TEHNIČKO-EKONOMSKA OPRAVDANOST PRIKUPLJANJA BIOMASE POSLIJEŽETVENIH OSTATAKA U PROIZVODNJI ENERGIJE

SAŽETAK
Poljoprivredna biomasa predstavlja značajan obnovljiv izvor energije, no posliježetveni ostatci ratarskih kultura još uvijek su nedovoljno iskorišteni u proizvodnji energije. Istraživanje u okviru ovog rada obuhvatilo je nekoliko ratarskih kultura pri čemu su analizirani nadzemni i podzemni dijelovi biljaka te različite morfološke frakcije biomase. Provedene su fizikalno-kemijske, elementarne i strukturalne analize biomase, određivanje energetskih svojstava te procjena ekonomske opravdanosti prikupljanja biomase. Rezultati istraživanja pokazali su da raspoloživa količina biomase i njezina energetska svojstva značajno variraju među kulturama i između pojedinih dijelova biljke. Morfološka struktura biljke pokazala se kao važan čimbenik koji utječe na kemijski sastav i energetski potencijal biomase. Frakcije bogatije ligninom pokazale su veću termostabilnost i prikladnost za termokemijske procese poput pirolize, dok su se nadzemni dijelovi bogati celulozom i hemicelulozom pokazali kao sirovina za biokemijsku pretvorbu poput proizvodnje bioplina. Analiza elementarnog sastava pokazala je da se određeni mikroelementi, uključujući željezo, mangan, cink i bakar te potencijalno toksični kadmij, u većim koncentracijama akumuliraju u donjim dijelovima biljke i korijenu, što može imati tehnološke i okolišne implikacije pri energetskom korištenju biomase. Rezultati također ukazuju da univerzalni pragovi za uklanjanje posliježetvenih ostataka s polja, poput često navedenih 30 % ostataka koji moraju ostati na tlu radi očuvanja plodnosti tla, ne mogu biti istovjetni za sve kulture i agroekološke uvjete. Ekonomska analiza pokazala je da isplativost prikupljanja biomase u velikoj mjeri ovisi o organizaciji logističkog sustava, troškovima prikupljanja i transporta te tržišnim uvjetima. Dobiveni rezultati ukazuju da posliježetveni ostatci ratarskih kultura predstavljaju vrijedan obnovljivi energetski resurs, čije učinkovito korištenje zahtijeva selektivnu i frakcijsku valorizaciju biomase uz istodobno očuvanje plodnosti tla i dugoročnu održivost agroekosustava.

Ključne riječi: poljoprivredna biomasa, posliježetveni ostatci, lignocelulozna biomasa, energija, fizikalno-kemijska svojstva, energetska valorizacija, održivo korištenje biomase

TECHNOLOGICAL-ECONOMIC LEGITIMACY OF POSTHARVEST RESIDUES BIOMASS COLLECTING FOR ENERGY PRODUCTION

EXTENDED ABSTRACT
Increasing climate change, growing energy demand and the need to reduce greenhouse gas emissions highlight the necessity of gradually abandoning fossil fuels and developing sustainable energy systems. In this context, renewable energy sources play a key role in the energy transition, with biomass representing one of the most important renewable resources.
Biomass is an organic substance of plant or animal origin that can be converted into various forms of energy, including heat, electricity and different types of biofuels. Of particular importance are post-harvest residues of field crops, such as cereal straw, corn cobs, sunflower stalks and rapeseed, which are generated in large quantities during agricultural production. Despite their significant availability, post-harvest residues are often insufficiently utilised in energy systems. Part of the biomass remains in the field to preserve soil fertility, while part is burned or used for other agricultural or other purposes. It is often stated in the literature that approximately 30 % of crop residues can be removed from the field without negatively affecting soil fertility, but such an assumption may not be equally applicable to all crops or agro-ecological conditions. For this reason, it is necessary to analyse in detail the quantity and quality of available biomass and to assess the technical and economic justification for its collection and use in energy production. The aim of this doctoral thesis was to investigate the potential of post-harvest residues of various field crops for energy production and to determine the technical and economic justification for their collection and use.
Special emphasis is placed on the analysis of the physicochemical, elemental and structural properties of biomass, determination of energy parameters and assessment of the economic viability of biomass collection and use. The research begins with a review of European energy and climate policies that encourage an increase in the share of renewable energy sources and a reduction in greenhouse gas emissions.
Within the framework of the European Green Deal and the Renewable Energy Directive, special emphasis is placed on the use of biomass and agricultural residues as sustainable energy resources. In this context, the role of biomass in the energy system of the European Union and the possibilities for its integration into energy production systems were analysed. The research specifically analysed the potential of post-harvest residues of field crops, including barley, wheat, corn, sunflower, soybean and

oilseed rape. The research covered above-ground and underground parts of plants and different morphological fractions of biomass. Samples were collected from experimental fields, after which detailed laboratory analyses of physicochemical properties, elemental composition and macro- and microelement content were conducted. The lignocellulosic composition of biomass was also analysed and the upper and lower heating values of the samples were determined. In addition to laboratory analyses, an economic analysis of the collection and use of post-harvest residue biomass was also conducted. The analysis of morphological characteristics showed that the distribution of biomass between above-ground and underground parts of plants varies significantly among the studied crops. Such differences affect the total available amount of biomass that can be used for energy purposes.
Physicochemical and elemental analysis showed that the chemical composition of biomass significantly depends on the type of crop and the analysed part of the plant. Differences were observed in the content of ash, fixed carbon, volatile substances and in the content of basic elements such as carbon, hydrogen, nitrogen and oxygen. Differences were also found in the content of lignin, cellulose and hemicellulose, which are key components of lignocellulosic biomass and significantly affect the energy value of the raw material. The results obtained show that biomass fractions with a higher lignin content exhibit greater thermostability and suitability for thermochemical processes such as pyrolysis or gasification, while parts rich in cellulose represent a suitable raw material for biochemical processes such as bioethanol or biogas production. Analysis of the elemental composition also showed that certain microelements, including iron, manganese, zinc, copper and potentially toxic cadmium, accumulate in higher concentrations in the lower parts of the plant and roots, which may have technological and environmental implications for the energy use of biomass. In addition to the energy properties of biomass, the paper also analyses the economic feasibility of collecting post-harvest residues. The analysis shows that the cost-effectiveness of such systems largely depends on the organisation of the logistics system for biomass collection, transport costs, the availability of appropriate machinery, and market conditions for energy sales. It has also been determined that the universal threshold for removing post-harvest residues from fields, often cited in the literature as 30%, cannot be equally applied to all crops and agro-ecological conditions. The research shows that post-harvest residues of field crops represent a significant potential source of renewable energy. The quantity and quality of available biomass vary significantly between crops and individual plant parts, indicating the need for a selective approach to the collection and use of biomass. The results show that the energy valorisation of post-harvest residues can make an important contribution to the development of sustainable energy systems and the bioeconomy, provided that soil fertility and the long-term sustainability of agroecosystems are preserved.

Keywords: agricultural biomass, post-harvest residues, lignocellulosic biomass, bioenergy, physicochemical properties, energy valorization, sustainable use of biomass