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Potential of fast growing poplar, willow and paulownia for bioenergy production

N. Yavorov*, St. Petrin, I. Valchev, S. Nenkova

Department of Pulp, Paper and Printing Arts, University of Chemical Technology and Metallurgy, 8 St. Kliment Ohridski blvd. 1756 Sofia, Bulgaria

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The use of renewable energy sources is one of the possible prospects offering a real alternative to fossil fuels in combination with various eco-oriented advantages. In Bulgaria's forests, there exists an extensive set of fast growing tree species. The most preferred are intensive forest plantations and short-rotation systems from selected clones of poplar, willow, paulownia, acacia, etc. The biomass from plantations of fast growing tree species can be an alternative and attractive base for bioethanol production.

The investigation is performed for determination the potential of fast growing hardwood species from Bulgaria (paulownia (*Paulownia elongata*), poplar (*Populus alba*) and willow (*Salix viminalis rubra*)) as energy crops.

Highest cellulose content is established in *Populus alba*, while the amount of lignin is lowest in *Paulownia elongata*. The obtained lowest calorific value for *Paulownia elongata* is related with the determined content of lignin. The glucose yield after cellulase hydrolysis of steam-exploded *Paulownia elongata* is up to 52%. That result is approximately 24% higher in comparison with corresponding treatment of *Populus alba* and *Salix viminalis rubra*. The obtained result can be explained with the specific structure of *Paulownia elongata*. The chemical composition of wood and especially the cellulose content has no direct effect on the glucose yield.

The plantation harvesting, the calorific value and the glucose yield from fast growing *Populus alba*, *Salix viminalis rubra* and *Paulownia elongata* from Bulgaria make that tree species perspective and suitable for bioenergy production.

Key words: bioenergy, poplar, willow, paulownia, enzyme hydrolysis, steam explosion

INTRODUCTION

Bioenergy is receiving increasing attention because it may reduce greenhouse gas emissions, secure and diversify energy supplies and stimulate rural development. It is well known that transport is almost totally dependent on fossil particularly petroleum based fuels such as gasoline, diesel fuel, liquefied petroleum gas, and compressed natural gas. As the amount of available petroleum decreases, the need for alternative technologies to produce liquid fuels that could potentially help prolong the liquid fuels culture and mitigate the forthcoming effects of the shortage of transportation fuels increases [1, 2].

A potential source for low-cost bioenergy production is to utilize lignocellulosic materials such as crop residues, grasses, sawdust, wood chips, and solid animal waste. Biomass-based fuels, also known as biofuels can be produced via thermochemical and biochemical conversion technologies such as liquefaction [3, 4], pyrolysis [5], gasification [6, 7], hydrolysis [8, 9], fermentation [8], etc. Lignocellulosic biomass has long been recognized as a potential sustainable source of mixed sugars fermentation to biofuels and other biochemical [10, 11]. In the current environment of renewable energy development one option is the production of energy from fast growing forest trees in short rotation intensive culture plantations (SRIC), called bioenergy feedstock. The potential of fast growing forest trees high productivity, coppice ability and ease of vegetative propagation in SRIC plantations has been recognized for over thirty years [12]. One of the most popular fast growing trees are willow [12-14], poplar [12, 13, 15, 16], eucalyptus [15], paulownia [17, 18], etc.

The main object of this study is to establish the suitability of fast growing hardwood species cultivated in Bulgaria (*Paulownia elongata*, *Populus alba* and *Salix viminalis rubra*) as a potential sources of fermentable sugars (glucose) for bioethanol production.

*E-mail: nyavorof@gmail.com

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EXPERIMENTAL

Fast growing hardwood tree species of the genus *Paulownia* (species *Paulownia elongata*), *Salix* (species *Salix viminalis rubra*) and *Populus* (species *Populus alba*), were used in these study. They have been harvested for three years in Experimental Station for Fast-growing Forest Tree Species, Svishtov, (north Bulgaria, 43° 37′ N 25° 21′ E).

The tree species were analysed for cellulose [19], lignin (TAPPI standard T222 om-11), ash (TAPPI standard T211 om-12) and calorific value (TAPPI standard T684 om-11).

The steam explosion pretreatment of wood chips was performed in 2 dm^3 stainless steel laboratory installation at the following conditions: a hydromodul ratio 1:10; an initial temperature of 100 ºC; a maximum temperature of 190 and 200 ºC; pressure of 12.8 and 15.85 bar; heating time of 60 min followed by additional 10 min at the maximum temperature. The steam exploded lignocellulosic mass was washed with distilled water and was subjected to enzymatic hydrolysis as a second stage of treatment.

The cellulase complex NS 22086 with activity 1.000 BHU g^{-1} and β-glucosidase NS 22118 with activity 250 CBU g^{-1} of Novozymes AS were used for the enzymatic hydrolysis. The enzyme charge of NS 22086 was 5%, while that of NS 22118 was 0.5%, both referred to the mass. The enzymatic treatment was carried out in polyethylene bags in a water bath previously heated to 50 °C, pH 5.0 – 5.6 and reaction time 72 h.

The glucose, cellobiose, xylose, furfural and HMF content were analysed with a Dionex HPLC system, according to the NREL standard biomass analytical procedure [20].

RESULTS AND DISCUSSION

Properties of the studied materials

The chemical composition and the calorific value of *Salix viminalis rubra*, *Paulownia elongata* and *Populus alba* are presented in Table 1. The results show that higher content of cellulose and lignin is in *Populus alba* and *Salix viminalis rubra*, and the lowest in *Paulownia elongata*. The ash content of the *Salix viminalis rubra*, 1.59%, is very similar to that of *Populus alba* (1.58%).

The calorific value ranging from 17 970 to 19 660 kJ kg^{-1}. The highest calorific value is determined in *Populus alba* and the lowest in *Paulownia elongata*. Relationship between the lignin content and the calorific value of the substrates is found. In the sample with the highest content of lignin was obtained the highest calorific value which may be due to the higher content of carbon and hydrogen in the lignin, which are the main heat producing elements [21, 22].

Table 1. Chemical composition and calorific value of *Salix viminalis rubra, Paulownia elongata* and *Populus alba*

Feedstock	Component (%)			Calorific value (kJ kg^{-1})
	Lignin	Cellulose	Ash	
Salix viminalis rubra	24.7	46.43	1.59	18 850
Paulownia elongata	21.87	44.03	1.03	17 970
Populus alba	25.31	49.72	1.58	19 660

Evaluation of pretreatment of various biomass materials used in this study

Pretreatment of the substrates by steam explosion shows that the optimum temperature for full defibrillation of *Paulownia elongata* is 190 °C, while of *Salix viminalis rubra* and *Populus alba* is 200 °C, which is possibly due to the differences in the anatomical structure of tree species. The additional refining of the pulp is necessary at lower temperatures of treatment.

The soluble hemicelluloses are removed with the filtrate during the washing of steam exploded pulp. By the separation of the prehydrolysate from the lignocellulosic mass is effectively reduced the inhibition products as furfural, hydroxymethyl furfural (HMF), and phenolics. The results of the analysis of the prehydrolysates using HPLC system are summarised in Table 2.

Table 2. Reducing sugars obtained in the prehydrolysates of *Paulownia elongata*, *Salix viminalis rubra* and *Populus alba*.

	Paulownia elongata (190 °C)	*Salix viminalis rubra* (190 °C)	*Salix viminalis rubra* (200 °C)	*Populus alba* (200 °C)
Glucose (%)	1.71	1.62	-	-
Xylose (%)	2.41	1.18	1.43	0.73
HMF (%)	-	0.38	0.10	-
Furfural (%)	0.24	0.18	0.28	0.10

The lowest furfural and xylose yields of 0.10% and 0.73% are obtained from *Populus alba*, while the yield of xylose is greatest from *Paulownia elongata* and that of the furfural from *Salix viminalis rubra* (200 °C).

The studied pulps after steam explosion pretreatment present low glucose conversion of 1.62% and 1.71% for *Salix viminalis rubra* (190 °C) and *Paulownia elongata*, respectively, and absent of conversion for *Populus alba* and *Salix viminalis rubra* (200 °C).

Enzymatic hydrolysis of the pretreated feedstock

The pretreated feedstock are hydrolysed with cellulases (NS 22086) supplemented with β-glucosidase (NS 22118). The yields of glucose and xylose are determined using the HPLC and the results obtained for *Salix viminalis rubra* (190 and 200 °C) are presented in Fig. 1.

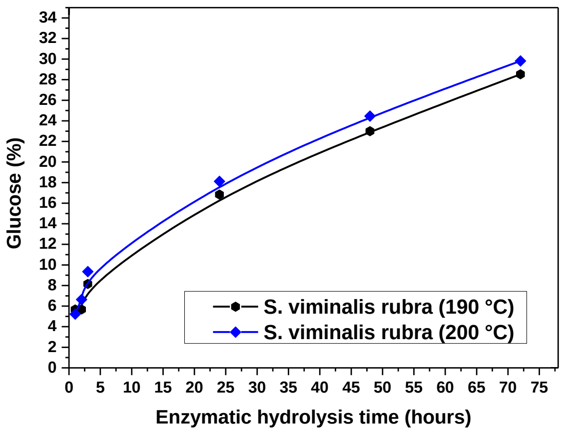

Fig. 1. Glucose yield after hydrolysis of pretreated *Salix viminalis rubra*.

As seen in Fig. 1, the glucose yield reaches nearly 28.7% and 29.8% for *Salix viminalis rubra* (190 °C) and *Salix viminalis rubra* (200 °C), respectively. The results obtained are approximately identical but the short refining must be included at low treatment temperatures. The yields of glucose from *Paulownia elongata* and *Populus alba* are presented in Fig. 2.

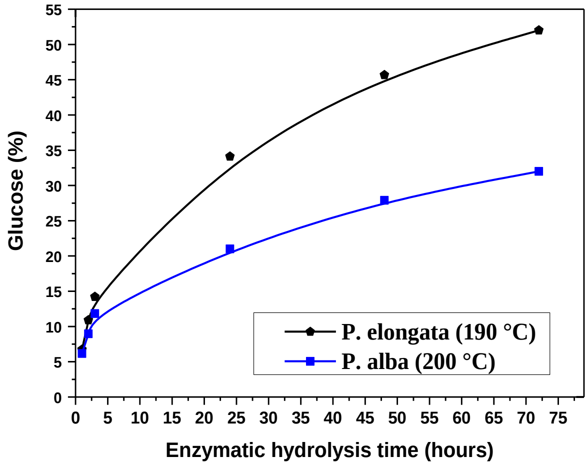

Fig. 2. Glucose yield versus enzymatic hydrolysis time of *Paulownia elongata* and *Populus alba*.

The results show that greater amount of glucose is prepared from *Paulownia elongata* (52%) compared to *Populus alba* (32.1%). This effect is due to the anatomical characteristics and full defibrillation of *Paulownia elongata* during the pretreatment, which contributes to a more efficient enzyme hydrolysis.

The comparing of the obtained results for *Paulownia elongata, Populus alba and Salix viminalis rubra* shows the significant advantage of the paulownia.

The results for *Populus alba* are comparable with those of the enzyme treatment of wheat straw, while the data for *Salix viminalis rubra* are slightly lower [23].

During the cellulase hydrolysis of *Salix viminalis rubra* and *Populus alba* is removed and certain amount of xylose, while for paulownia that effect is not observed (Fig. 3). That is connected with the steam exploded treatment of wood.

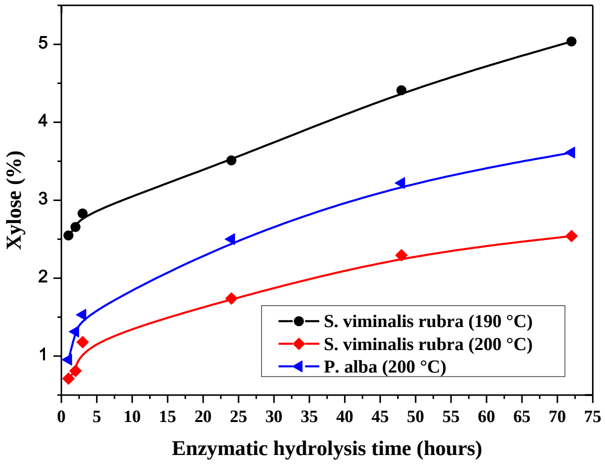

Fig. 3. Xylose yield versus enzymatic hydrolysis time of *Salix viminalis rubra* and *Populus alba*.

CONCLUSIONS

The largest yield of glucose is obtained for *Paulownia elongata* compared with *Populus alba* and *Salix viminalis rubra*.

Poplar and willow, which are a typical tree species on the territory of Bulgaria, shows results comparable with those obtained for wheat straw.

The anatomical structures of tree species, which are selected for testing, explain the different temperatures required for steam exploded treatment.

In conclusion it can be said that the fast-growing tree species, grown in Bulgaria, show a great potential for second-generation bioethanol producing, on the one hand by the high yields obtained sugars, and on the other by the possibility of cultivation in the short rotation plantations.

REFERENCES

1. A. Demirbas, *Appl. Energy*, **86**, Suppl. 1, S108 (2009).
2. M.A. Meyer, J.A. Priess, *Biomass Bioenergy*, **65**, 151 (2014).
3. Z. Liu, F.-S. Zhang, *Energy Convers. Manag.*, **49**, 12, 3498 (2008).
4. M. Balat, M. Balat, E. Kirtay, H. Balat, *Energy Convers. Manage.*, **50**, 12, 3147 (2009).
5. D.R. Vardon, B. K. Sharma, G. V. Blazina, K. Rajagopalan, T. J. Strathmann, *Bioresour. Technol.*, **109**, 178 (2012).
6. M. Balat, M. Balat, E. Kırtay, H. Balat, *Energy Convers. Manage.*, **50**, 12, 3158 (2009).
7. L. Wang, C.L. Weller, D.D. Jones, M.A. Hanna, *Biomass Bioenergy*, **32**, 7, 573 (2008).
8. S. Brethauer, C.E. Wyman, *Bioresour. Technol.*, **101**, 13, 4862 (2010).
9. P. Alvira, E. Tomas-Pejo, M. Ballesteros, M.J. Negro, *Bioresour. Technol.*, **101**, 13, 4851 (2010).
10. Y. Sun, J. Cheng, *Bioresour. Technol.*, **83**, 1,1 (2002).
11. S. Ewanick, R. Bura, in: Bioalcohol production. Biochemical conversion of lignocellulosic biomass, K. Waldron (ed.), Woodhead Publishing Limited, 2010, p. 3.
12. F.A. Aravanopoulos, *Biomass Bioenergy*, **34**, 11, 1531 (2010).
13. C. Hofmann-Schielle, A. Jug, F. Makeschin, K.E. Rehfuess, *Forest. Ecol. Manag.*, **121**, 1–2, 41 (1999).
14. M. Labrecque, T.I. Teodorescu, *Biomass Bioenergy*, **25**, 2, 135 (2003).
15. S. Gonzalez-Garcia, M.T. Moreira, *Biomass Bioenergy*, **39**, 378 (2012).
16. L. Ciadamidaro, E. Madejon, M. Puschenreiter, P. Madejon, *Sci. Total Environ.*, **454–455**, 337 (2013).
17. N. Ayrilmis, A. Kaymakci, *Ind. Crop. Prod.*, **43**, 457 (2013).
18. M.E. Lucas-Borja, C. Wic-Baena, J.L. Moreno, T. Dadi, C. Garcia, *Appl. Soil Ecol.*, **51**, 42 (2011).
19. K. Kurschner, A. Hoffer, *Fresen. J. Anal. Chem.*, **92**, 145 (1933).
20. A. Sluiter, B. Hames, R. Ruiz, C. Scarlata, J. Sluiter, D. Templeton, Laboratory Analytical Procedure, National Renewable Energy Laboratory (NREL), 2006.
21. A. Demirbas, *Energy Convers. Manag.*, **42**, 2, 183 (2001).
22. C. Telmo, J. Lousada, *Biomass Bioenergy*, **35**, 5, 1663 (2011).
23. I. Valchev, S. Petrin, in: Proc. 21st EU Biomass Conf. Exhib., Copenhagen, 2013, p. 1547.

ИЗСЛЕДВАНЕ ПОТЕНЦИАЛА НА БЪРЗОРАСТЯЩА ТОПОЛА, ВЪРБА И ПАУЛОВНИЯ ЗА ПОЛУЧАВАНЕ НА БИОЕНЕРГИЯ

Н. Яворов*, Ст. Петрин, И. Вълчев, С. Ненкова

Катедра „Целулоза, хартия и полиграфия“, Химикотехнологичен и металургичен университет, бул. „Св. Климент Охридски“ 8, 1756 София, България

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(Резюме)

Използването на възобновяеми енергийни източници е една от възможните перспективи, които предлагат реална алтернатива на минерални горива в комбинация с различни еко-ориентирани предимства. В горите на България, съществува богат набор от бързорастящи дървесни видове с потенциал за плантационно отглеждане. Най-предпочитаните са избрани клонове на топола, върба, пауловния, акация и др. Биомасата от насаждения от бързорастящи дървесни видове може да бъде алтернативна и привлекателна основа за производство на биоетанол.

Целта на настоящата работа е изследване и установяване потенциала на бързорастящите, широколистни дървесни видове, отглеждани на територията на България (*Paulownia elongata*, *Populus alba* и *Salix viminalis rubra*) като енергийни култури.

Най-високо съдържание на целулоза е установено при тополата, докато количеството на лигнина е най-ниско при пауловнията, което обяснява получената ниска стойност на калоричност при *Paulownia elongata*. Добивът на глюкоза след целулазна хидролиза на пауловния, предварително третирана с парен взрив е до 52%, който е приблизително 24% по-висок от този при тополата и върбата при равни други условия. Тази разлика най-вероятно се дължи на специфичната структура на пауловнията, т.к. се вижда, че химичният състав на дървесината и особено съдържанието на целулоза няма директно влияние върху добива на глюкоза.

Възможностите за плантационното отглеждане, получените данни за калоричност и високият добив на глюкоза от изследваните бързорастящи дървесни видове, отглеждани в България, прави тези дървесни видове перспективни и подходящи за производство на биоенергия.