CHOSEN PHYSICO-MECHANICAL PROPERTIES OF CUTLEAF CONEFLOWER (*RUDBECKIA LACINIATA* L.) SHOOTS

Krzysztof Mudryk, Jaroslaw Fraczek, Zbigniew Slipek, Slawomir Francik, Marek Wrobel
University of Agriculture in Krakow, Poland
krzysztof.mudryk@ur.krakow.pl

Abstract. Biomass is one of the oldest renewable energy sources. It is obtained mainly from agricultural production, forestry as waste or residue production. One of the plants that can be used for energetic crops is Cutleaf coneflower *Rudbeckia laciniata* L. It forms dense clumps. Currently, this plant is quite common in the wild, wet positions, located along watercourses. Effective use of cutleaf coneflower biomass for biofuel production is possible after determining these properties, which significantly affect the course of the different stages of processing. The scope of work included the determination of the following physico-mechanical properties of the shoots: length and diameter (on height of cut at harvest), work of cutting, modulus of elasticity, specific density and calorific value. The obtained results indicate that cutleaf coneflower shoots have the characteristics desired from the point of view of their use for energy purposes (e.g., the heating value at the air-dry state 15.2 $MJ \cdot kg^{-1}$, work of cuts 0.021 $J \cdot mm^{-2}$, the specific density 348.7 $kg \cdot m^{-3}$). It was found that the tested plant has properties similar to those of other energy plants (such as Miscanthus giganteus, Virginia mallow).

Keywords: Cutleaf coneflower, biomass, energy plants.

Introduction

Biomass is one of the oldest and now surviving renaissance sources of renewable energy. We collect it mainly from agricultural and forestry production as waste or residue from production. More and more often we encounter a situation of crops used for energetic purposes. These crops, known as energetic, are often conducted in areas excluded from the food production. The growing demand for biofuels, particularly solid, generated mostly by the large energetic units, makes the purposeful production of biomass as an opportunity for Polish agriculture [1; 2].

The areas currently used for growing crops for energy purposes are characterized by a relatively high diversity of habitat features which makes it necessary to choose the appropriate plant species. Only such approach to projects of biomass production will enable to obtain adequate yields of biomass [3; 4].

Many research institutes in Poland and abroad conduct research related to determining the production potential of individual plant species with indicating of dedicated habitat conditions [5]. One of such plants is Cutleaf coneflower *Rudbeckia laciniata L* [6; 7].

Cutleaf belongs to the family Asteraceae and is a perennial plant that originates from North America, reaching a height of 2.5 m, width 90 cm, forming dense clumps. Cutleaf blooms from July to the end of September, producing tapered, single flowers in a bright yellow color and a diameter of 10-12 cm. Inflorescences are located on the long branched stems and the leaves have a slight waviness with serrated edges. Cutleaf coneflower is characterized by good frost resistance (group 4) and the relatively large tolerance on the growing conditions [7].

Cutleaf coneflower is quite common in the wild on damp positions located along the waterways. According to the Institute of Nature Conservation Polish Academy of Sciences in Cracow, which keeps a record of alien species in Poland, this species has been classified as invasive plants [7]. In accordance with the provided information, prohibition of cultivation of Cutleaf applies to protected areas and protection zones. The most effective way to combat it is mowing, which suppresses the expansion, in the long term Cutleaf fits fully in the program of reducing its occurrence. Harvesting of plants by mowing them effectively inhibit its expansion into new areas, and the collected mass (including seeds), processed in solid biofuels, will be effectively "neutralized". So, it seems a highly rational combination of efforts of naturalists fighting with invasive and expansive species in the nature with economy of energetic crops. The ability to use it associated wild solanaceous species, not only cutleaf, as a source of biomass for energetic purposes, creates an opportunity to stop their expansion (Fig. 1).

To allow correct design of machinery and the manufacturing technology of solid biofuels from plants of cutleaf, it is necessary to know the properties which significantly affect the processes. The aim of this study was to determine the basic physical properties of Cutleaf shoots which are important in the process of conversion to solid biofuels.

Fig. 1. **Area occupied by Cutleaf coneflower (*Rudbeckia laciniata* L.) [8; 9]**

The scope of work included the designation of the following properties:

- Shoot length and diameter at the cutting height during harvesting (about 4-5 cm),
- Size of crop,
- Work of cutting, depending on the humidity and the diameter of shoots,
- Elastic constant of shoots,
- Specific density of shoots,
- Calorific value.

The above studies were conducted at two humidities of the material, i.e., 31.5 % (during harvesting) and 16 % (after seasoning).

Materials and methods

The material for the research was derived from the experimental energy plantations located at the Faculty of Production and Power Engineering. Collection of shoots was made in autumn 2011. The harvested plant shoots were formed into bundles, and were subjected to the process of seasoning in order to reduce the humidity (covered shed).

For implementation of the planned stages of work testing equipment supplied by the Laboratory of Technician and Technology of Solid Biofuels Production at the Department of Mechanical Engineering and Agrophysics was used.

Geometry of shoots

In order to determine the geometry of Cutleaf coneflower shoots direct measurements were carried out with the use of a linear gauge (5 m ± 0.01), and an electronic caliper (140 mm ± 0.01). The diameter was measured at the base and at the length of the shoots.

Static work of cuts

In order to mark the work of the cut shoots, the test was carried out at the position, which consists of the endurance machine MTS Insight 2 and a special adapter for cutting the plant material (Fig. 2).

a) b)

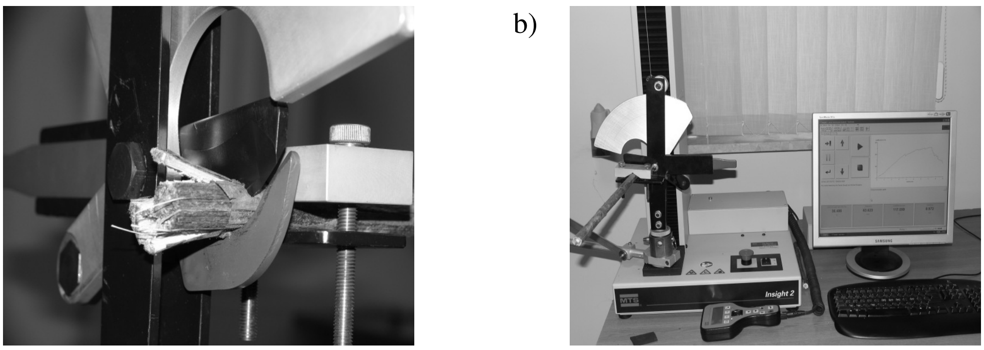

Fig. 2. **Stand for determining the static work of cut plant materials:** a – cutting device, b – control unit (PC) with software TestWorks 4

Elastic constant

Elastic constant for shoots was set by a static method, by using a special adapter used for the sampling of three-point bending. This adapter was attached to the MTS endurance machine (Fig. 3). The measurement methodology is based on the standards PN-75/D-04123 and PN-63/D-04117.

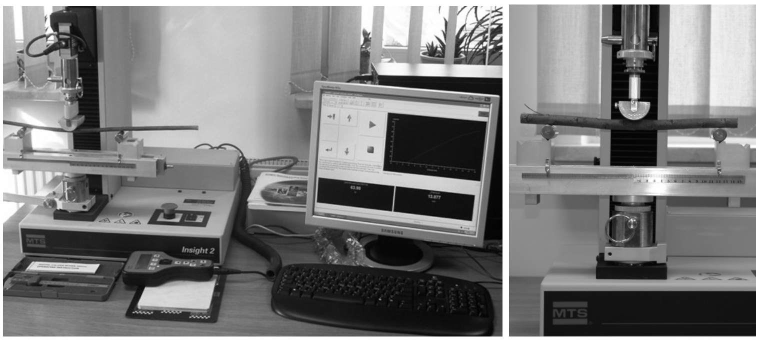

Fig. 3. **Endurance machine MTS with adapter for three- point bending**

The elastic constant for the shoots was set at two levels of humidity. The measurement of humidity and diameter of the shoot was performed immediately before assay elastic constant.

Specific density

Determination of the specific density of the Cutleaf shoots was carried out using the stand to determine the density of the solids RADWAG - WPS 510/C/1 (mass accuracy of 0.001g), (Fig. 4). The measurement was made in accordance with the guidelines contained in the norm PN EN 15150:2012.

Fig. 4. **Stand for determining the specific density**

Calorific value

In order to determine the energy potential of biomass from the shoots of Cutleaf determination of the calorific value was made in the calorimeter KL-12 of Bit-Precyzja firm (see Fig. 5), in accordance with the procedure laid down in the standard PN EN 14918 2010. This information is the basis for the preparation of energetic plans. This parameter was determined for two relative humidities: 16 % and 32 %.

Fig. 5. **Calorimeter KL-12 of Bit-Precyzja firm**

Results and discussion

The obtained values of the determined parameters, included in to the basic characteristics of the material are shown in Table 1. The results of the geometry of the Cutleaf shoot, i.e., the length and diameter at the base, as well as the data from the cutting test (work of cutting) and bending (elastic constant) should help to modify the process of the existing technical systems and in designing new innovative solutions (reel combs, cutting systems, etc.). The data on the calorific value are needed information in the drafting of the demand for biofuel and to estimate the energetic potential of the plantation.

Table 1

Values of the measured parameters for Cutleaf coneflower shoots (*Rudbeckia laciniata* L.)

Parameter	Humidity, %	
	31.5	18
Diameter at the base, mm	4.14-15.1	
Length of shoots, m	0.73-1.97	
Specific density, $kg \cdot m^{-3}$	433.1 ± 29.1	348.7 ± 21.3
Yield, $t \cdot ha^{-1}$	12.04 ± 0.65	10.02 ± 0.36
Work of cuts, $J \cdot mm^{-2}$	$0.013 \pm 7.8 \cdot 10^{-4}$	$0.021 \pm 1.12 \cdot 10^{-3}$
Elastic constant, MPa	4652.7 ± 361.1	7213.1 ± 482.8
Calorific value, $MJ \cdot kg^{-1}$	12.8-13.3	14.8-15.9

The results of the research in Cutleaf coneflower shoots, for their basic properties suggest that they are characterized by the desirable features in the aspect of possible use as energetic crops. Referring to the obtained results of the characteristics of other plant species recognized as energetic plants such as *Miscanthus giganteus* Greef et Deu or *Sida Hermaphrodita* Rusby (Table 2) it can be concluded that Cutleaf has similar properties.

Table 2

Physical properties of plants *Miscanthus giganteus* and *Sida hermaphrodita* [10]

Parameter	Miscanthus giganteus		Sida hermaphrodita	
	w-20, %	w-33, %	w-20, %	26.5, %
ϕ, mm – diameter at the base	8.62		13.78	
h, m – plant height	3.53		3.19	
ρ, $kg \cdot m^{-3}$- specific density	462.8	499.2	378.8	443.5
W, $J \cdot mm^{-2}$– unitary work of cut	0.032	0.027	0.021	0.014
E, MPa – elastic constant	21528.2	17832.9	7236.4	6560.8
Q, $MJ \cdot kg^{-1}$–calorific value	14.3	12.7	13.9	12.6

The mechanical properties described by the elastic constant and unitary work of the cut are similar to Sida. It can be therefore initially assumed that the behavior of the cutleaf shoots, in the process of mechanical processing (mowing, shredding) will be similar to the shoots of Sida. However, in the case of thermal parameters described by the calorific value, the shoots of cutleaf are characterized by similar properties as Sida and also Miscanthus. Therefore, the carried out preliminary assessment of the biomass extracted from cutleaf plants gives grounds for considering that is highly justified for energetic use.

Conclusion

Cutleaf coneflower shoots (*Rudbeckia laciniata L.*) pre-tested in terms of energetic use are characterized by the desired properties regarding to the plants being considered as energetic species. Additionally, as mentioned in the introduction, this plant as an alien species pose a threat to native vegetation, it seems reasonable to recommend making a collection of these plants and processing into biofuels. Mowing of cutleaf plants in incomplete seed development phase will limit their expansion, and, on the other hand, will allow to gain biomass with favorable properties. It also seems possible, due to the habitat requirements, conducting of controlled crops on wet areas or even periodically flooded. These areas are often excluded from the production of food, which means that it will not compete with food production.

Taking into account a sort of cutleaf shoots and their physical properties, it seems to be possible to use in the harvesting technology the machinery fleet used in the production of hay or haylage. From this perspective, the use of this machinery fleet, that is relatively popular among farmers, will facilitate the collection of the existing "crops" and purposely assumed the plantation.

Thus, taking into account the above arguments relating to the need to control the Cutleaf crop and the fact that it is characterized by pro-energetic physical and mechanical properties, it can be determined as a source of biomass for energy purposes. However, it is necessary to conduct further researches related to combustion and to the development of optimal techniques, and its processing technology.

References

1. Dreszer K., Michałek R., Roszkowski A., Energia odnawialna – możliwości jej pozyskiwania i wykorzystania w rolnictwie. (Renewable energy - possibilities of its acquisition and use in agriculture). Publisher PTIR Cracow - Lublin - Warsaw 2003. ISBN 83-9170-530-7 (In Polish).
2. Kubica K., Spalanie biomasy i jej współspalanie z węglem. (Biomass combustion and co-combustion of coal it.). Part I. Bulletin of the Ecological 2003, No 5, pp. 3-5 (In Polish).
3. Frączek J., Mudryk K.: Wpływ wilgotności rozdrabnianych pędów wierzby Salix viminalis L. na skład granulometryczny uzyskiwanych zrębków. (Influence of moisture level of chipped stems of willow Salix viminalis L. on the granulometric composition of chips obtained). Acta Agrophysica vol. 14 (2009), No 1, pp. 49-60 (In Polish).
4. Pearson C.H., Halvorson A.D., Moench R.D., Hammon R.W.: Production of hybrid poplar under short-term, intensive culture in Western Colorado. Industrial Crops and Products No 31 (2010) pp. 492-498.
5. Frączek J., Mudryk K., Wróbel M., Klon jesionolistny Acer negundo L. - Nowy potencjalny gatunek energetyczny. (Ash-leaved maple Acer negundo L. – the new potential energy species). Acta Agrophysica, vol. 14 (2009), No 2, pp. 313-322 (In Polish).
6. Frączek J., Mudryk K., Metoda określenia oporów cięcia pędów wierzby energetycznej. (Method of determining resistance of cutting power willow shoots) Agricultural Engineering 2006. No 13 (88). pp. 91-98 (In Polish).
7. Gatunki obce w Polsce. [online] [09.03.2013.] Available at: http://www.iop.krakow.pl/ias/
8. Bieszczady - Chmiel nad Sanem [online] [09.03.2013.] Available at: http://bieszczady-chmiel-nad-sanem.blogspot.com/2011/03/bieszczady-zote-kwiaty-rudbekii-przy.html.
9. Rudbekia Naga, Rudbeckia laciniata (L.). [online] [09.03.2013.] Available at: http://www.kul.pl/rudbekia-naga-rudbeckia-laciniata,art_24194.html
10. Mudryk K., Wróbel M., Właściwości fizyczne" Rozdział 6.2 w: Optymalizacja procesu produkcji paliw kompaktowych wytwarzanych z roślin energetycznych. (Physical properties" in Chapter 6.2: Optimization of compact fuels produced from energy crops). (redactor J. Frączek). PTIR, Cracow 2010, ISBN 978-83-930818-0-6 pp. 101-110 (In Polish).
11. Grzybek A., Biomasa w energetyce. Czysta Energia. (Biomass in the energy sector. Clean Energy). 2011 (In Polish). [online] [09.03.2013.] Available at: www.czystaenergia.pl/pdf/farma2011/2_grzybek_itp.pdf