Original Research

Comparing Emission Factors and Physicochemical Properties of Waste-Biomass Leaves of Selected Species of Trees

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Abstract

This study describes the problems of managing biodegradable waste in the form of leaves in the thermochemical conversion process of waste biomass. The results of experimental studies of physicochemical properties of leaves of 4 selected tree species (i.e., oak, hazel, maple, and walnut) are shown. The study consisted of determining the energy parameters in the form of markings gross and net calorific value of the test material. In addition, the ash and moisture content of the material was tested. Moreover, an elementary analysis for the tested leaves by determining the content of carbon, hydrogen, and nitrogen was measured. The studies have shown great energy potential for the examined leaves, in particular oak leaves, where the gross calorific value amounted to 18.77 MJ·kg^{-1}, net calorific value of 17.70 MJ·kg^{-1}, and an ash content of 21.98%. Oak leaves are also characterized by the highest carbon content of 47.66%, hydrogen at 6.32%, 0.88% nitrogen, and sulfur 0.14%. Determined emission rates indicate a reduction of 28-35% CO, 24-53% NO$_x$, 26-32% CO$_2$, 53-60% SO$_2$, and 31-54% dust depending on the type of biomass used.

Keywords: biomass, leaves, energy, tree, emission factors

Introduction

Legal regulations in the European Union impose the obligation to implement a national solid waste disposal management system, including an efficient biowaste disposal management system [1-2]. The major objectives of the *acquis communautaire* include the aim of reducing the volume of municipal solid waste that is biodegradable. In order to solve that problem, it is necessary to implement new thermal treatment facilities for solid waste, including biowaste that is biodegradable [3] – particularly within the framework of the municipal solid waste disposal management systems in urban agglomerations and macroregions. To this end, technological arrangements should aim at reducing substantial volumes of biodegradable waste and concurrently generating electric energy and thermal power in terms of renewable energy sources [4-6].

Leaves, falling off trees, represent a kind of biomass that may be used for power generation purposes

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to a great extent [7-9]. When the latest work is being done, it is affecting the life of the city to spread the leaf of the leafy trees. Although leaves can absorb CO_2, environmental pollution comes to the forefront when they are poured. Recent studies demonstrate how human health is affected by the quality with PM10 and CO_2. Several studies on air pollution exposure have shown the problems concerning human health and fine particulate organic matter [10-14]. In autumn they cause huge problems in urban agglomerations since large quantities of leaves are carried away in the course of cleaning cities and suburbs in the autumn every year, to be mainly disposed of at landfill sites [15-16]. Incineration is not a very popular method of disposing leaves. The related literature treats it as an innovative approach and it has recently aroused interest to the extent of using it for urban power generation purposes [17].

Incineration of tree leaves may be an alternative approach to those that have already been applied, namely landfilling and composting. Furthermore, using leaves for power generation purposes will contribute to the production of alternative fuel in terms of the national energy-fuel balance [18]. This is significant due to insufficient fossil fuels. It needs to be emphasized that biomass is an ecological fuel since it maintains zero balance of CO_2 in the atmosphere as a result of the incineration of leaves [19-21]. This is an additional advantage of using leaves for power generation purposes [17, 22]. Thermal-and-chemical conversion of biomass is a process that does not cause any additional emission of CO_2 into the atmosphere and which does not contribute to the greenhouse effect [23-25]. Reducing the emission of hazardous substances into the atmosphere is currently required and recommended by various global political and economic organizations [26-27]. The aim of reducing the emission of hazardous substances makes it necessary to seek innovative and ecological energy sources [28-30]. Incineration of leaves (biomass) in incinerators is normally preceded by the procedures of collecting, drying, and storing in adequate facilities, and finally grinding (in most cases).

The aim of our study was to perform physicochemical analysis of waste-biomass leaves and determine emission factors of individual gases and dust of selected species of trees in terms of their suitability for use for energy purposes and environment protection.

Material and Methods

Our research focused on leaves of four tree species: maple, hazel, oak, and walnut. The sampling procedure was compliant with the EN 14780 standard [31]. At the first stage of the research the leaf samples were disintegrated. They were first dried and purified. All the leaves were ground by means of the laboratory grinder IKA A 11 and underwent pre-selection.

The incineration gross and net calorific value were adjusted by means of the LECO AC 600 calorimeter in conformity with the EN 14918 standard [32]. The incineration gross calorific value was set as a result of the incineration of samples in conditions of ambient oxygen in a pressurized pot placed in water. The net calorific value was set by means of computer software and the input figures of water content and hydrogen content in the matter under consideration, according to the following net calorific value formula arising from the said standard (Eq. 1):

$$Q_{ia} = Q_{sa} - 24.43 \cdot (W_a + 8.94 \cdot H^a) \quad (1)$$

…where Q_{ia} is net calorific value in analytical terms (J·g-1), Q_{sa} is gross calorific value in analytical terms (J·g-1), 24.43 is water evaporation at 25ºC (corresponding to 1% of water content in fuel), 8.94 is hydrogen content conversion rate, H^a is hydrogen content in a sample in analytical terms (%), and W_a is water content in a fuel sample in analytical terms (%).

Ash content was measured in conformity with the EN 14775 standard [33] and water content – in compliance with the EN 14774-1 standard [34]. For the purposes of the measurements, we used a LECO TGA701 thermogravimetric analyzer. Nineteen samples were automatically weighed by the device, and ash content and water content were measured on the basis of the weight loss of the matter after it had been heated up when being strictly controlled in the conditions of ambient oxygen. Water content of the sample was computed in analytical terms according to the following formula (Eq. 2):

$$W_a = ((m_1 - m_2)/(m_1 - m_3)) \cdot 100 \quad (2)$$

…where W^a is water content in analytical terms (%), m_1 is weight of the pot containing the sample before drying (g), m_2 is weight of the pot containing the sample after drying (g), and m_3 is weight of an empty pot (g).

Ash content was measured in analytical terms in conformity with the EN 14775 standard [33] according to the formula (Eq. 3):

$$A = ((m_3 - m_1)/(m_2 - m_1)) \cdot 100 \quad (3)$$

…where A is ash content in a sample in analytical terms (%), m_1 is weight of a calcined pot (g), m_2 is weight of the pot containing a sample (g), and m_3 is weight of a pot containing ash (g).

Total carbon content (C), hydrogen content (H), and nitrogen content (N) were measured in conformity with EN ISO 16948:2015-07 [35] and sulfur EN ISO 16994:2016 standard [36]. The analysis was conducted by means of the CHNS 628 analyzer made by LECO. The process of measuring carbon content, hydrogen content, and nitrogen content was performed at 950ºC, and sulfur content (S) was analyzed in a separate module at 1,350ºC.

Table 1. Results of technical and elemental analysis for the tested leaves.

Material	Oak tree leaves	Maple tree leaves	Hazel tree leaves	Walnut tree leaves	F	p-value	F_w	p_w-value
Gross calorific value (MJ·kg^{-1}) ±S_x	18.58a ±0.03	18.00b ±0.56	17.41c ±0.24	17.38c ±0.04	47.51*	0.00	2193.3	0.00
Net calorific value (MJ·kg^{-1}) ±S_x	17.36a ±0.03	16.92b ±0.56	16.35c ±0.24	16.21c ±0.04	53.96*	0.00	2529.05	0.00
Moisture (%)	7.51	7.41	8.70	12.29	-	-	-	-
Ash (%) ±S_x	21.98a ±2.34	12.75b ±0.31	8.55c ±0.25	12.95b ±2.11	152.49*	0.00	-	-
Carbon (C) (%)±S_x	47.66a ±0.18	44.34b ±0.37	44.45b ±0.22	43.07c ±0.13	193.24*	0.00	-	-
Hydrogen (H) (%)±S_x	6.32a ±0.04	5.88b ±0.06	6.06c ±0.01	6.64d ±0.05	191.61*	0.00	-	-
Nitrogen (N) (%)±S_x	0.88±0.12	0.63±0.02	0.89±0.33	0.55±0.07	0.14	0.93	1.12	0.44
Sulfur (S) (%)±S_x	0.14a ±0.00	0.12b ±0.00	0.12b ±0.00	0.13a ±0.00	7.67*	0.00	-	-

S_x – standard deviation; *Significant value of the F test at significance level α = 0.05; *a, b, c, d* – Significant difference at the level of significance of α = 0.05; *F* – F test; F_w – Welch's F test, p_w – p-value for Welch's F test

Determining emission levels of individual gases and dust was based on the factor's emission method. The CO_2 emission factor was calculated using the calculation method based on the carbon content and calorific value of fuels. Formulas 4-6 were used for the calculations [37]:

SO_2:
$$E = B \cdot w \cdot S \qquad (4)$$

$NO_2/CO/CO_2$:
$$E = B \cdot w \qquad (5)$$

Dust:
$$E = \frac{B \cdot w \cdot A \cdot 100}{(100 - K)} \qquad (6)$$

…where E is amount of emission (kg), B is fuel consumption (Mg), S is sulfur content in fuel (%), A is ash content in fuel (%), K is combustible components content in dust (5% for biomass) (%), and w is emission ratio.

The results underwent statistical analysis conducted by means of STATISTICA 13 software. The normality of distribution of the properties under consideration was checked by means of the Shapiro-Wilk compliance test. The impact of a certain matter upon the value of incineration gross and net calorific value, ash content, C, H, N, and S content was assessed by means of the ANOVA test. Homogeneity of variance was checked by Lavene's test. In the case of heterogeneity of variance, the F Welch test (F_w) was performed. The significance level of diversity was also confirmed by means of the Tukey (HSD) test. All statistical analyses were conducted at the significance level of α = 0.05.

Results and Discussion

In the course of our research, we measured the incineration gross and net calorific values for oak, hazel, maple, and walnut leaves (Table 1). The measurements were repeated 10 times for each type of leaf. The results of the received state of the fuels confirms the lower calorific value, lower sulfur content, and lower ash compared to hard coal [37]. The research output figures for the incineration gross and net calorific value allowed us to demonstrate differences among the species of tree leaves that had undergone analysis. The highest values were proven by oak tree leaves. The average value of the incineration gross calorific value for that kind of matter stood at 18.58 MJ·kg^{-1}. The second ranked species of tree leaves proving the higher value of the incineration gross calorific value was the maple tree leaf. Its average value of incineration gross calorific value for that kind of matter stood at 18.00 MJ·kg^{-1}. The remaining leaves under consideration (maple and walnut) did not vary much in terms of the incineration gross and net calorific values, i.e., they were diversified by approximately 0.01%. The output figures for the values of physical and chemical properties of the tree leaves under consideration underwent statistical analysis in order to assess the impact of the species of tree leaves on the level of the incineration gross and net calorific values. The Shapiro-Wilk test for all analyzed data in work confirm the normality of distribution of the properties under consideration with the significance level of α = 0.05. In next step the ANOVA test of two factors was performed. Four groups of leaf varieties were compared (Table 1).

The ANOVA test proved that the kind of matter under consideration did have an impact indeed upon

Table 2. Comparison of estimated gas-dust emission ratios for biomass.

Material	Unit	CO	NO_x	CO_2	SO_2	Dust
Oak tree leaves	kg·Mg^{-1}	58.72a	1.95a	1438.00a	2.44a	27.76a
Maple tree leaves	kg·Mg^{-1}	54.63b	2.24b	1337.80b	2.13b	16.11b
Hazel tree leaves	kg·Mg^{-1}	54.75b	1.99a	1340.82c	2.07b	10.80c
Walnut tree leaves	kg·Mg^{-1}	53.07c	1.96a	1299.52d	2.40a	16.36b
Hard coal [37]	kg·Mg^{-1}	82.01	4.09	1969	5.20	23.57

a, b, c, d – Significant difference at the level of significance of $\alpha = 0.05$

the level of gross calorific value incineration and net calorific value. The significance of the diversity of the groups was measured by means of the Tukey HSD test (Table 1). The Tukey HSD test proved that the properties under consideration are substantially diversified in those groups for the majority of the values of p<0.05. Only in the case of the walnut and hazel leaves did the output figures not vary significantly among these two groups.

The research output figures for the ash content for the four species of tree leaves under consideration (incinerated at 600°C) have been presented in the Table 1. The research output figures make it plausible to state that the highest ash content was demonstrated by the oak tree leaves – 22% – and the lowest at 9% for hazel. The difference of the ash content between hazel and maple approximated 4%. The second top ash content was proven by the walnut tree at 13%. The research output figures for ash content in the four varieties of tree leaves underwent statistical analysis. ANOVA was also performed for the four varieties of leaves. The ANOVA test proved that the variety of leaves had a considerable impact upon ash content. Therefore, the significance of diversity among the groups was confirmed by the Tukey HSD test and it proved that only in the case of maple and walnut did the research output figures not vary significantly among these two groups (Table 1).

For incineration of the samples under consideration, the resulting figures for carbon, hydrogen, nitrogen, and sulfur contents in the leaves under consideration were determined. In the course of our research, the percentage rates of the content of chemical elements under consideration were computed (Table 1). The ANOVA test proved that the type of species of tree leaves significantly influenced the contents of carbon, hydrogen, and sulfur. No significant difference was reported for nitrogen content. Therefore, the significance level of the differences between carbon, hydrogen, and sulfur was confirmed. The Tukey HSD test proved that only in the case of oak and walnut did they vary significantly among all the groups as far as carbon content was concerned. In the case of hydrogen content, significant diversity was recorded for all groups. For sulfur content differences were shown between oak, walnut, maple, and hazel.

The calculated emission values are presented in Table 2. The figures show that CO_2 and SO_2 emissions are lower during the combustion of biomass fuel (tree leaves) compared to hard coal. In addition, lower emission ratios of coal emission gases may be observed. The highest emission factors were observed among CO (28.39% lower than hard coal), CO_2 (26.97% lower than hard coal), SO_2 (53.07% lower than hard coal), and dust (15% higher than hard coal) for oak. The highest NOx emissions were found for maple tree leaves (45.23% lower than hard coal). The lowest emission rates CO (35.28% lower than hard coal) and CO_2 (34% lower than hard coal) were found for walnut, while SO_2 (60.19% lower than hard coal) and dust (54.17% lower than hard coal) for hazel. Based on the obtained results it can be stated that the advantages of the analyzed biomass are lower values of emission factors compared to conventional fuels (coal). The ANOVA test proved that the variety of leaves had a considerable impact upon emission ratios for biomass. Therefore, the significance of diversity among the groups was confirmed by the Tukey HSD test and it proved that in all groups of emission factors output figures vary significantly among whole groups (Table 2). No significant differences were found between the leaves of the maple and the hazel in CO emission. Significant differences in NO_x emissions were found only for maple in relation to other materials. Tukey HSD test in terms of SO_2 emissions showed significant differences between oak and walnut, and maple and hazel. In the case of emissions of CO_2 and dust, the Tukey HSD test showed significant differences between all groups.

In the case of the studied biomass sources, only for nitrogen oxides was there an increase in their level per unit of energy in relation to hard coal (Table 3).

For oak, the highest emission rates per unit of energy were observed for CO (12.1% lower than hard coal), CO_2 (13.25% lower than hard coal), SO_2 (50% lower than hard coal also for walnut tree leaves), and dust (27.84% higher than hard coal). The highest NOx emissions were reported for maple (69.23% lower than hard coal). The lowest emission factors for CO (21.14% lower than hard coal) and CO_2 (4.02% higher than hard coal) were observed for maple, SO_2 (57.14% lower than hard coal) for maple and hazel, dust (53.50% lower than hard coal) for hazel, and NOx (69.63% lower than hard coal) for the three others. The ANOVA test proved that the variety of leaves had a considerable impact on gas-dust emission

Table 3. Gas-dust emission indices for biomass per unit of energy.

Material	Unit	CO	NO$_x$	CO$_2$	SO$_2$	Dust
Oak tree leaves	kg·GJ^{-1}	3.34a	0.11	81.70a	0.14	1.58a
Maple tree leaves	kg·GJ^{-1}	3.10b	0.13	76.01b	0.12	0.92b
Hazel tree leaves	kg·GJ^{-1}	3.11b	0.11	76.18b	0.12	0.61c
Walnut tree leaves	kg·GJ^{-1}	3.02b	0.11	73.84c	0.14	0.93b
Hard coal [37]	kg·GJ^{-1}	3.83	0.04	70.87	0.28	1.14

a, b, c, d – Significant difference at the level of significance of α = 0.05

indices for biomass per unit of energy in all groups except NO$_x$ and SO$_2$. Therefore, the significance of diversity among the groups was confirmed by the Tukey HSD test and it proved that in the groups of emission factors, per unit of energy varies significantly among whole groups for CO, CO$_2$, and dust emission (Table 3). The analysis of CO emissions showed significant differences between the oak leaves and other materials. The Tukey HSD test also showed that CO$_2$ emissions are not significantly different for the maple leaves and hazel leaves in the studied group. In the case of walnut and maple, the output figures for dust emissions did not vary significantly among these two groups.

On the grounds of the related literature, Table 4 presents the elementary composition of certain kinds of energy sources in terms of carbon, hydrogen, nitrogen, and sulfur content, and it was compared with the leaves under consideration and energy crops, i.e., Jerusalem artichoke sunflower and Reynoutria sachalinensis, one-year-old sprouts of Salix viminalis, oak timber, potato starch residue, and hard coal.

The highest content of carbon (C) is represented by hard coal, followed by oak timber, oak leaves, and energy crops. The content of that chemical element in maple, hazel, and walnut is a bit lower, but it approximates the content of other energy sources. The highest percentage share of hydrogen (H) is represented by the potato starch residue, followed by walnut and oak. The percentage share of nitrogen (N) in the matter under

Table 4. Elemental composition of selected types of energy raw materials [21, 38-40].

Material	C (%)	H (%)	N (%)	S (%)
Jerusalem artichoke sunflower	45.77	6.08	0.31	0
Reynoutria sachalinensis	46.81	5.69	0.38	0
Salix viminalis (one-year-old sprouts)	44.96	5.79	0.70	0
Oak timber	49.00	6.00	0.20	0.21
Potato starch residue	43.35	7.31	1.21	0.44
Miscanthus	48.4	6.0	0.4	0
Hard coal	75.7	4.3	1.2	1.2

consideration is the highest in the case of the potato starch reside and hard coal. The most efficient property, that is the lowest content of those chemical elements, is represented by energy crops and oak timber. The matter under consideration proved to contain nitrogen (N) similar to in one-year-old sprouts of Salix viminalis. In comparison to the remaining energy crops, the content of elementary chemical elements is generally similar. According to Fournel et al. [21], Miscanthus has a high nitrogen content and it is higher than the maximum obtained in studies for the oak leaves of 1.04%. While comparing the obtained results for sulfur content (S) it can be stated that the analyzed biomass has a lower content compared to other plants and hard coal.

Table 5 presents physicochemical properties of selected types of leaves obtained in research by Garcia et al. [18] and Fernandes et al. [41] in order to compare with results obtained in research. Analysis of the obtained results with literature data suggests that the results for gross calorific value of all leaves is comparable with that of the leaves of other species of trees.

According to Fernandes et al. [41], the gross calorific value for the oak leaves in their research was lower by 1.07 Mg·kg^{-1} than that obtained in studies. It could also be noticed that analyzed leaves of the hazel had gross calorific value of only 0.46 Mg·kg^{-1} higher. By comparing the gross calorific value of all the other leaves from the literature, it can be concluded that the highest value was found in banana leaves at 19.8 Mg·kg^{-1}, which is 1.22 Mg·kg^{-1} higher than the one obtained for the oak leaves, which was the highest value in the studies. Both analyzed leaves of hazel and walnut are characterized by a gross calorific value at a similar level as the leaves of apple, cherry, orange, and peach. However, in the case of oak and maple their gross calorific value is similar to the gross calorific value of banana (19.8 Mg·kg^{-1}) and peach (18.33 Mg·kg^{-1}) leaves.

While comparing the ash content of the studied leaves of trees it can be noticed that the highest value has been obtained from oak leaves (21.98%), whose value is very high. The literature data for this kind of raw material is only 3.8%. The difference can be the result of species of oak. Analyzing the obtained ash from the leaves of maple (12.75%) and walnut (12.95%), it can be stated that they are comparable to the ash content from leaves of orange (15.4%) and peach (10.2%).

Table 5. Physicochemical properties of selected types of tree leaves [18, 41].

Material	Gross calorific value (MJ·kg⁻¹)	Moisture (%)	Ash (%)	C (%)	H (%)	N (%)	S (%)
Apple tree	17.51	9.3	12.0	44.45	6.15	1.61	0.23
Cherry tree	17.73	10.4	7.4	45.52	6.25	1.49	0.19
Huzelnut tree	17.87	9.10	8.0	45.52	6.25	1.49	0.31
Oak tree	17.51	9.1	3.8	46.90	5.47	3.04	0.38
Orange tree	16.17	9.2	15.4	41.11	5.28	2.59	0.40
Peach tree	18.33	7.44	10.02	59.59	9.79	2.03	0.77
Almond tree	17.56	7.5	9.3	43.25	5.50	2.85	0.23
Banana tree	19.8	8.3	8.7	43.5	6.3	1.3	0.2

The ash content of hazel leaves is comparable with the literature data for leaves of cherry, almond, apple, or banana, and does not differ more than 1.85% for the results obtained.

Elemental analyses were comparable to the content of both carbon (C) and hydrogen (H) for the analyzed raw materials and with literature data for other species of tree leaves. It can be seen that the highest carbon (C) content for the analyzed samples was seen in oak leaves. In comparison to data with other samples and the literature data, the ash content is higher by approximately 2%. Only as indicated by Fernandes et al. [41] did carbon content for peach leaf differ from the data obtained in studies and literature. For this kind of leaf the ash content is slightly higher by about approximately 12%. The hydrogen content is similar for all tested materials and the literature data for other species of tree leaves. Only for the peach leaves was the hydrogen content about 3.5% lower than the obtained results.

The obtained content of nitrogen (N) for the tested material is at a similar level and is in the range 0.55-0.89%. By comparing the obtained values with the literature data it can be concluded that oak, maple, walnut, and hazel leaves have the lowest content of this element relative to the literature data. It can also be stated that the greatest differences are in relation to almond leaves. In this case the nitrogen content is 2.3% lower relative to the walnut leaves by 2.2% compared to maple, and approximately 2% relative to the leaves of hazel and oak. The smallest differences are in relation to the banana leaves. We should mention the difference for leaves of walnut 0.94% to 0.86% maple leaves, and the leaves of oak and hazel 0.6%. It should also be noted that the results obtained for sulfur content are lower for all analyzed cases than for other tree species in literature. The difference in sulfur content is 0.05-0.65%, depending on the plant.

The presented emission rates indicate a reduction of 28-35% CO, 24-53% NO_x, 26-32% CO_2, 53-60% SO_2, and 31-54% dust depending on the type of used biomass. Only in the case of oak tree leaves did a dust emission ratio increase by 17% in relation to hard coal. It should be noted that the use of leaves of trees (biomass) as fuel significantly reduces the emission of harmful compounds to the natural environment. Hence, the possibility of developing this type of fuel gives real environmental benefits, which is very important for the environment.

Conclusions

The use of biowaste for producing energy contributes to a reduction of emissions of hazardous substances and consequently to protection of the natural environment as well as to a reduction in the use of conventional fuel. The use of alternative fuel causes the emission of hazardous substances to be reduced and the international pro-ecological obligation, required by global renewable energy sources organizations, to be satisfied. In consequence, it is necessary to seek innovative environmentally friendly energy sources such as plant biomass that may also be derived from green waste. Biomass is particularly environmentally friendly because the volume of carbon dioxide emitted into the atmosphere in the course of its incineration is balanced by the volume of CO_2 that is absorbed by plants that produce biomass in the course of the photosynthesis process. Using leaves that have fallen out for power generation purposes will allow us to arrange urban areas and to reduce the volume of solid waste to be landfilled. Research has proven that the physical and chemical properties of the leaves under consideration indicate a considerable energy potential of that type of solid waste. Therefore, it is plausible to state that in comparison with other energy sources, tree leaves may contribute to the diversification of energy as far as the energy and fuel balance in the national economy is concerned. The related literature that has been studied and the research that has been conducted provide for the following conclusions:

1) Of the matter under consideration, oak leaves have proven to show the best energy properties with

an incineration gross calorific value at 18.58 MJ·kg⁻¹ and net calorific value at 17.36 MJ·kg⁻¹, whereas the walnut tree leaves have proven to show the smallest energy efficiency with an incineration gross calorific value at 17.38 MJ·kg⁻¹ and net calorific value at 16.21 MJ·kg⁻¹.

2) Research has proven that the biomass under consideration distinguished itself by the considerable content of ash ranging from 21.98% for oak tree leaves to 8.55% for hazel tree leaves. Notwithstanding, the leaves may be used as a source of thermal power to the extent of the biomass incineration technology and co-incineration technology as well as other plant-derived biomass thermal and chemical conversion technologies.

3) The statistical analysis of the research output figures at the significance level of $\alpha = 0.05$ has proven the considerable impact of a kind of plant biomass upon the incineration gross and net calorific value, as well as the ash and hydrogen content (H) and carbon content (C).

4) Estimated emission factors for the studied biomass show lower emissions of up to 32% CO_2, 53% NO_x, and 60% SO_2 relative to hard coal. This provides the basis for a positive assessment of this kind of biomass as green fuel.

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