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Briquettes produced from the mixture of agro-industrial residues composed of eucalyptus sawdust with turnip or corn cob cake

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ABSTRACT. The generation of waste and/or by-products in the agro-industrial sector is inevitable and, depending on the situation, it can lead to inadequate disposal. The aim of this study was to evaluate the physical properties and the energetic viability of agro-industrial residues composed of the mixture of eucalyptus sawdust with turnip or corn cob cake. The experiment was set up in a completely randomized design with eight treatments, resulting from the mixture of eucalyptus sawdust with turnip/corn cob cake. Pure residues were characterized by immediate analysis, calorific value and thermogravimetric analysis. For briquettes, immediate analysis; apparent and energetic density; diametrical compression resistance, HCV, LCV and thermogravimetric analysis were carried out. For statistical analyses, the Tukey's test was applied in qualitative analyses and regression was used in quantitative analyses with the Sisvar statistical software. The volatile material content decreases as forage turnip cake is added; the composition of 50% of forage turnip cake and 50% of eucalyptus (TN50) presented 76.38% of it, while composition containing 15% of cake, 79.87%. The ash content increased from 3.25% (TN15) to 6.27% (TN50). Both HCV and LCVdecreased with the addition of turnip cake from 17.73% (TN15) to 16.96% (TN50) for HCV and from 16.38% (TN15) to 15.64% (TN50) for LCV. In thermograms, the temperature at which peaks appear is similar among the different mixtures. In the resistance test, the addition of forage turnip cake significantly influenced the addition of residues, increasing from 0.76 MPa (TN15) to 1.52 MPa (TN50). Considering the analyses carried out, and comparing them with results in literature, it is possible to verify that both, briquettes produced from forage turnip cake and those made from corn cob, have energy potential.

Keywords: biomass; agricultural waste; sustainability; energy.

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Introduction

The growing concern with the environment and social needs raises the importance of sustainable forms of development. Among them the use of renewable energy sources (Omena, Souza, & Soares, 2013). The production of fuels alternative to fossil fuels has been encouraged worldwide since they do not emit sulphur dioxide (SO_2) and sulphur trioxide (SO_3), being thus considered clean (Khorshidi, Ho, & Wiley, 2014). Examples include the production of biodiesel, bioethanol, biogas, biohydrogen, dendroenergetic fuels, among others (Garcez & Vianna, 2009; Pant & Adholeya, 2007; Pottmaier et al., 2013).

Brazil has been investing in programs supported by laws that encourage the rural economy and the use of biodiesel blended with diesel in its trading network (Leite, Bijman, Giller, & Slingerland, 2013; Law No. 13.033/14). The production of biodiesel from oilseeds produces residues (cake and glycerin) at the end of the process, and the industry is responsible for managing these residues (Federal Law No. 12, 305/2010). Thus, this cost is often embedded in production (tons of cakes are generated at the initial production phase).

The potential use of forage turnip oil for biodiesel production has been widely studied, and the major benefit of its use is the easy turnip production. The cake obtained from this process is mostly extracted by cold pressing (Fortaleza et al., 2013). Despite still being the subject of studies, turnip cake has the potential to beused in animal feed due to its high protein content (Fortaleza et al., 2013; Santos et al., 2018).

When the lipid portion is extracted, the residues generated have high levels of polysaccharides such as cellulose, hemicelluloses, and starch, which may be used for the production of ethanol by the hydrolysis pathway (Santos et al., 2018). The presence of these polysaccharides enables the production of other types of fuel.

Like oilseed cake, several by-products are generated after the processing of primary sources, which is also the case of corn. Most corn harvests keep their residues in the field, contributing to increase the organic matter content and promoting the sustainability of the productive system. However, during the process in self-propelled harvesters, these residues end up reaching cereal companies, resulting in discounts and forcing warehouses to perform the disposal. In this sense, using residues for energy purposes is an alternative to add value to the product, allowing their use in the cereal industry itself, reducing the use of native wood in ovens for drying grains.

The energetic potential of eucalyptus as wood is known, although this source demands more time for development when compared to turnip and corn. In this sense, the aim of this work was to evaluate the physical properties and the energetic viability of agro-industrial residues from the mixture of eucalyptus sawdust with turnip or corn cob cake.

Material and methods

Turnip cake (*Raphanus spp*) samples were collected at the Federal University of Paraná - Palotina Sector, resulting from oil extraction (mechanical extraction) for biodiesel production at the Laboratory of Biofuel Production (LPB).

The material was dried in the sun for two days and then ground using 1-mm mesh sieve. Small grain size is associated with better particle compaction. Okot, Bilsborrow and Phan (2018) recommend particles <4 mm in order to meet quality standards. The material was stored in a ventilated place, above the ground, protected from the weather.

The corn cob (*Zea mays ssp*) residue was obtained from a local cereal company (Palotina-PR), ground using 1-mm sieve mesh, and stored in a protected place. Eucalyptus sawdust residue samples (*Eucalyptus* spp.) used for briquetting were donated by LENECO (Capitão Leônidas Marques, Paraná State, Brazil).

The experiment was conducted in a completely randomized design (CRD), composed of eight treatments and five replicates, which are shown in Table 1.

Table 1. list of percentages of each waste for the different mixtures.

Mixtures	Percentages of each residue
TN50	50% forage turnip cake x 50% eucalyptus sawdust
TN35	35% forage turnip cake x 65% eucalyptus sawdust
TN25	25% forage turnip cake x 75% eucalyptus sawdust
TN15	15% forage turnip cake x 85% eucalyptus sawdust
S50	50% corn cob x 50% eucalyptus sawdust
S35	35% corn cob x 65% eucalyptus sawdust
S25	25% corn cob x 75% eucalyptus sawdust
S15	15% corn cob x 85% eucalyptus sawdust

Source: the author (2018).

The mixing of the different materials was manually executed before briquetting. The material was compacted in a Lippel briquetting machine; BL 95/210 (three-phase), with piston. Feeding was performed in batch (200 beats per minute), with each impact corresponding to 130 tons. After compaction, 5 briquettes randomly collected from each mixture were used to make analyses.

Immediate analysis was carried accomplish for mixtures before and after compaction using ASTM (E-870-82), according to Sánchez (2010). In order to carry out the immediate analysis of the fresh material and mixtures before compaction, triplicates were carried out.

The calorific value of the fresh waste (turnip cake, cob, and sawdust) was determined according to methodology described by Normas Técnicas (1984) ABNT NBR 8633 (1984). The methodology proposed by Eriksson and Prior (1990) was used to determine the higher and lower calorific value of briquettes, which uses the ash and moisture contents present in the sample, according to Equations 1 and 2, for the higher calorific value (HCV)and lower calorific value (LCV) of briquettes, respectively, where, A represents ash percentage and M, moisture percentage.

$$HCV = 20.0X(1 - \%A - \%M) \quad (1)$$

$$LCV = 18.7X(1 - \%A) - (21.2X\%M) \quad (2)$$

To determine thermogravimetric parameters and derivatives, the equipment used was SETARAM SETSYS EVOLUTION TGA-DTA/DSC in Alumina Crucible, using approximately 10 mg of sample. The analysis was performed from room temperature to 600°C, at 10°C $min.^{-1}$ and Argon flow of 20 mL $min.^{-1}$, with change in the flow from Nitrogen to Argon, both inert gases (Santos et al., 2012).

The apparent density was determined from the relationship between the sample mass of briquettes and their volume (Rezende, Escobedo, & Ferraz, 1988). The energy density of briquettes was determined by means of the product of the average basic density by the higher calorific value (Equation 3), as carried out by Protásio, Goulart, Neves, Assis, and Trugilho (2014).

$$\rho\, E = \rho(Kg.m^{-3})X\ HCV\ (MJ.kg^{-1}) \quad (3)$$

The ABNT NBR 7222 standard (1994) was used to perform the diametrical tensile strength tests of cylindrical specimens, a standard test regulation regarding the ABNT NBR 6118 standard (2004).

For the statistical analysis, the variables analyzed were moisture, fixed carbon, volatile material, and ash contents, as well as higher and lower calorific value, density, and energy density of briquettes. Data obtained were submitted to analysis of variance, then they were used for the Tukey test, in qualitative tests, and for regression analysis, in quantitative tests ($p < 0.05$), using the Sisvar® software. In the regression analysis ($p < 0.05$), for the selection of the best model, the following adjustment criteria were adopted: regression, non-significant regression deviations, and significant determination coefficient.

Results

Physicochemical characterization of samples and immediate analysis of briquettes

Tables 2 and 3 present the results of the immediate analysis for the different type of residues and different mixtures before compaction.

Table 2. immediate analysis of raw material prior to compression.

	Moisture (%)	Volatile Materials (%)	Fixed Carbon (%)	ASHES (%)
eucalyptus sawdust	8.81 b	83.74 a	13.94 b	2.31 b
SD eucalyptus sawdust	0.02	0.96	1.19	0.24
forage turnip cake	10.44 a	77.02 b	15.30 ab	7.66 a
SD forage turnip cake	0.21	0.73	0.44	0.89
corn cob	10.79 a	82.29 a	16.73 a	0.97 b
SD corn cob	0.04	0.18	0.15	0.13
CV (%)	1.50	1.06	5.91	18.00

Source: the author (2018). note: CV%: Coefficient of Variation; SD: standard deviation.

The difference in chemical composition between eucalyptus sawdust, forage turnip cake, and corn cob, is the main factor affecting the levels of volatile materials, fixed carbon, and ash. The ideal moisture to compact the material varies according to the press used. In this case, a piston press, the recommended moisture is 10 - 15% (Nogueira & Lora, 2003).

Nones, Brand, Cunha, Carvalho, and Weise (2015) found volatile material contents of 81.47 and 82.74% for *Eucalyptus benthamii*with 5 and 13 years, respectively. Trugilho, Lima, Mori, and Lino (2001) reported volatile material contents between 77.58 and 81.59% for different eucalyptus clones. For the same parameter, Silva et al. (2015), recorded value of 83.98%, which is close to that observed in the present work for eucalyptus sawdust residues (83.74%).

Regarding eucalyptus sawdust, Trugilho et al. (2001) recorded fixed carbon content between 18.05 and 21.91%, for different eucalyptus clones. Silva et al. (2015), observed value of 15.78%, higher than that observed in this work (13.94%).

Barrichelo and Brito (1985), performed immediate chemical analysis of different eucalyptus species in which the bark presented higher ash content when compared to wood, ranging from 0.30 to 6.40%. In the study of Silva et al. (2015) on *Eucalyptus benthamii* wood for energy production, ash content of 0.24% was observed. Trugilho et al. (2001) reported ash content between 0.33 and 0.53% for different eucalyptus clones, values lower than that observed in this work (2.31%).

For turnip cake, the volatile material value was 77.03% and the fixed carbon value was 15.31%. There are no reports in literature on the analysis of volatile material contents and fixed carbon for forage turnip cake. In a study on the chemical characterization of different oil seeds, among them turnip cake, Souza, Favaro, Ítavo, and Roscoe (2009), observed ash content of 5.25% for turnip cake, value lower than that observed in this study (7.66%).

Zambrzycki, Vale, and Dantas (2013), found volatile material content of 84.68% and fixed carbon of 13.67% for corn cob. Paula, Trugilho, Rezende, Assis, and Baliza (2011) observed values of 81.31% and 18.32% for volatile material and fixed carbon, while Raveendran, Ganesh, and Khilar (1995) found values of 85.40% and 11.80%, respectively, which are close to those observed in the present work, 82.29% and 16.73%.

In a study on the energy potential of corn crop residues, carried out by Zambrzycki, Vale, and Dantas (2013), the ash content was 1.65%, value higher than that found in the present work (0.97%).

Table 3. Presents the immediate analysis of briquettes produced from mixtures selected in the experimental design.

Table 3. Immediate analysis of mixtures after compaction.

Mixtures	Moisture (%)		Volatile Materials (%)		Fixed Carbon (%)		Ashes (%)	
	Average	SD	Average	SD	Average	SD	Average	SD
TN50	8.88	1.56	76.38	0.83	17.34	0.75	6.27	0.22
TN35	8.94	0.67	77.46	0.43	17.40	0.37	5.13	0.38
TN25	8.78	0.55	78.01	0.39	17.27	0.50	4.71	0.54
TN15	8.07	1.05	79.87	1.36	16.87	1.24	3.25	0.91
CV (%)	13.33		1.22		5.10		13.22	
	p > 0.05		p < 0.05		p > 0.05		p < 0.05	
S50	9.79	0.35	79.61	0.53	18.18	0.43	2.21	0.13
S35	9.58	0.27	81.10	1.19	16.81	1.15	2.08	0.13
S25	8.93	0.52	80.07	0.87	17.15	0.77	2.76	0.14
S15	8.93	0.39	80.07	1.45	17.28	1.23	2.64	0.27
CV (%)	4.73		1.48		6.10		8.71	
	p < 0.05		p > 0.05		p > 0.05		p < 0.05	

Source: the author (2018). note: CV%: Coefficient of Variation; SD: standard deviation.

According to Nogueira and Rendeiro (2008), the thermophysical characteristics typical of briquettes are 12% moisture, 84% volatile material, 14% fixed carbon, and 2% ash. These values are close to those observed for briquettes in this work.

After compaction, the volatile material content decreases and the ash content increases, as the addition of turnip cake increases, because, according to Table 2, this parameter is lower in turnip cake than in eucalyptus sawdust. The moisture content of corn cob decreased as the content of corn in the mixture decreased, because the initial moisture of eucalyptus sawdust is lower than that of corn cob.

Slow and more homogeneous burning is a desired characteristic of the consumer market, a characteristic affected by the low volatile content. Reduced moisture is desired since the higher this parameter, the more energy is spent drying the material before it is effectively burned (Grover & Mishra, 1996).

The low ash content represents an advantage over the other types of biomass. According to Obernberger and Thek (2010), ash contents above 3% reduce the energy properties of materials. Thus, it could be inferred that forage turnip cake is more likely of having low energy efficiency compared to eucalyptus sawdust and corn cob (Table 1).

When making the mixtures (Table 3), the ash content of the turnip/eucalyptus cake increased, indicating the impossibility of using high turnip cake concentration in mixtures. Furthermore, after compaction, the ash contents increased for mixtures containing turnip cake (Table 3), which is a negative result, since the higher the ash content, the greater the likelihood of decreasing the calorific value. In addition, it increases the oven cleaning rate due to the high ash production, which may lead to corrosion and degradation (Vital, Carneiro, & Pereira, 2013).

Calorific value of pure materials and briquettes

Table 4 shows the calorific value for the different residues (determined in calorimetric pump), and Table 5 shows the upper (HCV) and lower (LCV) calorific value for the different mixtures (determined based on moisture and ash contents).

Table 4. Higher calorific power of residues before compaction (MJ kg^{-1}).

Residues	Higher calorific power
Eucalyptus sawdust	17.01 b
Forage turnip cake	20.15 a
Corn cob	16.06 c

Source: the author (2018).

Table 5. Calorific power of briquettes (mj kg^{-1}).

	HCV		LCV	
	Average	SD	Average	SD
TN50	16.96	0.34	15.64	0.35
TN35	17.18	0.16	15.84	0.17
TN25	17.31	0.15	15.95	0.15
TN15	17.73	0.07	16.38	0.09
CV (%)	1.33		1.50	
	p < 0.05		p < 0.05	
S50	17.60	0.05	16.21	0.05
S35	17.66	0.05	16.27	0.05
S25	17.66	0.13	16.29	0.14
S15	17.68	0.05	16.31	0.06
CV (%)	0.49		0.56	
	p > 0.05		p > 0.05	

Source: the author (2018). note: CV%: Coefficient of Variation; SD: standard deviation.

After the compaction of materials, the HCV and LCV of the turnip cake treatment increased as the sawdust percentage increased. Protásio, Alves, Trugilho, Silva, and Baliza (2011) made the compaction of eucalyptus sawdust briquettes and obtained calorific value of 18.46 MJ kg^{-1}. No calorific value results were found in literature for forage turnip cake. Protásio et al. (2011), executed the compaction of corn waste briquettes and obtained calorific value of 18.89 MJ kg^{-1}.

The calculated HCV values for mixtures containing corn cob are higher than those determined for eucalyptus sawdust and corn cob.

Thermal analysis – thermogravimetric analysis (tg) of pure materials and briquettes

Thermogravimetric analysis represents mass degradation as a function of temperature. Table 6 shows a summary of events observed in thermograms. Temperature ranged from room temperature to 600ºC, at 10ºC $min.^{-1}$ for all materials under analysis.

Table 6. List of events observed in thermograms.

Mixture	First Event	Second Event	Third Event
Eucalyptus sawdust	90-100ºC	250-300ºC	350-400°C
Forage Turnip Cake	90-100ºC	280-290ºC	310-320ºC
Corn cob	89-100ºC	250-300ºC	300-350ºC
TN50	98-102ºC	210-280ºC	340-350ºC
TN35	90-100ºC	210-280ºC	340-350ºC
TN25	90-100ºC	210-280ºC	340-350ºC
TN15	90-100ºC	210-280ºC	340-350ºC
S50	90-100ºC	210-340ºC	340-350ºC
S35	90-100ºC	250-300ºC	340-350ºC
S25	90-100ºC	250-300ºC	340-355ºC
S15	90-100ºC	250-300ºC	340-350ºC

Source: the author (2018).

Mixtures presented close degradation temperature range (Table 6). The event close to 100ºC refers to the loss of moisture in the material. Lignin degradation starts from approximately 150ºC and continues until the end of the process, which is why there is no specific peak for lignin, as it occurs for cellulose and hemicellulose (Vital et al., 2013).

Hemicellulose is degraded mainly between 150 and 275°C, while cellulose, between 275 and 400°C (Oliveira et al., 2010; Figueroa & Moraes, 2009). The temperature difference is associated with the structure of these polysaccharides. Hemicelluloses may present one type of sugar in the main chain (homopolysaccharides) or more than one type in its basic chain (heteropolysaccharides) (Ebringerova, 2006), with such variety implying the degree of polymerization up to 200 units. In addition, they have short chains, therefore low molecular weight and branches.

Differently, cellulose presents high molecular weight, and its major chain is homopolysaccharide (several β-D-glycopyranose units joined through glycosidic bonds of β-(1-4) type) and may present polymerization degree of up to 25,000 units. It is also important to consider that the pulp structural organization is stable due to the presence of hydrogen bonds, resulting in ordered regions. These structural differences between cellulose and hemicellulose are responsible for the early hemicellulose degradation, followed by cellulose degradation (Junior, Fonseca, & Silva, 2014).

It is important to know the phases of biomass degradation, since this information will be used to determine the temperature range to be used for the complete burning of the material (Vital et al., 2013). Therefore, briquettes in our example were degraded at temperatures considered low, which enables their use as energy source.

Apparent and energy densities of briquettes

Table 7 shows the apparent and energy densities for the different mixtures.

Table 7. Apparent density (kg m^{-3}) and energy density (MJ m^{-3}) of briquettes in tn and s mixtures.

	Apparent Density		Energy Density	
	Average	SD	Average	SD
TN50	890.70	84.86	15131.00	1627.96
TN35	828.12	34.92	14231.00	611.69
TN25	914.12	61.06	15818.00	1124.16
TN15	999.85	178.45	17730.20	3153.62
CV (%)	12.92		1.50	
	p > 0.05		p > 0.05	
S50	959.38	135.66	16884.60	2379.83
S35	960.75	161.13	16977.80	2876.37
S25	1058.16	179.40	18693.20	3208.55
S15	1043.99	132.18	18460.80	2329.61
CV (%)	17.05		17.15	
	p > 0.05		p > 0.05	

Source: the author (2018). note: CV%: Coefficient of Variation; SD: standard deviation.

Protásio et al. (2011) executed the compaction of briquettes of eucalyptus sawdust and obtained 950 kg m^{-3} for apparent density and 17,430 MJ m^{-3} for energy density. Paula et al. (2011) executed the compaction of different lignocellulosic materials/waste and obtained apparent density of 900 kg m^{-3} for wood briquettes. Sette Jr et al. (2018) found apparent density of 1,320 kg m^{-3} and energy density of 25,520 MJ m^{-3} for eucalyptus wood briquettes.

Yamaji, Vendrasco, Chrisostomo, and Flores (2013), in their study on the analysis of the hygroscopic behavior of briquettes, observed that briquettes of eucalyptus sawdust have density of 800 kg m^{-3}. Silva et al. (2015) recorded density value of 920 kg m^{-3} for eucalyptus sawdust. There are no apparent density and energy density values in literature for briquettes containing forage turnip cake.

Okot, Bilsborrow, and Phan (2018) performed the compaction of corn cobs, obtaining density variation between 516 and 1,058.2 kg m^{-3}. Protásio et al. (2011) performed the compaction of corn waste briquettes and obtained 930 kg m^{-3} for apparent density and 17,639.6 MJ m^{-3} for energy density. Paula et al. (2011) obtained apparent density of 870 kg m^{-3} for corn briquettes.

Muazu and Stegemann (2015) found briquette density values between 366 and 570 kg m^{-3}. According to these authors, the value recommended for standard solid biofuels by the UK good practices standard should be higher than 500 kg m^{-3}. Kaliyan and Morey (2009) reported that briquette produced from corn cobs and/or corn straw should be uniform, with density values from 500 to 600 kg m^{-3}.

Biomass properties vary according to the material used, and some materials may have higher density than others. Biomass with high lignin content, starch content (acting as binder), and protein, have better compaction when compared to those with higher cellulose content (Tumuluru, Wright, Hess, & Kenney, 2011; Muazu & Stegemann, 2015).

For corn cobs, lignin, protein, and starch contents are 15.3, 2.7, and 1.61%, respectively (Perotti & Molina, 1988; Steffens, 2012; Bazzana, Camp, Fox, Schffino, & Wing, 2011), while for the same parameters, Kaliyan and Morey (2010) found 5.8, 2.5, and 2.1%, respectively. For forage turnip cake, Souza et al. (2009) reported crude protein content of 49.47% and starch content of 14.79%.

Kaliyan and Morey (2009) observed that some variables (such as particle size, moisture content, and temperature affect the density and durability of briquettes. This work reported that the ideal values for these variables are particle size between 0.5 and 1.0 mm; moisture content between 8 and 20% and preheat temperature of 65°C and 100°C.

The results for the energy density of the material have a positive trend when compared to the apparent density. Therefore, the concentrated energy per volume unit increases; therefore, it is more economically viable to compact than to transport/use fresh biomass (Sette Jr et al., 2018).

Resistance of briquettes

Sette Jr et al. (2018) found average diametrical compression resistance of 4.40 MPa for *Eucalyptus* ssp wood briquettes. In studies on the compaction of vegetable biomass for the production of solid biofuels, Protásio et al. (2011) obtained diametrical compression resistance of 0.82 MPa for eucalyptus sawdust briquettes. Paula et al. (2011) obtained mechanical resistance of 18.65 MPa for wood briquettes.

In the same study, Protásio et al. (2011) analyzed briquettes with ground corn residues (straw, cob, stem, and leaves) and obtained value of 0.91 MPa. Paula et al. (2011) recorded mechanical resistance of 7.25 MPa for briquettes produced from corn cob.

There is no diametrical compression resistance test in literature for forage turnip cake briquettes or mixtures containing it.

High mechanical resistance is desired due to several factors, among them resistance to exposure and to shock during transport so that the material does not suffer from crumbling, disintegration, or softening during heating (Reineke, 1964).

Briquettes composed of different mixtures presented different mechanical resistance values (Table 8).

Table 8. Diametrical compression resistance of briquettes (mpa)

	Resistance of briquettes	
	Average	SD
TN50	1.52	0.07
TN35	0.35	0.16
TN25	0.56	0.08
TN15	0.76	0.30
CV (%)	24.14	
	p < 0.05	
S50	1.57	0.02
S35	0.98	0.51
S25	4.89	1.07
S15	3.12	0.68
CV (%)	26.96	
	p > 0.05	

Source: the author (2018). note: CV%: Coefficient of Variation; SD: standard deviation.

Several factors may be associated with this difference, such as homogenization of the pre-baking material, which was manually performed; absence of binder, responsible for maintaining the packaging after the process and during storage (Schneider & Mühlen, 2011); and the transport itself, performed between the production site and analysis.

Several researchers reported difficulty in obtaining repeatability in compression resistance test results, even if briquettes and/or pellets have the same origin (Franke & Rey, 2006; Li & Liu, 2000). Also, according to Li and Liu (2000), the compression resistance test might not indicate the true compression resistance of the compacted material. This difficulty could be due to interactions between particles.

The strength and durability of densified materials depend on the physical forces that bind particles together, with the main binding forces that act between particles being classified into 5 groups: 1st - Solid bridges; 2nd - Forces of attraction between solid particles; 3rd - Mechanical interconnected bonds; 4th - Adhesion and cohesion forces; and 5th - Interfacial forces and capillary pressure (Kaliyan & Morey, 2009).

Moreover, the presence of lipids in briquettes may also interfere with attraction and adhesiveness forces, among other factors that contribute to their high hardness values (Manickam, Ravindran, & Subramanian, 2006). This factor may also have influenced the resistance of briquettes, since those containing forage turnip cake presented lower resistance when compared with those containing corn cob.

The preheating temperature (between 65 and 100ºC $min.^{-1}$) and the temperature used and/or generated during compaction may also directly affect the final properties of briquettes and the energy consumption during compaction (Kaliyan & Morey, 2009). According to Bhattacharya et al. (1989), quoted by Quirino, Pinha, Moreira, Souza, and Tomazello Filho (2012), "the resistance of briquettes depends on the compaction temperature, and the maximum resistance is reached close to 220°C." This dependence is related to the presence of binding forces between particles. Another factor that may have influenced briquette resistance was the fact that there was no preheating of the material before starting the briquetting process or heating (at controlled temperature). However, after some time, the friction between materials generated heat, inducing mixtures to certain preheating. The first mixture to be compacted was mixture 1 (TN = forage turnip cake with eucalyptus sawdust), followed by mixture 2 (S = corn cob with eucalyptus sawdust).

Conclusion

Both mixtures (mixture of eucalyptus sawdust and turnip and mixture of eucalyptus sawdust and corn cob cake) point to the feasibility of use after compaction, since as the turnip cake content decreases, the ash content also decreases due to the chemical constituents in the turnip, which do not combust at low temperatures. Thus, based on results, the mixture with 15% turnip and 85% sawdust presents benefits such as lower ash content, lower content of volatile materials (when compared to eucalyptus sawdust), and higher calorific value (upper and lower), also showing good resistance. In the same way after compaction, treatments containing more or less corn cobs did not differ statistically from each other (except for moisture - which results from the moisture content of cob coming from the field - and the ash content - representing an advantage, since treatments with high cob contents present lower ash contents). Thus, based on results, corn cobs can be used with eucalyptus sawdust without resulting in any lower energy efficiency.

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