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Carya illinoinensis Husk Biomass Pellets as a Bioenergy Source in a Circular Economy Context

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In *Carya illinoinensis* (Pecan) producing areas, large quantities of fruit shells of this natural species are generated, which are not used properly, the same ones that are generally incinerated or inconveniently disposed of. The research presented a proposal to make pellets with the biomass constituted by the shell of *Carya illinoinensis* as a bioenergy source and thus incorporate these residues into the production process in the context of a circular economy. In the investigation, 4 types of pellets with different granulometry of the shell were made, as a binder the same shell was used at a lower granulometry. Once the biomass was homogenized, it was made in a mold, obtaining pellets with a diameter of 15 mm and a length of 6 to 10 cm, using a pressure of one ton, then they were dried at 20°C for 15 days. The pellets were characterized obtaining 51.92% moisture percentage, 43.95% fixed carbon, 53.15% volatile material, 2.90% ash and calorific power of 9981.90 Kcal/kgr, to produce pellets with a granulometry of +0.30 mm. It is established in this way that the biomass of residues of *Carya illinoinensis*, it is feasible to be used as raw material to obtain bioenergy.

1. Introduction

The use of fossil fuels has been causing negative environmental impacts on the planet, one of them is coal, which is currently the most used primary source for obtaining electricity, the second largest source of primary energy and the largest source of emissions. of CO2 related to energy (IEA, 2021). The activities of harvesting agricultural products produce a large quantity and variety of residues that are often used as fuels but that in their primary form are also sources of pollution by generating carbon monoxide, hydrocarbons, particulate matter that cause a negative impact on health. of people and environment (Smith, 2006). In countries like Peru with favourable climates, the production of *Carya illinoinensis* (Pecan) is considerable, especially in the towns of Ica and Ancash, in such a way that in 2017, according to INEI data, there was a production of 2,863 tons.(Silvestre, 2020). In other countries they see this alternative in native species of the place (Cabeza I. et al., 2018).

It is known that the composition of the pecan shell has an average of 2.2 g/100 g of protein, 16.8 g/100 g of moisture, 1.1 g/100 g of lipids, 1.4 g/100 g of minerals, 48.6 g/100 g of total fibres, 3.1 g/100 g of soluble fibres, 45.4 g/100 g of insoluble fibres, 29.6 g/100 g of carbohydrates and 331 kcal/100 g of calorific value, with these characteristics, pellets with a diameter of 6 mm and a length of 24 mm were produced, obtaining a calorific value of 4.91 kcal/g. (Prado et al., 2009); Also another investigation indicates that it determined that the pecan shell had 136.78 Kcal/g (Flores-Córdova et al., 2016). To efficiently take advantage of the energy of vegetable waste from trees, plants and agricultural species, these are being conditioned in the form of pellets or briquettes that, due to their compaction, acquire characteristics of combustion efficiency.(Diaz and Benites, 2020) and studies have been carried out in this regard with various plant biomasses to obtain bioenergy such as the use of ground coffee residues (Paredes, 2019), use of corn residues (Wongsiriamnuay and Tippayawong, 2015), use of pruned branches of jujube (Li et al., 2022), production of mixed pellets of sewage sludge and biomass were also tested, where it is indicated that there is synergy between protein and lignin in the mechanism of co-pelletization (Jiang et al., 2014). But care must be taken in making optimal designs of biofuel mixtures regarding the generation of biomass ash in industrial use in boilers due to the risk of sintering that may occur.(Rodriguez et al., 2020). Another way of using biomass is directly, but it has disadvantages mainly in its handling and storage.(Leite S. et al., 2018)

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In this context, the objective of the research was the characterization of biomass from *Carya illinoinensis* shell residues to produce pellets as a source of bioenergy with the use of residues, incorporating them into the life cycle with probable economic and social benefit under the concept of economy circular.

2. Methodology

In the elaboration of the pellets having as raw material shell of *Carya Illinoinensis* (pecan), the process shown in Figure 1 was followed.

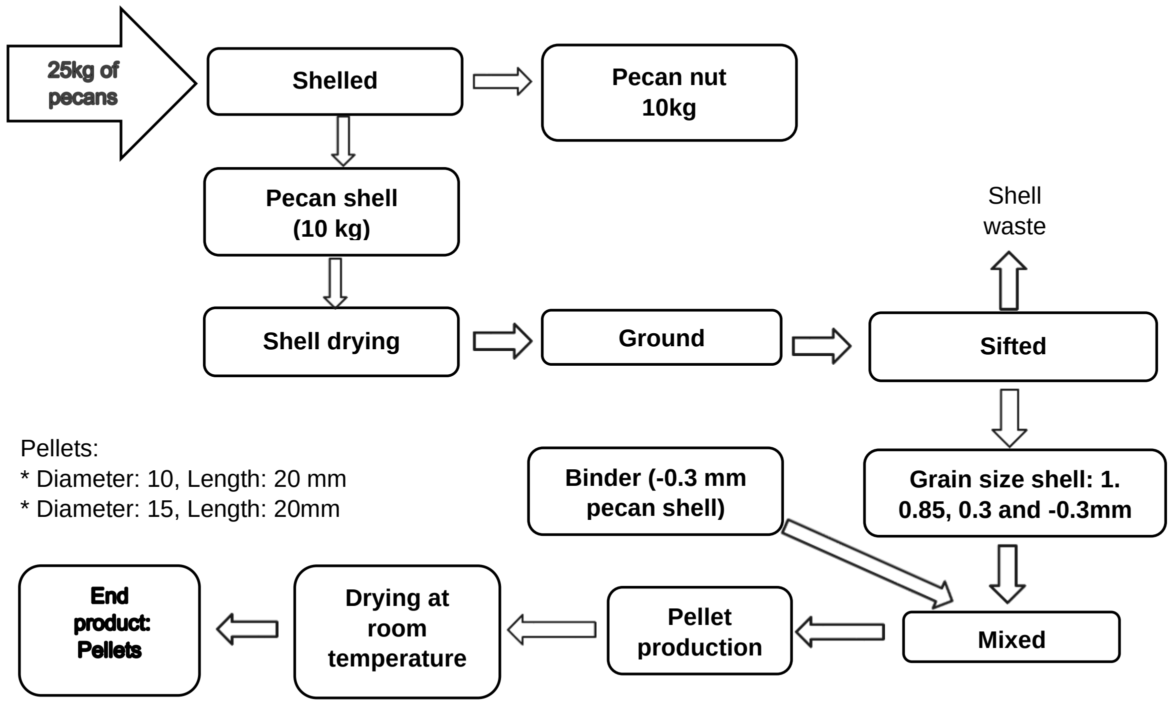

Figure 1: Pellet manufacturing process

2.1 Raw material: Shell of *Carya illinoinensis*

The shell of *Carya illinoinensis*, known by the common name of pecan (Figure 2), was obtained in an agricultural field to produce this product in the Ica region, where it´s considered as a residue of the shelling process and separation of the edible part. called pecan nut.

Figure 2: Shell of Carya illinoinensis

The shell sample was 10 kg that followed a drying and grinding process. Then a sieve was performed (Figure 3), to separate samples of meshes 1.0, 0.85, +0.3 and -0.3 mm, respectively. As a binder, the same pecan shell with a mesh size of -0.3 mm was used.

Figure 3: Screening of Carya illinoinensis Shell

2.2 Pellet production

Homogenized mixtures were prepared for 10 minutes with a 1:1 ratio between pecan shell and binder (150 g of each) using 200 mL of water. Humidity, volatile material, fixed carbon, and ashes were determined from this mixture. With a mixture of biomass and binder, two-dimensional pellets were made: 10 mm in diameter by 20 mm long and 15 mm in diameter by 20 mm long, using a mold and equipment with a pressure of 1 ton for densification. The elaborated pellets were dried at room temperature for 7 days (Figure 4). The already dry pellets were characterized around the calorific power, as well as the energy efficiency. See Figure 3

Figure 4: Drying of Carya illinoinensis pellets

Figure 5: Energy Efficiency Test

2.3 Methods for calculating biomass characteristics for pellet production.

To determine the humidity, Eq (1) was used.

$$\%\ of\ moisture = \frac{(\text{crucible weight} + \text{sample}) - (\text{crucible weight} + \text{sample at } 150\ °\text{C})}{(crucible\ weight + sample) - (crucible\ weight)} * 100 \tag{1}$$

Eq (2) was used to determine the percentage of volatile material.

$$\%\ MV = \frac{(\text{crucible weight} + \text{sample}) - (\text{crucible weight} + \text{sample at } 900\ °\text{C} * 7')}{(crucible\ weight + sample) - (crucible\ weight)} * 100 \tag{2}$$

In the determination of the percentage of ashes, a crucible was used where the sample was subjected to a temperature of 900 °C for 1 hour and then the percentage of ashes was found considering the initial and final weights. See Eq(3)

$$\% \, MV = \frac{(\text{crucible weight} + \text{sample}) - (\text{crucible weight} + \text{sample at } 900\ \text{°C} * 7')}{(crucible\ weight + sample) - (crucible\ weight)} * 100 \tag{3}$$

To calculate the percentage of fixed carbon, the Goutal relation was used, which uses the data on the percentage of ashes and volatile material. See Eq(4)

$$\% \text{ Fixed coal} = 100 - (\% \text{ Ashes } + \% \text{ MV}) \tag{4}$$

The calorific power was used in Eq (5), considering the fixed carbon (CF) and volatile material (MV)

$$\% \text{ Calorific power } = (82 * \% \text{ de CF}) + (120 * \% \ de\ MV)\ Kcal/Kg \tag{5}$$

3. Results and Discussion

3.1 Granulometry of the shell biomass of *Carya illinoinensis*

Table 1 shows the granulometry level of the raw material consisting of biomass of *Carya illinoinensis* (pecan) sieved after grinding that was used to make pellets. Biomass particle size is an important factor for physical stability in the pellet densification process(Kaliyan and Vance Morey, 2009) for this reason, four types of particle diameter size were tested to determine the most optimal.

Table 1: Granulometry of the raw material

Sample	particle diameter (mm)	
Sample a	+1.00	Grain size greater than 1 mm
Sample b	+0.85	Grain size between 1 and 0.85 mm
Sample c	+0.3	Grain size between 0.85 and 0.3 mm
Sample d	-0.3	Grain size less than 3 mm

Characterization of the biomass of the samples for pellets

Table 2 shows the main physicochemical characteristics of the biomasses to make the pellets with four types of mixtures according to granulometry of *Carya illinoinensis* husk biomass and binder, which corresponds to the following coding:

M1: Sample 1, for pellets of shell granulometries and binders of 1 mm and +0.3 mm
M2: Sample 2, for 1 mm and -0.3 mm shell and binder granulometry pellets
M3: Sample 3, for 0.85 mm and -0.3 mm shell and binder granulometry pellets
M4: Sample 4, for pellets with granulometries of shell and binders of +0.3 mm and -0.3 mm

The physicochemical characteristics of the raw materials are very important for the elaboration of the pellets, the moisture percentage content must be low to favor densification, that is why the shells of *Carya illinoinensis* were dried before being milled, the humidity value and the other parameters presented in Table 2, corresponds to the mixture prepared for the elaboration of the pellets. The percentage of fixed carbon in sample M4 is higher than the others, the higher the value means that there is more solid material for combustion.(Severns et al., 2007).

The percentage of ashes of the mixture of biomass and binder presented low values, this favors the calorific power of the processed pellets, since a higher content of ash would have a negative impact on the performance of the combustion of the pellets. (Zhou et al., 2016)

Table 2: Characteristics of the biomass used to manufacture the pellets

	M1	M2	M3	M4
Humidity (%)	54.39	48.72	47.07	51.92
Volatile Material (%)	49.86	46.23	51.32	53.15
Fixed coal (%)	46.86	50.07	44.44	43.95
Ashes (%)	6.43	3.7	4.24	2.9

3.2 Calorific power of the pellets

Table 3 shows the calculation of the calorific power of the different types of pellets produced and after drying at room temperature. A good range of calorific power was found in the pellets, this favored by the presence of volatile components and fixed carbon that, at a higher percentage, favors the generation of energy.(Li et al., 2022), another factor that improved the energy potential was the use of finer granulometry biomass of the same nature (*Carya illinoinensis*) as a binder that allowed maintaining the same energy density, in case of using binders of another type, the properties that possesses in energy density, humidity, ashes, together with the stability function that it can offer (Niu et al., 2016).

The results indicate that the pellets with the M4 sample have a higher value, but the others are within the same level, which means that the biomass used is suitable for the production of this type of biofuel, which according to the German Institute of Standards (Deutsches Institut fur Normung – DIN), DIN Plus51731 establishes that the calorific value must be greater than 16.5 MJ/kg or 4.6 KWh/kg(Rangel et al., 2018), a fact that is fulfilled.

Table 3: Calorific power of the pellets

	M1	M2	M3	M4
Calorific Value (kcal/Kg)	9,566.6	9,653.34	9,802.48	9,981.90
Calorific Value (MJ/Kg)	40.02	40.38	41.02	41.76

3.3 Thermal efficiency of the pellets

The test was carried out considering the pellets M2, M3 and M4. 250 mL of water and 10 pellets of each type of sample were used and burned until the water reached a boil, noting the times used. The results are shown in Table 4, the test called Water Boiling Test (WBT for its acronym in English), allows to find the thermal efficiency that is a relationship between the task of boiling and evaporation of water against the energy supplied by combustion biomass *(Hernandez, 2014)*

Table 4: Efficiency of the calorific power of the pellets

	M2	M3	M4
Water boiling time (min)	10	15	18

4. Conclusion

The pellets made with biomass consisting of shell of Carya *illinoinensis* with granulometry +3 mm mixed with the same biomass, but with a finer granulometry (-3 mm) as a binder, resulted in a calorific value of 9,981 Kcal/kg. In the same way, the other pellets made with other granulometries also had an approximate value. These results confirm the possibility of making pellets from the biomass as an alternative for reusing agricultural residues in *Carya illinoinensis* producing areas,

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