INVASIVE HERBACEOUS PLANT BIOMASS USE FOR SOLID BIOFUEL PRODUCTION

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Abstract
Invasive herbaceous plants pose ecological risks but also provide opportunities as renewable energy resources. This study evaluated Sosnowsky's hogweed (Heracleum sosnowskyi) and giant knotweed (Fallopia sachalinensis) for solid biofuel production, with pinewood as a control. Biomass was harvested, processed into pellets, and tested for physical, mechanical, elemental, and combustion properties. Pellets from invasive plants reached densities above 1100 kg m⁻³ and compressive strengths exceeding thresholds for safe handling. Giant knotweed demonstrated lower ash content (5.7%) and higher calorific value (17.8 MJ kg⁻¹) compared to hogweed (12.6%; 16.6 MJ kg⁻¹), approaching pinewood values. Combustion tests revealed higher CO and NO_x emissions from invasive biomass, though all remained within regulatory standards. Biomass accumulation patterns indicated hogweed yielded higher peaks, while knotweed sustained steadier growth. Findings confirm invasive plants, particularly giant knotweed, as viable supplementary biofuel feedstocks, providing both renewable energy and ecological management benefits.

Keywords: *invasive plants, biomass utilization, pellet quality, combustion emissions, renewable energy*

INTRODUCTION

Invasive plant species are among the leading drivers of biodiversity loss and ecosystem change in Europe, with their rapid spread causing ecological and economic damage *(Pyšek & Richardson, 2010; Vilà et al., 2011)*. Conventional control measures such as herbicides or mechanical removal are often costly, resource intensive, and provide only temporary solutions *(Kettenring & Adams, 2011)*. At the same time, invasive plants accumulate large amounts of biomass annually, which is usually treated as waste.

Growing demand for renewable energy has increased interest in alternative feedstocks beyond traditional wood and agricultural residues *(Demirbas, 2011)*. Herbaceous biomass, including invasive species, is particularly promising because of its fast growth, low input requirements, and potential to couple ecological management with energy production *(Barney & DiTomaso, 2008)*. However, differences in biomass properties, such as ash content, calorific value, and emissions, remain insufficiently studied and may influence fuel quality *(Obernberger & Thek, 2004)*.

The aim of this study was to evaluate the potential of Sosnowsky's hogweed *(Heracleum sosnowskyi)* and giant knotweed *(Fallopia sachalinensis)* as raw materials for pellet production. Biomass accumulation, pellet physical and mechanical properties, elemental composition, and combustion emissions were assessed and compared with pinewood, a conventional solid biofuel.

MATERIALS AND METHODS

Two invasive species, Sosnowsky's hogweed *(Heracleum sosnowskyi)* and giant knotweed *(Fallopia sachalinensis)*, were harvested in Lithuania; pinewood *(Pinus sylvestris)* served as the control. Biomass was mechanically cut, baled, dried, and milled to ≤ 2 mm particles. Fractional composition was determined with a Retsch AS 200 sieve shaker using five sieves *(2–0 mm)* and three replicates per sample *(EU DD CENT/TS15149-1, 2006)*.

Prepared raw material was pelletized in a laboratory-scale biomass granulator *(ZLSP200B)* with a horizontal matrix and die holes of 6 mm diameter. The machine operated at 7.5 kW with a capacity of 100–120 kg h⁻¹. The feedstock moisture content was adjusted to 12–15% prior to pelletization. Pellets were produced without binding additives, at temperatures between 70–90 °C. The resulting pellets were cut to lengths of 25–30 mm, cooled under ambient conditions, and stored for subsequent testing. Additional mixtures of pinewood and invasive plant biomass *(1:1 ratio)* were also pelletized. *(Jasinskas, Kučinskas, & Arak, 2013)*.

Pellet density was determined by measuring mass, diameter, and length of ten randomly selected pellets per treatment. Moisture content was measured gravimetrically after drying samples at 105 °C for 24 h. Pellet durability was evaluated using a tumbling device operating at 13 rpm for 3 min, with five replications. Compression resistance was measured on an INSTRON 5965 testing machine *(5 kN capacity)* at a loading rate of 20 mm min^{-1}, with ten replications per plant species.

Ash content, elemental composition *(C, H, N, S, O, Cl)*, and calorific value of pellets were analyzed at the Lithuanian Energy Institute following standardized procedures *(LST EN 14775:2010; LST EN 15104:2010; LST EN 14918:2010)*.

Combustion tests were performed at the Lithuanian Energy Institute using Datatest 400CEM and VE7 analyzers to quantify CO_2, CO, NO_x, SO_2, and hydrocarbons released during pellet combustion.

Biomass accumulation was assessed in experimental plots of 2 m^2 established for Sosnowsky's hogweed *(Heracleum sosnowskyi)* and giant knotweed *(Fallopia sachalinensis)*. Above-ground biomass was harvested manually at the end of each month from April to August, cut at ground level, and weighed fresh in the field. Samples were then oven-dried at 105 °C until constant mass to determine dry matter yield. Experimental data were statistically evaluated using MS Excel. Mean values, standard deviations, and 95% confidence intervals were calculated. Differences between treatments were determined using the least significant difference test *($LSD_{0.05}$)* at $p \leq 0.05$.

RESULTS AND DISCUSSION

Fractional composition. The milling of Sosnowsky's hogweed, giant knotweed, and pinewood produced a uniform particle size distribution, with no fractions below 0.1 mm. The drying process ensured that particles remained discrete, preventing clumping and facilitating consistent milling. Such homogeneity is important, as uniform particle sizes improve pellet durability and reduce energy demand during densification *(Kaliyan & Morey, 2009)*.

Since particle sizes were within the recommended ≤ 2 mm range, both invasive species meet the physical requirements for pelletization *(Granado et al., 2023)*. These findings confirm that Sosnowsky's hogweed and giant knotweed can serve as suitable raw materials for biofuel production, with processing characteristics closely matching those of conventional woody biomass *(Platace, Adamovics, & Gulbe, 2013)*.

Physical characteristics of pellets. The diameter of all pellets corresponded closely to the die size of the granulator *(6 mm) (Tab. 1)*, with Sosnowsky's hogweed *(6.2 ± 0.22 mm)* and giant knotweed *(6.1 ± 0.09 mm)* showing no practical deviation from pinewood pellets *(6.1 ± 0.13 mm)*.

Tab. 1 Physical characteristics of produced pellets

Plant species	Pellet parameters				
	Diameter d, mm	**Length l, mm**	**Volume V, m^3**	**Mass m, g**	**Density ϱ, kg m^{-3}**
Sosnowky's hogweed	6.2 ± 0.22	23.6 ± 0,93	*(7.5 ± 0.59)*·10^{-7}	0.7 ± 0.08	1145.6 ± 37.50
Giant knot-weed	6.1 ± 0.09	23.1 ± 0.84	*(6.8 ± 0.25)*·10^{-7}	0.7 ± 0.04	1227.5 ± 39.82
S.H. 50%	6.1 ± 0.15	23 ± 0.79	*(6.7 ± 0.25)*·10^{-7}	0.8 ± 0.05	1188.6 ± 34.52
G.K. 50%	6 ± 0.1	17.8 ± 0.81	*(5.1 ± 0.25)*·10^{-7}	0.7 ± 0.09	1278.0 ± 33.32
Pinewood	6.1 ± 0.13	30.7 ± 0.88	*(8.9 ± 0.83)*·10^{-7}	1.1 ± 0.14	1182.5 ± 34.46

The diameter of all pellets corresponded closely to the die size of the granulator *(6 mm) (Tab. 1)*, with Sosnowsky's hogweed *(6.2 ± 0.22 mm)* and giant knotweed *(6.1 ± 0.09 mm)*. Slight expansion of the pellets after extrusion was consistent with thermal expansion effects reported in densification studies *(Kaliyan & Morey, 2009)*.Mixtures of pinewood with invasive biomass exhibited intermediate densities *(1188.6 ± 34.52 and 1278.0 ± 33.32 kg m⁻³)*, suggesting potential for blending strategies to optimize both durability and combustion properties. High density is particularly advantageous, as it increases energy content per unit volume and improves pellet mechanical strength *(Nath et al., 2023)*.
Overall, the results demonstrate that pellets produced from invasive species possess physical characteristics comparable, and in some cases superior, to those of pinewood. In particular, giant knotweed shows promising densification potential, while Sosnowsky's hogweed achieves acceptable fuel quality parameters. These findings align with earlier reports on tall grasses and non-woody biomass as viable pellet feedstocks *(Platace, Adamovics, & Gulbe, 2013)*.
Compressive resistance. The compressive strength of pellets varied between species and mixtures, with values ranging from ~650 N in 50% blends to ~950 N in pinewood pellets *(Fig. 1)*. Pure Sosnowsky's hogweed pellets showed the highest resistance among the invasive species *(≈920 N)*, approaching pinewood, while giant knotweed averaged slightly lower *(≈820 N)*. Mixtures of invasive biomass with pinewood *(1:1)* exhibited reduced resistance *(≈650–700 N)*, indicating that blending may weaken pellet structure compared to pure feedstock.

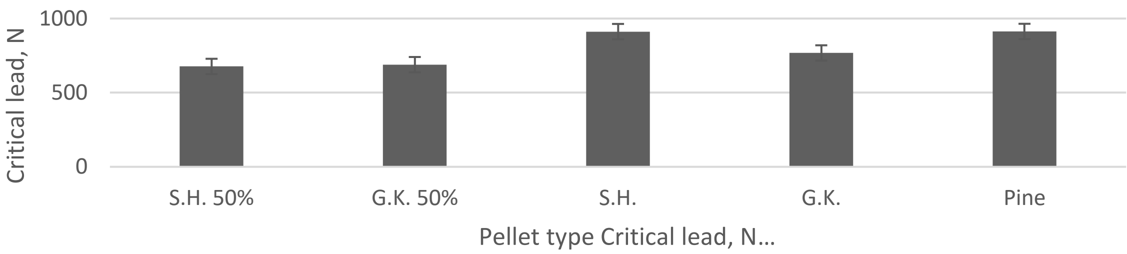

Fig. 1 Horizontal compressive resistance of pellets.

Nevertheless, all pellets exceeded the minimum compressive resistance values typically reported for herbaceous biomass fuels *(>400 N)*, confirming their suitability for storage and transportation without excessive fragmentation *(Kakitis et al., 2011)*.g
Elemental and energetic properties. Elemental analysis revealed marked differences between invasive biomass and pinewood *(Tab. 2)*. Sosnowsky's hogweed showed the highest ash content *(12.6%)*, well above giant knotweed *(5.7%)* and pinewood *(4.0%)*, suggesting higher slagging risk during combustion *(Krugly et al., 2014)*.

Tab. 2 Elemental properties of Sosnowsky's hogweed, Giant knotweed and Pinewood.

Parameter	S.H.	G.K.	S.H. 50%	G.K. 50%	Pine
Ash content, %	12.56	5.74	8.29	4.88	4.03
Higher calorific value, MJ kg^{-1}	17.93	19.11	18.41	19.00	18.89
Lower calorific value, MJ kg^{-1}	16.60	17.78	17.08	17.67	17.56
C, %	46.15	48.38	47.70	48.38	49.26
N, %	1.11	1.45	0.97	13.13	0.83
H, %	5.34	5.75	5.59	5.38	5.86
S, %	< 0.002	0.033	0.301	0.302	0.016
O, %	34.84	38.65	37.34	33.32	40.01
Cl, %	< 0.005	< 0.005	< 0,005	< 0.005	<0.005

Calorific values were greatest in giant knotweed *(HHV 19.1 MJ kg^{-1}, LHV 17.8 MJ kg^{-1})*, slightly higher than pinewood *(18.9 and 17.6 MJ kg^{-1})*, while hogweed was lowest *(17.9 and 16.6 MJ kg^{-1})*. Carbon and hydrogen contents followed the same trend, with pinewood highest *(C = 49.3%, H = 5.9%)* and hogweed lowest *(C = 46.2%, H = 5.3%)*.

Nitrogen and sulfur were higher in invasive biomass *(N = 1.1–1.5%, S up to 0.033%)* than pinewood *(N = 0.83%, S = 0.016%)*, which may increase NO_x and SO_2 emissions, though values remain within solid biofuel limits *(Sippula et al., 2017)*. Oxygen contents ranged from 34.8% in hogweed to 38.7% in knotweed, consistent with their energy densities. Chlorine was negligible *(<0.005%)*, reducing corrosion risks.

Giant knotweed outperformed Sosnowsky's hogweed with lower ash and higher calorific value, making it a stronger biofuel candidate. While pinewood remains the benchmark, giant knotweed demonstrated fuel properties that are comparable to, and in some respects exceed, conventional woody biomass.

Emissions. Combustion of Sosnowsky's hogweed, giant knotweed, and pinewood pellets revealed distinct emission profiles *(Tab. 3)*. Carbon dioxide *(CO_2)* levels were comparable across all fuels *(≈4.6–5.5%)*, confirming complete oxidation during combustion. However, large differences were observed in carbon monoxide *(CO)* emissions: hogweed produced 1778 ppm, nearly double that of knotweed *(915 ppm)* and almost tenfold higher than pinewood *(188 ppm)*. Elevated CO indicates incomplete combustion, likely due to higher ash and volatile matter in hogweed, which impedes stable flame development *(Krugly et al., 2014)*.

Tab. 3 Emissions of produced solid biofuel.

Plant species	**CO_2, ppm**	**CO, ppm**	**NO_x, ppm**	**C_xH_y, ppm**
Sosnowky's hogweed	4.6	1778.4	121.3	92.5
Giant knotweed	5.5	915.3	67.4	66
Sosnowsky's hogweed 50%	4.2	402	96	18
Giant knotweed 50%	4.5	195	111	14
Pinewood	4.7	187.5	43.3	9.3

Nitrogen oxides *(NO_x)* were also higher in invasive biomass, reaching 121 ppm in hogweed and 67 ppm in knotweed, compared to 43 ppm in pinewood. This trend correlates with the higher nitrogen content in invasive plants *(Tab. 3)*, supporting previous findings that N-rich herbaceous fuels promote thermal NO_x formation *(Sippula et al., 2017)*.

Hydrocarbon *(C_xH_y)* emissions were significantly elevated in herbaceous pellets *(92 ppm in hogweed, 66 ppm in knotweed)* relative to pinewood *(9 ppm)*. Such emissions arise from incomplete breakdown of volatile compounds, a problem often reported in grass-based fuels *(Hutla et al., 2005)*.

Despite these differences, all emission levels fell within the Lithuanian standard LAND 43-2013 limits for small biofuel boilers.

Biomass accumulation. Biomass accumulation patterns of Sosnowsky's hogweed and giant knotweed, revealed distinct growth dynamics *(Tab. 4)*. Hogweed showed rapid early development, reaching 6.48 t ha^{-1} in May and peaking at 8.96 t ha^{-1} in July before declining to 4.85 t ha^{-1} in August. In contrast, giant knotweed accumulated biomass more gradually, peaking at 6.40 t ha^{-1} in July and maintaining steadier residual growth into August *(3.26 t ha^{-1})*.

Tab. 4 Accumulated biomass of invasive plants *(Dry mass)*

Month	**Sosnowsky's hogweed, t ha^{-1}**	**Giant knotweed, t ha^{-1}**
April	0.92	1.47
May	6.48	2.40
June	7.15	6.15
July	8.96	6.40
August	4.85	3.26

These trends reflect species-specific strategies: hogweed invests in rapid growth and seed production, producing higher short-term yields but offering a narrower harvest window, while knotweed sustains biomass accumulation longer, making it more suitable for flexible harvesting regimes *(Halmova & Feher, 2009)*.
Overall, hogweed achieved higher peak yields, whereas knotweed provided more stable seasonal productivity. Both species, even under conservative estimates, fall within reported productivity ranges—hogweed 4–20 t ha^{-1} and knotweed 8–15 t ha^{-1} *(Halmova & Feher, 2009; Streikus et al., 2017)*

CONCLUSIONS

Sosnowsky's hogweed and giant knotweed were successfully processed into pellets with physical and mechanical properties comparable to pinewood. Giant knotweed showed lower ash content and higher calorific value than hogweed, making it the more suitable invasive feedstock. Combustion tests confirmed higher CO and NO_x emissions from invasive biomass, though all values remained within regulatory limits. Biomass accumulation patterns suggest hogweed offers higher peak yields, while knotweed provides steadier seasonal growth.
In summary, invasive plants, particularly giant knotweed, represent a viable supplementary biofuel resource, combining renewable energy production with invasive species control. Future applications should focus on blending invasive biomass with woody feedstocks to optimize combustion performance and reduce emissions.

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ISBN 978-80-213-3541-7