. The rate of change becomes smaller at higher temperatures (75-100°C and 100-125°C), suggesting a slower decrease in moisture content as the temperature increases.

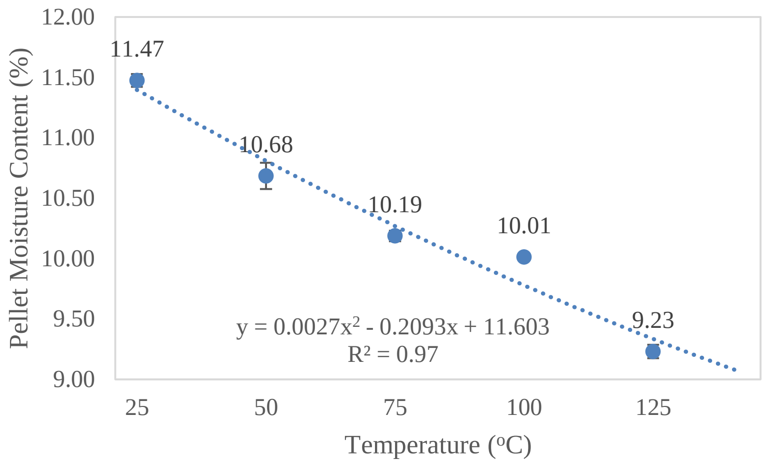


**Figure 3:** Illustration of moisture content variability influenced by pelletization temperature diversity in pellet feedstock.

Elevated temperatures can lead to a decrease in the moisture content of pellets. Elevated temperatures have the potential to decrease the moisture content of pellets by promoting greater water release during the pelletization process [13]. The $R^2$ value of 0.97 indicates a strong correlation between the temperature and moisture content data. A value close to 1 suggests that 97% of the variability in the moisture content can be explained by changes in temperature. In other words, the temperature has a significant impact on the moisture content of the biofuel pellets.

When the biofuel pellets are exposed to higher temperatures, several physical and chemical processes occur that contribute to the decrease in moisture content. As temperature increases, the kinetic energy of water molecules also increases. This heightened energy allows more water molecules to transition from the liquid phase to the gas phase, resulting in increased evaporation. Consequently, the moisture content of the biofuel pellets decreases as water is lost in the form of vapor [11,12]. A previous study by [16] further added that the process of moisture evaporation can be likened to the pyrolysis phenomenon, taking place within a limited and dynamic region referred to as the evaporation front. The velocity of the aforementioned front is contingent upon the temperature of its surface.

The current study's findings corroborate the ideas of [13], who suggested that the utilization of biomass with a moisture content as high as 20% results in the production of low-quality pellets due to their reduced durability and bulk density, as well as elevated moisture content. The findings suggest that for optimal pellet quality and durability, a low biomass moisture content is recommended at low temperatures, while an intermediate biomass moisture content is more suitable at higher temperatures.

Another possible explanation is that the vapor pressure of water increases exponentially with temperature. When the temperature rises, the vapor pressure of water within the biofuel pellets also increases. This creates a pressure gradient between the pellets and the surrounding environment. As a result, moisture moves from an area of higher pressure (inside the pellets) to an area of lower pressure (the external environment), leading to moisture loss and decreased moisture content. As previously stated, elevated temperatures resulted in enhanced process flexibility, thereby facilitating material pressing and yielding higher adhesive strength [14,15]. The intense heating of a fuel and water evaporation starts once the particle is introduced into the high-temperature medium [16].

Moreover, the absence of overlap in the error bars strengthens the evidence for the statistical significance of the findings. Error bars typically represent the variability or uncertainty in the measurements. The lack of overlap suggests that the differences in moisture content between the temperature levels are distinct and unlikely to occur due to random fluctuations.

To determine the statistical significance of the results, the researchers conducted an ANOVA (Analysis of Variance) test. The results indicated that the observed differences in moisture content among the various temperatures were statistically significant. The p-value of 2.07E-07, which is less than the conventional significance level of 0.05, suggests that the probability of obtaining these results by chance alone is extremely low. The statistically significant differences and the lowest moisture content observed at 125°C further support the influence of temperature on the moisture content of *Khaya senegalensis* biofuel pellets.

### 3.4 Compression Pressure Influence on Moisture Content

The moisture content values significantly influence the properties of the pellets. The moisture content refers to the overall quantity of moisture present in a given sample of pellets. A lower moisture content is considered more desirable due to its potential to inhibit the proliferation of microorganisms, which could have a detrimental impact on the quality of the pellets. The investigation into the influence of compression pressure on moisture content in energy pellets revealed a moisture content range spanning from 10.48% to 11.57%, as shown in Figure 4.

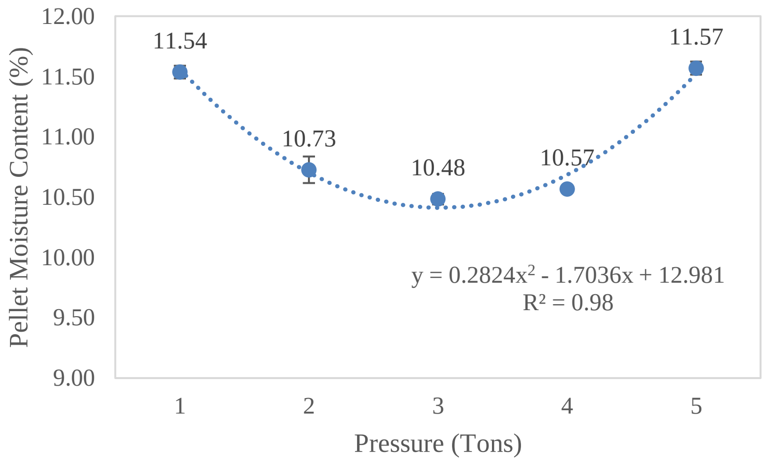


**Figure 4:** Influence of compression pressure distribution on the modulation of moisture content in energy pellets.

The observed trend exhibited a quadratic relationship with a robust coefficient of determination ($R^2 = 0.97$). Moisture content values were associated with varying compression pressures, where each ton of pressure resulted in distinct moisture content percentages: 1 ton = 11.54%, 2 ton = 10.73%, 3 ton = 10.48%, 4 ton = 10.57%, and 5 ton = 11.57%.

The application of the Analysis of Variance (ANOVA), a single-factor statistical analysis, confirmed the significance of these outcomes. The obtained p-value, a measure of statistical significance, was remarkably low at 1.62E-17, far below the conventional threshold of 0.05. This indicates a strong connection between compression pressure and the resulting variations in moisture content.

From a scientific standpoint, this trend implies an interaction between compression pressure and moisture content. The quadratic trend indicates an optimal pressure range that yields the lowest moisture content. This might be attributed to the balance between pellet compaction and moisture expulsion under varying pressures. The moisture content decreases as compression pressure increases, aligns with expectations, as higher pressure levels lead to enhanced expulsion of moisture. The author [17] further supports the findings of this study by stating that the moisture content also influences the ignition delay, especially at the early stage, because moisture evaporation is an endothermic reaction.

The distinctive response of moisture content to compression pressure can be linked to the varying degrees of pellet densification. As pressure increases, the biomass particles are more compacted, facilitating moisture removal and decreasing moisture content. However, at excessive pressures, the pellets might become too compacted, potentially reducing their porosity and increasing the risk of moisture retention. Several other researchers also investigated the impact of compression pressure on energy pellet qualities [1], [18], [19].

## 4. CONCLUSION

In conclusion, the moisture content of energy pellets holds significant implications for their quality and performance as biofuel sources. It is intricately tied to thermal properties, influencing combustion efficiency, heating value, and emissions. The present study examined the impact of various process parameters on energy pellet moisture content, unveiling compelling insights. Particle size exhibited a clear quadratic trend, indicating that larger particle sizes correlated with higher moisture content. The ANOVA analysis substantiated the statistical significance of this relationship. Similarly, compression pressure displayed a quadratic relationship, showcasing an optimal range for minimizing moisture content, while excessive pressure led to elevated levels. Pelletization temperature revealed a decreasing trend in moisture content with increasing temperature, supported by a strong correlation. This effect could be attributed to enhanced water evaporation under elevated temperatures. This study helps to optimize the manufacture of energy pellets by analyzing these complex relationships, enabling knowledgeable choices to obtain desired moisture content, and ensuring the overall effectiveness of these pellets as a renewable energy source.

## ACKNOWLEDGEMENTS

The research was conducted as part of a doctoral programme in engineering at Universiti Malaysia Perlis (UniMAP), Faculty of Mechanical Engineering & Technology. The Higher Education Ministry of Malaysia (FRGS), specifically research grant number FRGS/1/2020/TK0/UNIMAP/03/22, is sincerely thanked for providing the necessary funding for this endeavour.

## REFERENCES

[1] Ma, J., Feng, S., Shen, X., Zhang, Z., Wang, Z., Kong, W., ... & Mu, L.. Integration of the pelletization and combustion of biodried products derived from municipal organic wastes: The influences of compression temperature and pressure. Energy, vol 219, (2021) p. 119614.

[2] Mostafa, M. E., Hu, S., Wang, Y., Su, S., Hu, X., Elsayed, S. A., & Xiang, J. The significance of pelletization operating conditions: An analysis of physical and mechanical characteristics as well as energy consumption of biomass pellets. Renewable and Sustainable Energy Reviews, vol 105, (2019) pp. 332-348.

[3] Wattana, W., Phetklung, S., Jakaew, W., Chumuthai, S., Sriam, P., & Chanurai, N. Characterization of mixed biomass pellet made from oil palm and para-rubber tree residues. Energy procedia, vol 138, (2017) pp. 1128-1133.

[4] Labanovska, A., Vigants, H., & Blumberga, D. Energy management in wood pellets

production. Energy Procedia, vol 95, (2016) pp.237-242.
[5] Hansted, A. L. S., Hansted, F. A. S., Tomeleri, J. O. P., Cacuro, T. A., Sette Jr, C. R., Yamaji, F. M., & Costa, V. E. Biomass in an industrial boiler: characterizing and reducing waste from the burning process. Research, Society and Development, vol 11, issue 9 (2022) pp. e45511931948-e45511931948.
[6] Labbé, R., Paczkowski, S., Knappe, V., Russ, M., Wöhler, M., & Pelz, S. Effect of feedstock particle size distribution and feedstock moisture content on pellet production efficiency, pellet quality, transport and combustion emissions. Fuel, vol 263, (2020) p. 116662.
[7] Yılmaz, H., Çanakcı, M., Topakcı, M., & Karayel, D. The effect of raw material moisture and particle size on agri-pellet production parameters and physical properties: A case study for greenhouse melon residues. Biomass and Bioenergy, vol 150, (2021) p. 106125.
[8] Zhang, X., Cai, Z., Chen, L., Zhang, D., & Zhang, Z. Effects of moisture content and temperature on the quality of water hyacinth pellets. BioResources, vol 11, issue 1 (2016) pp. 1407-1416.
[9] Lisowski, A., Matkowski, P., Mieszkalski, L., Mruk, R., Stasiak, M., Piątek, M., ... & Karpio, K. Influence of fraction particle size of pure straw and blends of straw with calcium carbonate or cassava starch on pelletizing process and pellet. Materials, vol 13, issue 20 (2020) p. 4623.
[10] Jezerska, L., Drozdova, J., Rozbroj, J., Zegzulka, J., & Frydrych, J. Pelletization of energy grasses: A study on the influence of process and material parameters on pellet quality. International Journal of Green Energy, vol 16, issue 14 (2019) pp. 1278-1286.
[11] Kaliyan, N., & Morey, R. V. Factors affecting strength and durability of densified biomass products. Biomass and bioenergy, vol 33, issue 3 (2009) pp. 337-359.
[12] Faizal, H. M., Rahman, M. R. A., & Latiff, Z. A. Review on densification of palm residues as a technique for biomass energy utilization. Jurnal Teknologi, vol 78, issue 9-2 (2016) pp. 9-18.
[13] García, R., Gil, M. V., Rubiera, F., & Pevida, C. Pelletization of wood and alternative residual biomass blends for producing industrial quality pellets. Fuel, vol 251, (2019) pp. 739-753.
[14] Liu, Y., Wan, K., He, Y., Wang, Z., Xia, J., & Cen, K. Experimental study of potassium release during biomass-pellet combustion and its interaction with inhibitive additives. Fuel, vol 260, (2020) p. 116346.
[15] Liu, Y., Wang, Z., Xia, J., Vervisch, L., Wan, K., He, Y., ... & Cen, K. Measurement and kinetics of elemental and atomic potassium release from a burning biomass pellet. Proceedings of the Combustion Institute, vol 37, issue 3 (2019) pp. 2681-2688.
[16] Kuznetsov, G. V., Syrodoy, S. V., Gutareva, N. Y., Kostoreva, A. A., & Kostoreva, Z. A. Ignition of the wood biomass particles under conditions of near-surface fragmentation of the fuel layer. Fuel, vol 252, (2019) pp.19-36.
[17] Mock, C., Park, H., Ryu, C., Manovic, V., & Choi, S. C. Particle temperature and flue gas emission of a burning single pellet in air and oxy-fuel combustion. Combustion and Flame, vol 213, (2020) pp. 156-171.
[18] Frodeson, S., Henriksson, G., & Berghel, J. Effects of moisture content during densification of biomass pellets, focusing on polysaccharide substances. Biomass and Bioenergy, vol 122, (2019) pp. 322-330.
[19] Samuelsson, R., Burvall, J., & Jirjis, R. Comparison of different methods for the determination of moisture content in biomass. Biomass and Bioenergy, vol 30, issue 11 (2006) pp. 929-934.