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EVALUATION OF INVASIVE HERBACEOUS PLANTS UTILIZATION TO PRODUCE PRESSED BIOFUEL

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The technology of invasive herbaceous plant harvesting and pressing biofuel preparation are the main topics of the article, and the quality indicators and attributes have been examined and identified. For this study, two types of invasive plants were used: Sosnowsky's hogweed (*Heracleum sosnowskyi*) and giant knotweed (*Fallopia sachalinensis*). Pine wood biomass was used as a control. This plant material was collected, dried, and put to use in the creation of pressed biofuel. Plant biomass was cut, processed, and then compressed into cylindrical briquettes after being harvested and dried. The average density of briquettes was found to range between 615.60 and 867.31 kg m^{-3} after examination of their physical and elemental parameters. The briquettes' determined critical compressive strength was found to disintegrate when subjected to a critical force between 783 N and 1219 N. Briquettes estimated lower calorific value was from 15.90 to 18.60 MJ kg^{-1}. The test biofuel briquettes' harmful gas emissions were also assessed, and it was found that they were within acceptable limits and adequately low. In summary, it can be argued that all produced compressed biofuel from invasive plants complied with the majority crucial solid biofuel standards. Briquettes made from research plants can be burned in boilers designed for biofuel briquettes.

Keywords: *solid biofuel, Sonosky's hogweed, giant knotweed, burning;emissions*

INTRODUCTION

Recently, the utilization of biomass in new energy plants for sustainable energy has drawn increasing interest in the field of agricultural research. One of the primary sources of renewable energy is biomass. The use of biofuel made from herbaceous plants significantly reduces the greenhouse effect when compared to solid fossil fuels; CO_2 emissions are almost negligible because the CO_2 released during combustion creates organic matter during photosynthesis (Vares et al., 2007).

Invasive plant species are spreading quickly, endangering natural ecosystems everywhere in the world. Invasive plants can also be harmful to the economy and public health. As a result, a number of management techniques have been created. Among these, hoeing and digging are two common mechanical and chemical control techniques. Although these techniques work, they frequently need a lot of capital and labour, and the energy cycle is not reversible. Herbicides and other chemical management methods may also unintentionally endanger local species and to the health of general public. Therefore, it is crucial to create creative and cost-effective methods for controlling invasive plants (Le Roux, 2021).

Invasive species Sosnowky's hogweed and Giant knotweed are common in Lithuania. Mentioned plants produce a lot of biomass, which can be chopped, dried, and compressed for use as biofuel. This might pay for the technology needed to get rid of these invasive herbaceous species. Invasive herbaceous plants also have no culture costs because they don't require sowing, fertilizing, or upkeep. Therefore, the cost of harvesting and preparing the biomass for burning should be offset by it's stored energy in the form of biomass (Kseniia et al., 2021).

Sosnowsky's hogweed, a monocarpic, perennial herbaceous and seed-propagated member of the *Heracleum genus* (family *Apiaceae*, synonym *Umbelliferae*), is another name for *Heracleum sosnowskyi*. High seed productivity (10000-20000 seeds per plant) and first-year germination of up to 90% increase the competitiveness of the plant, which is essential for successful propagation (Mishyna et al. 2015). Due to its photoallergenic properties, the highly toxic furanocoumarin present in the sap of the Sosnowsky's hogweed is of great concern to the general public. After to the contact with plants and sun exposure, large blisters and burns can occur (Jakubowicz et al. 2012).

Originally from Eastern Asia, Giant knotweed (*Fallopia sachalinensis*) can grow up to 3.5 meters tall. Every year, a woody base is exposed, revealing the perennial plant known as knotweed. These plants are capable of producing a large amount of 15 t ha^{-1} d.b. (dry basis). There are many different varieties of Knotweed, including *Fallopia bohemica, Persicaria wallichii*, *Fallopia sachalinensis* and also the Himalayan knotweed (*Persicaria wallichii*) (Prather et al., 2009).

European nations have special regulations in place to control the quality generated of solid biofuel. The SS187120 standard governs solid biofuel quality in Sweden, and DIN 51731, which similarly outlines the standards for solid biofuels, is in force in Germany. A wood briquette certification program known as "ENplus" exists in Europe and uses the ISO, EN and CEN/TC standards for solid biofuel.

The Minister of the Environment of the Republic of Lithuania adopted the emission norms of fuel-burning devices, which determine the emission limit values of fuel-burning devices (LAND 43-2013). Norms control the pollutant limit values of burned biofuel, such as straw, grass and others.

At a standard O_2 concentration of 6% by volume, emission limit values have been established for both new and existing biofuel combustion plants with thermal outputs ranging from 0.1 to 1.0 MW (LAND 43-2013): NO_x is below 750 mg Nm^{-3}, SO_2 is above 2000 mg Nm^{-3}, solid particles are below 800 mg Nm^{-3} and CO is not rationed

Based on the research results, invasive grass species could hypothetically be an additional source of biofuels because they do not require energy to grow and require destruction and removal (Papamatthaiakis et al., 2021). You can utilize currently available agricultural aggregates that are designed for harvesting and cutting herbaceous plants to harvest them. There aren't enough in-depth research or studies using a wider variety of invasive herbaceous species, though.

The goal of this study is to examine the technology used to prepare solid biofuel and collect invasive herbaceous plants. To ascertain the physical characteristics, chemical element composition, and calorific value of invasive herbaceous plant briquettes, as well as to ascertain the emissions released during combustion in a low power boiler.

RESEARCH METHODS

Chopping and milling. The harvested, dried biomass is chopped as the first step in the technological process of processing biomass. Sosnowsky's hogweed and Giant knotweed biomass was used in this study. Maral 125 drum chopper and a Retsch SM 200 mill used to chop and mill the biomass.

Utilizing sieve layers with various hole diameters, the fractional content of milled biomass was determined. A Retsch AS 200 sieve shaker was used for this experiment. The five sieves hole measurements were used: 2 mm, 1 mm, 0.63 mm, 0.5 mm, 0.25 mm, and 0.1 mm, in that order. Three times, a 100-gram mass sieved, and the material left on sieve weighed after each sieve.

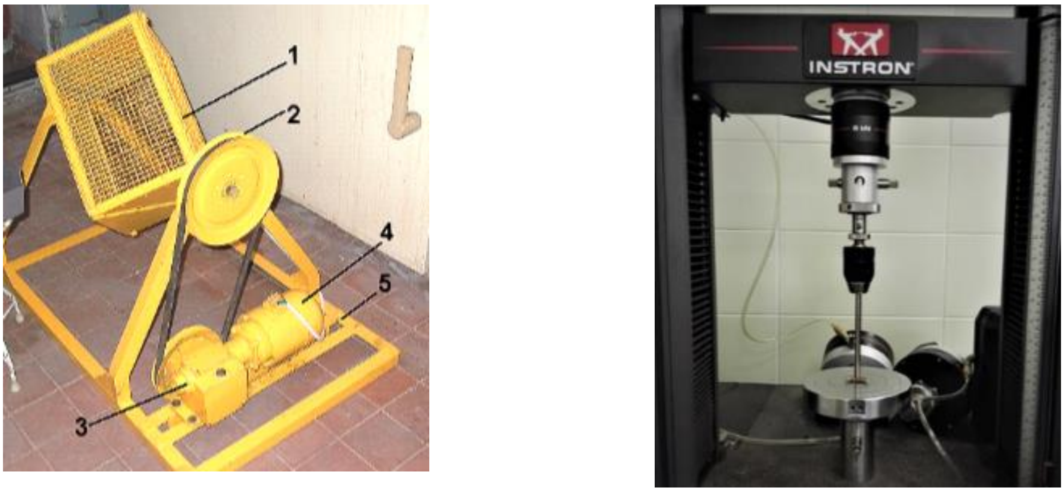
Briquette Production. The Agriculture Academy at Vytautas Magnus University's lab developed briquettes. For the manufacturing of briquettes, a prepared mill with a moisture content of 12–15% was utilized. Additionally were produced samples by combining pine wood in an equal ratio (1:1) with both Giant knotweed and Sosnowky's hogweed. Variables for the briquetting process were chosen based on the specifications of the manufacturer's instructions. The briquettes produced using 7.5 kW briquetting machine, with works on this principle a screw. The investigated biomass was squeezed in the press after being chopped and milled. The created briquette is forced out of the press and then sliced into cylinders that are between 150 and 200 mm in length. The briquetting procedure employed no binders. Biomass is heated to between 70 and 90 ºC during briquetting. The briquettes temperature is brought down gradually by passive cooling over a couple days.

Moisture content. Three samples of the biomass from each plant type were collected and placed in cruets in order to measure the moisture content of the briquettes. Samples weighed and placed into a dryer for 24 hours, at a temperature of 105°C. Next, the dried samples and empty cruets were weighed. Samples moisture content was calculated, including averages and standard deviations.

Briquette density. Ten generated briquettes were randomly selected and weighed to evaluate briquette density. Each briquette's length and diameter were measured in order to calculate its volume. The parameters of length and diameter were determined by measurement with a digital Vernier caliper LIMIT 150 mm (PRC), which met the requirements of DIN 863 (accuracy to 0.01 mm). These measurements were used to calculate the density of each briquette.

Briquette strength. Using a test bench (Fig. 1), the brittleness of the created briquettes is also assessed. The rectangular box is filled with weighed test briquettes, and the electric motor is turned on. The bench was then run for three minutes at a frequency of 13 turns per minute. Next, the crushed matter collected in a container that was positioned beneath the stand. After the three-minute test period, the dropped mass was weighed and the mass difference calculated, and the percentage of lost mass was determined. For each variety of briquette, the test is carried out five times. Jasinskas, together with other researchers, developed this methodology (Jasinskas et al. 2013).

Elemental composition, calorific value and ash content. The Lithuanian Institute of Energy's (LIE)Thermal Equipment Testing and Research laboratory served as the location for all of the studies to determinate the elemental composition, calorific value and ash content of tested samples. Tests' technique is acceptable in European countries and Lithuania. Device Number 8B/5 complies with LST EN 14775:2010 for ash content, Device Number 8B/3 complies with LST EN 15104:2010 for elemental composition, and Device Number 8B/2 complies with LST EN 14918:2010 for calorific value.



a **b**

Figure 1. (**a**) Testing stand for briquette fragility: 1 –box covered with mesh for briquettes; 2 – belt drive; 3 – drive; 4 – electric motor; 5 – frame; (**b**) Test machine Instron 5965.

Emissions. The emissions tests were conducted at the same LIE laboratory by burning manufactured briquettes according to the specifications of the LST EN 15104:2010 standard. Combustion product analysers Datatest 400CEM and VE7, were used to measure the amounts of total carbon, nitrogen, sulphur, hydrogen and oxygen during combustion (Sakalauskas et al., 2014).

RESEARCH RESULTS AND DISCUSSION

Determination of briquette properties. The qualities of the raw material, the employed machinery, the mass fractional composition, and the moisture content all affect briquette making. Figure 2 shows the fractional content of Sosnowsky's hogweed, Giant knotweed and Pine as control milled raw material.

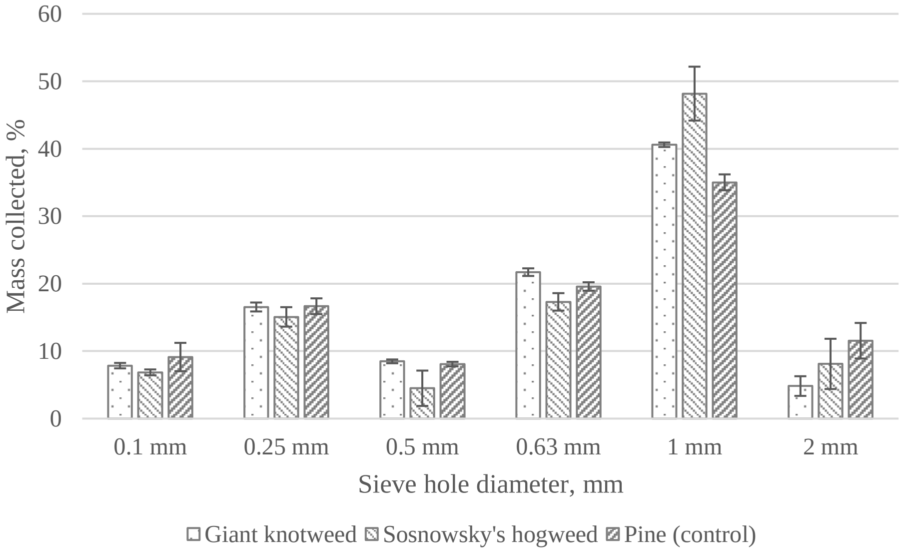


Figure 2. Milled Giant knotweed, Sosnowsky's hogweed and Pine biomass fractional composition.

The experiment demonstrates that there are no fragments with a diameter of less than 0.1 mm. It is also noteworthy that the biomass was properly dried and did not clump, which may have contributed to the particle sizes appearing similar after milling. Various findings demonstrate that the milling procedure can be used without modification on various kinds of herbaceous plants.

Briquette physical properties. According to researcher Granado, briquettes made from Sugarcane bagasse, Sugarcane straw and Cassava rhizome had a higher density than herbaceous plant briquettes, ranging from 1240 to 1300 kg m^{-3} (Granado et al. 2023).

After measuring the briquettes' geometrical characteristics, the diameters of the briquettes (cylindrical form) were: Pine wood was 80.4 mm in diameter, Sosnowsky's hogweed was 80.2 mm in diameter, Sosnowsky's hogweed was 80.1 mm in diameter, Giant knotweed was 80.1 mm in diameter, and Giant knotweed was 80.5 mm in diameter (Table 1). These average measures indicate that the briquettes had a quite similar diameter.

Table 1. Physical properties of Giant knotweed, Sosnowsky's hogweed and Pine briquettes.

Plant species	Briquette parameter			
	Length *l*, mm	**Diameter *d*, mm**	**Mass *m*, g**	**Density *ϱ*, kg m⁻³**
Sosnowsky's hogweed	89.5 ± 25.46	80.1 ± 0.32	326.3 ± 51.55	867.3 ± 116.50 d[1]
Sosnowsky's.hogweed and Pine.mix	107.7 ± 21.70	80.2 ± 0.25	385.6 ± 19.36	711.2 ± 106.70 ab[1]
Giant.knotweed	149.7 ± 20.18	80.5 ± 0.73	467.7 ± 62.65	615.6 ± 96.61 c[1]
Giant.knotweed and Pine.mix	131 ± 16.14	80.1 ± 0.35	431.3 ± 40.38	654.5 ± 19.35 c[1]
Pine wood (control)	142.3 ± 22.72	80.4 ± 0.62	553.8 ± 53.21	765.3 ± 128.76 b[1]

Note: [1] matching letter indicate no significant difference between plant species, t-test LSD_{05} = 74.14 kg m^{-3}.

Due to differences in fracture length, the measured lengths of the briquettes exhibited significant variability. Among herbal plants, the densities of Sosnowsky's hogweed and its mix with Pine wood were notably higher, measuring 867.3 ± 116.50 kg m^{-3}, in contrast to the lower densities of Giant knotweed and Pine wood mix at 654.5 ± 19.35 kg m^{-3}. Pine wood, used like control, briquettes density was 765.3 ± 128.76 kg m^{-3}. No appreciable distinctions were observed between Pine wood and Sosnowsky's hogweed and Pine wood blend briquettes. Likewise, minimal differences were noted between Giant Knotweed and its wood combination briquettes variants. The density of Pine wood briquettes lightly exceeded that of the investigated herbal plant materials. This increase in density is a typical outcome when wood mill is combined with mill from other plants. However, these variations in density lack statistical significance and are subject to the influence of diverse technological and other variables associated with the briquetting process.

As the densities of the other investigated plants were marginally lower than those of the wood briquettes, the customary trend of density elevation upon combining wood mill with mill from other plants was observed. Nevertheless, these slight fluctuations in density are intricately tied to various technological and procedural variables inherent in the briquetting process. Researchers Tumuluru and others found similar results when they made briquettes from a combination of herbal and woody biomass. They got the result of density to be above 750 kg m^{-3} (Tumuluru et al., 2020).

Briquette resistance to disintegration. The strength of the briquettes made from the invasive plants Sosnowky's hogweed and Giant knotweed was tested, and the results shown in Figure 3 (highest critical loads). This test ensures that the briquettes won't be ruined during the handling and use stages. The Pine briquettes, exhibiting an average strength with a semi-static mechanical stability (in the horizontal direction) of 1157.96 ± 171.56 N, emerged as the most mechanically stable variant based on the experimental findings illustrated in Figure 3. This particular briquette variant served as the control in the study. Following in the strength assessment were the Giant knotweed and Pine wood mixture (G.K.+Pine) briquettes, which demonstrated a compressive resistance of 1108.13 ± 93.93 N. Sosnowsky's hogweed (S.H.) and Giant knotweed (G.K.) briquettes reached strengths of 764.51 ± 230.30 N and Sosnowsky's hogweed and Pine wood combination (S.H.+Pine) briquettes exhibited strengths of 748.67 ± 98.45 N, securing positions on the strength hierarchy. No discernible differences were observed between S.H.+Pine and G.K. briquettes. Similarly, no statistically significant distinctions were found between G.K.+Pine and Pine briquettes, the latter serving as the control in this comparison. The resistance to compression test demonstrates that the Sosnowsky's hogweed and Giant knotweed briquettes meet the quality standards. It is interesting that a blend of pine and Sosnowsky's hogweed biomass resulted in briquettes with variable strengths.

Kakitis and other researchers from Latvia investigated the viability of employing the fibrous hemp varieties Bialobrzeskie, Santhica 27 and Futura 75 for the production of pressed biofuel. It was established the briquettes' mechanical characteristics, including strength. According the results, critical pressure ranged from 101.28 to 122.37 N (Kakitis et al. 2011).

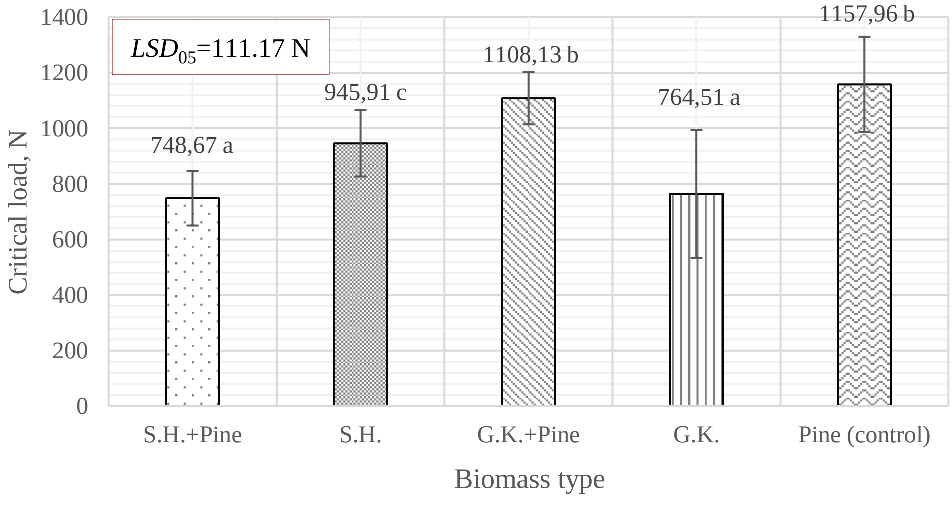


Figure 3. Compressive resistance of Giant knotweed, Sosnowsky's hogweed and Pine briquettes (Note: Matching letters indicate no significant difference between different briquettes type. Error bars represent the 95% confidence interval of the mean. A *t*-test was used for statistical analysis).

The produced briquettes subjected to a fragility test to determine their structural integrity and the results are shown in Figure 4.

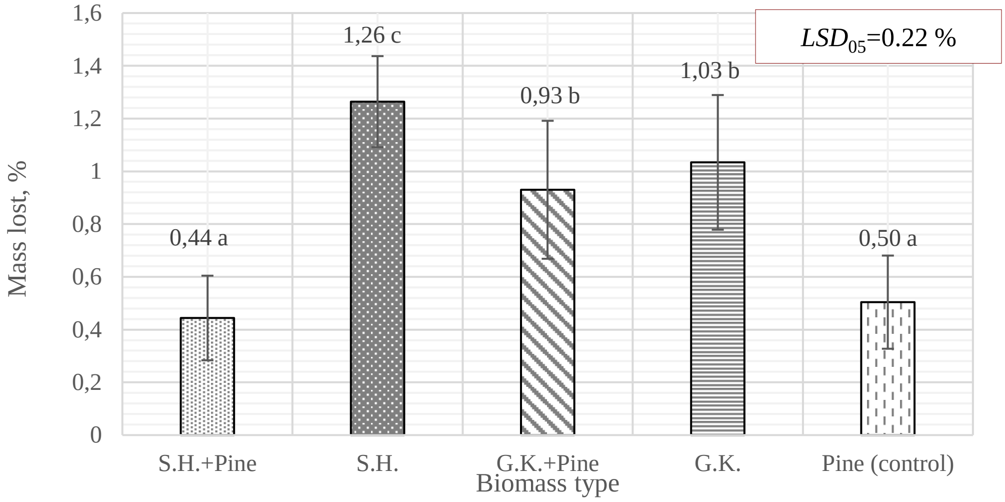


Figure 4. Test results of Giant knotweed, Sosnowsky's hogweed and Pine wood briquette fragility (Note: Matching letters indicate no significant difference between different briquettes type. Error bars represent the 95% confidence interval of the mean. A *t*-test was used for statistical analysis).

In the assessment of briquette fragility, it was determined that S.H. and G.K. variants displayed the highest susceptibility to mechanical forces, experiencing mass losses of 1.26% and 1.03%, respectively. Notably, no additional binders were incorporated in the fabrication of these briquettes. S.H.+Pine and the Pine briquettes used as a control demonstrated no significant distinctions. Furthermore, there was no difference between the G.K. briquettes and those of the G.K.+Pine. From figure 4 we can determine that there was no significant difference in mass lost between S.H.+Pine and Pine (control) briquettes and between G.K.+pine and G.K. briquettes. The briquettes of S.H. had a significant difference between all of the tested briquettes and performed the poorest.

In a parallel investigation by Nikiforov and colleagues, the fragility of briquettes composed of coal dust and sunflower husks was explored. The mass loss of these briquettes ranged from 25 to 38%, exceeding the brittleness of Sosnowsky's hogweed and Giant knotweed briquettes (Nikiforov et al., 2023). It is noteworthy that no extra binders were introduced in the creation of the briquettes in both studies, emphasizing the intrinsic differences in fragility characteristics among the tested materials.

Determination of harmful emissions. The laboratory at the LEI conducted studies on the burning of briquettes. The test was conducted following the specifications of the LST EN 15104:2010 standard and combustion product analyzers were used, such as the Datatest 400CEM and analyser VE7, to measure the amounts of total carbon, hydrogen, nitrogen, sulphur and oxygen produced during combustion. The emissions of NO_x, CO_2, CO, and hydrocarbons, from the complete combustion of Sosnowsky's hogweed and Giant knotweed pressed biofuel briquettes are shown in and Figures 5, 6, 7 and 8. Pine wood were burned as control in order to compare the variations in emissions.

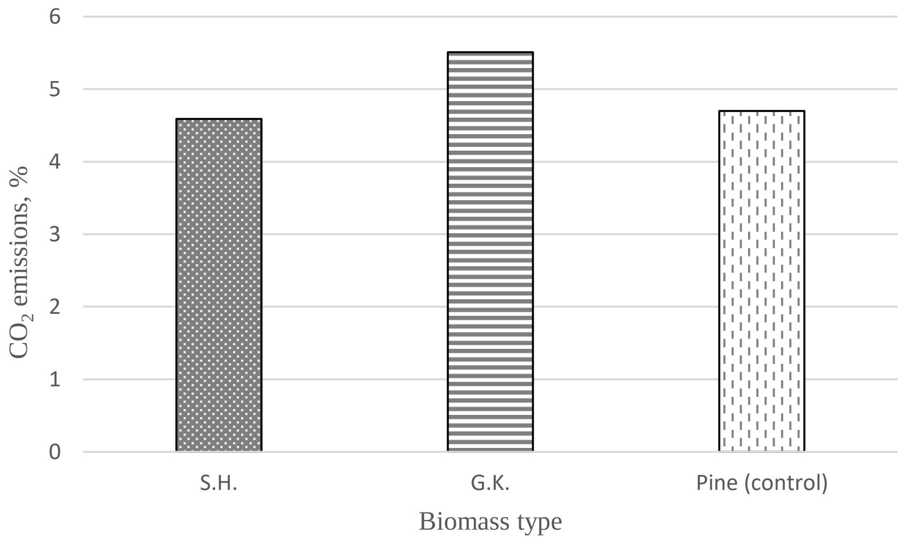


Figure 5. CO_2 **.** Emissions of Sosnowky's hogweed, Giant knotweed and Pine (control) briquettes

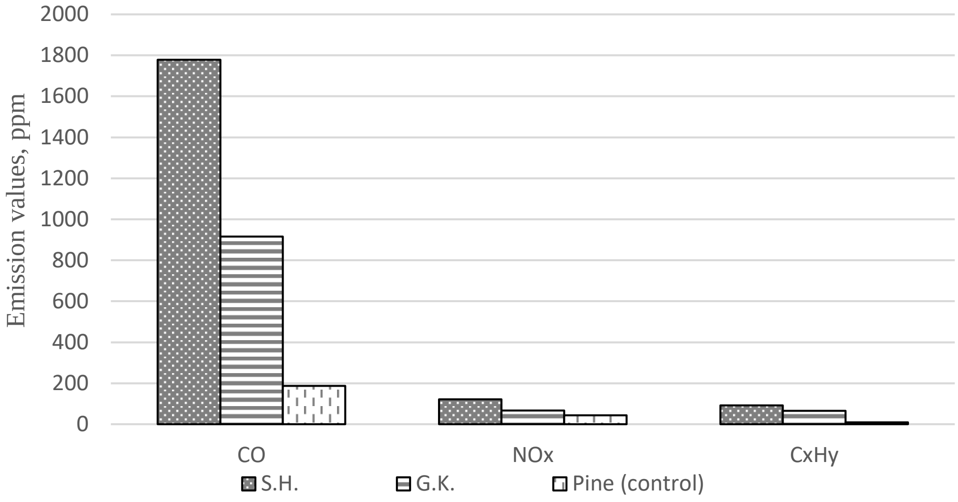


Figure 6. Emissions of Sosnowky's hogweed, Giant knotweed and Pine (control) briquettes

Elemental composition. It has been examined and determined whether Sosnowsky's hogweed and Giant knotweed are suitable for solid biofuel production (Figures 7 and 8). Although inferior than biomass produced from woody pine, solid biofuels made from invasive herbaceous plants did meet the aforementioned European standards.

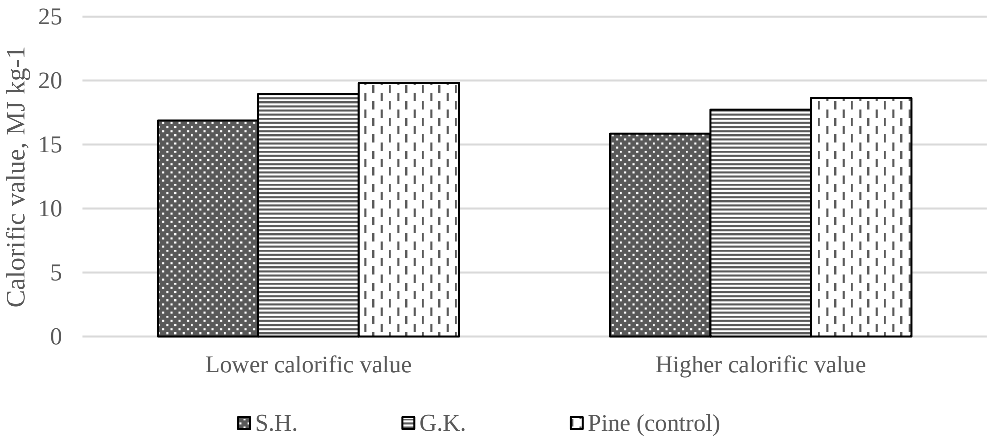


Figure 7. Sosnowsky's hogweed, Giant knotweed and Pine wood (control) calorific properties

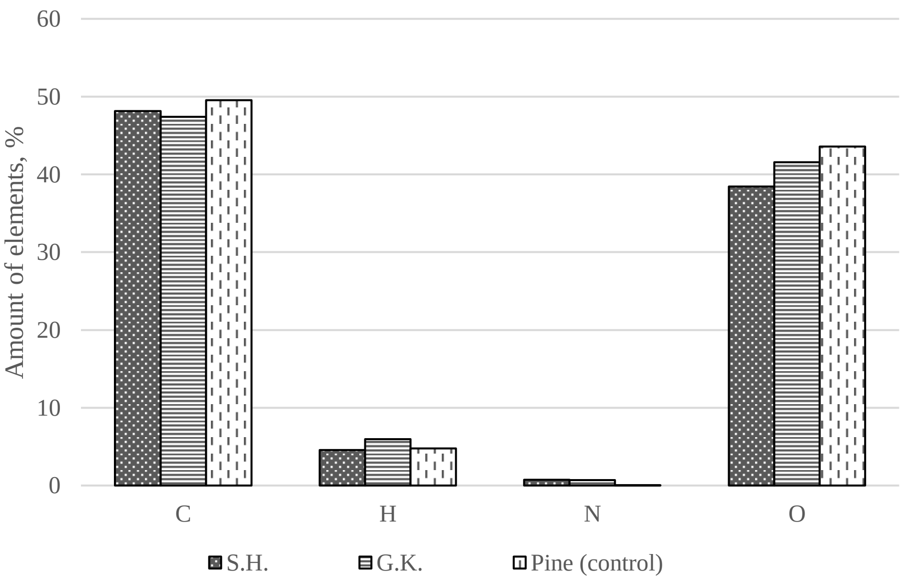


Figure 8. Sosnowsky's hogweed, Giant knotweed and Pine wood (control) elemental properties

The lower calorific value of Sosnowky's hogweed, which was obtained in our research at 15.89 ± 1,01 MJ kg^{-1}, seems to be quite similar to Paramonova's results, coming in at 16.50 MJ kg^{-1}(Paramonova et al., 2021). These measurements demonstrate that the biomass from Sosnowsky's hogweed and Giant knotweed is applicable for production of solid biofuels. From these results it can be gleaned that the most important carbon, hydrogen and oxygen values are similar to traditional biomass fuels and the amount of nitrogen does not exceed standard limits. In the tests of elemental composition of these briquettes there were trace amounts of chlorine and sulphur although their values were less than 0.05 % across all three biomass products. This information indicates that briquettes produced from these invasive herbaceous plants have sufficient carbon hydrogen and oxygen for the combustion process and do not have excess amounts of sulphur and chlorine to produce harmful acidic emissions or contaminate ash that accumulates during the combustion process.

CONCLUSIONS

1. Based on research results, Sosnowsky's hogweed and Giant knotweed prepared biomass can be used to make solid sustainable fuel. Sosnowsky's hogweed, Giant knotweed and Pine wood as control have calorific values of 15.86 ± 1.04 MJ kg^{-1}, 17.73 ± 0.33 MJ kg^{-1} and 18.63 ± 0.33 MJ kg^{-1}, respectively.

2. According to the experimental findings, the Pine briquettes' average strength was found to be the most mechanically stable, with 1157.96 ± 171.56 N. Giant knotweed and Pine mixture briquettes came in second in the strength test. Briquettes obtained a compressive resistance of 1108.13 ± 93.93 N. Sosnowsky's hogweed, Giant knotweed with 764.51 ± 230.30 N, and Sosnowsky's hogweed and Pine wood mixture briquettes (with 748.67 ± 98.45 N) are still on the list.

3. Giant knotweed briquettes, which had the lowest unit density at 1227.47 ± 39.82 kg m^{-3}, and Sosnowsky's hogweed briquettes, which had the highest unit density at 867.31 ± 116.50 kg m^{-3}, were tested for briquette density. During emission study, it was discovered that both herbal plants created significantly up damaging byproducts than pine wood, which generated 187.50 ppm of CO, compared to 1778.44 ppm for Sosnowky's hogweed, 915.30 ppm for Giant knotweed.

These invasive herbaceous plants adhere to the necessary requirements of European standards in terms of their parameters and traits. To find the ideal ratio of commonly utilized woody biomass and invasive herbaceous species, more research is necessary. Giant knotweed and Sosnowsky's hogweed make good complements to the woody biomass pellets now being made. The elimination of ash content is the sole disadvantage seen, as herbaceous plants produce more ash than woody biomass.

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