CHALLENGES IN BIOETHANOL PRODUCTION FROM INTERMEDIATE AND BY-PRODUCTS OF THE SUGAR BEET PROCESSING IN THE REPUBLIC OF SERBIA

IZAZOVI PROIZVODNJE BIOETANOLA IZ MEĐU- I NUSPROIZVODA PRERADE ŠEĆERNE REPE U REPUBLICI SRBIJI

Jelena DODIĆ*, Jovana GRAHOVAC*, Zorana RONČEVIĆ*, Radmila PAJOVIĆ-ŠĆEPANOVIĆ**,
Siniša DODIĆ*, Bojana BAJIĆ*, Damjan VUČUROVIĆ*

*University of Novi Sad, Faculty of Technology Novi Sad, 21000 Novi Sad, Bul. cara Lazara 1, Serbia

**University of Montenegro, Biotechnical Faculty, 81000 Podgorica, Mihajla Lalića 1, Montenegro
e-mail: ron@uns.ac.rs

ABSTRACT

The bioethanol market is large and has a constant upward trend, which requires the improvement of its production. In the Republic of Serbia, bioethanol is produced using sugar beet molasses-based media. Taking into account a few disadvantages of molasses as raw material, as well as a decreasing trend in its use in Serbia, it is necessary to consider other possibilities provided by the sugar beet processing technology. Therefore, the cogeneration of sugar and bioethanol may serve as an alternative and viable solution. In this paper, the data on the characteristics of intermediate and by-products of sugar beet processing, used as raw materials for bioethanol production, are summarized. The criteria for their selection are given, and the locations of their generation are mapped. Furthermore, the current bioethanol production capacities in the Republic of Serbia are presented, and the possibility of the cogeneration of sugar and bioethanol in domestic factories is considered.

Key words: bioethanol, sugar beet processing, alternative raw materials, sustainable development.

REZIME

Tržište bioetanola je veliko i ima konstantan trend porasta što zahteva unapređenje njegove proizvodnje. Bioetanol se proizvodi fermentacijom izvora ugljenika primenom kvasaca ili bakterija. Kako nisu svi izvori ugljenika odgovarajući za različite mikroorganizme, izbor sirovina, koje sadrže fermentabilne šećere ili konstituente koji se mogu ekonomski isplativim postupcima prevesti u takve, zavisi od primenjenog proizvodnog soja. Ove, alternativne, sirovine često su istovremeno izvor vode i različitih nutrijenata i jedinjenja koja mogu, a ne moraju biti koristan sastojak medijuma. U tom smislu, primeni potencijalnih sirovina u proizvodnji bioetanola moraju predhoditi sveobuhvatna razmatranja vezana za biološku dostupnost i koncentraciju izvora ugljenika, konzistenciju sirovine, lokaciju na kojoj se generiše, sezonsku dostupnost, alternativnu primenu, kao i njen lokalni tehnološki potencijal. U Republici Srbiji se za proizvodnju bioetanola koriste medijumi na bazi melase šećerne repe. Imajući u vidu nekoliko osnovnih nedostataka melase kao sirovine, kao i činjenicu da će je na našoj teritoriji biti sve manje zbog usavršavanja tehnologije šećera u smislu generisanja manjih količina efluenta i zbog smanjenja proizvodnih kapaciteta šećerana, očigledno je da je potrebno razmotriti i druge mogućnosti koje nudi tehnologija prerade šećerne repe, a kao alternativno i veoma atraktivno rešenje nameće se koproizvodnja šećera i bioetanola. U ovom radu objedinjeni su podaci koji se odnose na karakteristike među- i nusproizvoda prerade šećerne repe kao sirovina za proizvodnju bioetanola, dati su kriterijumi njihovog izbora i mapirane su lokacije na kojima se generišu. Takođe, prikazani su trenutni proizvodni kapaciteti bioetanola u Republici Srbiji i razmotrena je mogućnost koproizvodnje šećera i bioetanola u domaćim šećerana.

Gljučne reči: bioetanol, prerada šećerne repe, alternativne sirovine, održivi razvoj.

INTRODUCTION

Bioethanol, i.e. ethanol produced from biomass resources, has been known from ancient times. However, nowadays it is possible to claim that bioethanol represents an extraordinary and important raw material that is abundantly used in all strategic fields of development. Large amounts of bioethanol are traditionally used in everyday life in the form of beverages, antiseptic and disinfectants, whereas modern trends have intensified its use as an environmentally friendly and renewable energy source, i.e. as an additive or supplement to gasoline. The food, cosmetic, pharmaceutical and chemical industries use bioethanol as a solvent, extragent, preservative, additive or initial raw material. Since the fields of bioethanol usage are very diverse, its market, both locally and globally, is large and has a constant upward trend (Baras *et al.*, 2002). Therefore, the improvement of bioethanol technology is a priority for many

research centers, universities, private companies, and even governments, both for economic and environmental reasons.

It is known that bioethanol is produced in distilleries by alcoholic fermentation of carbon sources using suitable biocatalysts, yeasts or bacteria. Considering that not all carbon sources are appropriate for different microorganisms, the selection of raw materials, which contain fermentable sugars or constituents usable in bioethanol production, depends on the applied producing strain (Lin and Tanaka, 2006). Hence, one of the major problems with bioethanol production is the availability of convenient raw materials. The quality and quantity of selected raw materials can considerably vary from season to season and depend on geographic locations. The price of raw materials is also very volatile, which can highly affect the costs of bioethanol production. Because raw materials typically account for more than one-third of the production costs, the usage of cheap substrates has been suggested as an efficient manner of

increasing the cost-effectiveness of bioethanol technology (Balat et al., 2008).

Different renewable and economically acceptable raw materials are utilized for bioethanol production, and they can be classified into the following three groups: sugar containing substrates (e.g. sugar beet, sugar cane and molasses), starch-based feedstock (e.g. cereals and various carotid crops) and lignocellulosic material (e.g. wood, old paper, straw and similar agricultural by-products) (Lević et al., 2007). At present, bioethanol is obtained by the fermentation of sugar and starchy raw materials using the *Saccharomyces cerevisiae* strains, whereas the lignocellulosic bioethanol production is still economically challenging (Bai et al., 2008). However, among all the raw materials utilized worldwide, molasses and other sugar beet extracts are ideal substrates for bioethanol production because they do not require additional pretreatment stages as almost all of the sugar is in the form of sucrose. It is readily split into glucose and fructose in the initial stage of fermentation by the enzyme invertase, located in the periplasmic space between the yeast cell wall and cell membrane. Therefore, since the intermediate and by-products of sugar beet processing can be used without any modification, the preparation of fermentation media based on these raw materials is very simple, and includes diluting to the desired sugar content (if necessary), as well as the correction of pH value and sterilization (Jevtić-Mučibabić et al., 2008; Zbed et al., 2014).

European counties are major producers of sugar beet due to favorable climatic conditions and large area of arable land. This crop is grown in the most fertile regions where it is impossible to leave the land unused. Since the sugar beet yield per hectare of cultivated area is very high, the produced amount of sugar is larger than its consumption. For these reasons, the usage of agricultural residues as renewable energy sources is considered. Although the idea to produce bioethanol from alternative raw material is not new, the alcoholic fermentation of intermediate and by-products of sugar beet processing represents an attractive solution for sugar factories interested in a combined production of sugar and bioethanol, as well as distilleries located near the sugar facilities. Therefore, the potential for bioethanol production from raw juice, thin juice, thick juice, molasses and/or beet pulp have been studied in Croatia (Pavlečić et al., 2010; Šantek et al., 2010), Romania (Pătrașcu et al., 2009), Poland (Dziugan et al., 2013), Czech (Hinková and Bubník, 2001), Turkey (İçöz et al., 2009), and other countries in the Europe. On the basis of the results obtained, it is clear that all intermediate and by-products of sugar beet processing can be successfully used for bioethanol production. However, the formulation of media preparation, the optimization of fermentation conditions, and the development of new cultivation techniques can significantly increase product yields and consequently improve the efficacy and cost-effectiveness of the bioprocess.

In this paper, the literature data on the characteristics of intermediate and by-products of sugar beet processing as raw material for bioethanol production are summarized, the criteria for their selection are given, and the locations of their generation are mapped. In addition, the current bioethanol production capacities in the Republic of Serbia are presented, and the possibility of cogeneration of sugar and bioethanol in domestic factories is considered. The systematization of the collected data and their critical discussion will contribute to a better understanding of the challenges related to the bioethanol production using intermediate and by-products of sugar beet processing.

MATERIAL

The available scientific, technical and statistical publications were used as a primary material for this paper. The collated data were selected, systematized, compared and critically discussed.

DISCUSSION

Bioethanol production in the Republic of Serbia

In the Republic of Serbia, bioethanol is predominantly produced from sugar beet molasses, and to a certain extent, especially in factories of smaller capacity, from starchy raw materials such as cereals or potatoes (Baras et al., 2002; Nikolić et al., 2016). This is due to the existence of facilities built in the earlier period, the availability of raw materials and the simplicity of the technological process for their preparation. Furthermore, the lack of funding for the construction of facilities adapted to the application of cellulosic and lignocellulosic materials as a feedstock also makes it difficult to improve the bioethanol production in Serbia.

The locations of facilities for bioethanol production in the Republic of Serbia are presented in Figure 1 (Serbian Business Registers Agency). It is evident that all the producers mapped are located in the territory of AP Vojvodina, which is expected because the used raw materials are grown in the same region. The presented data do not indicate the purpose of the produced bioethanol, nor the quantities of effluents that each facility individually generates. However, the areas on which they are concentrated are clearly visible.

According to the data of the Statistical Office of the Republic of Serbia, the annual bioethanol production in the last seven years (2009-2016) was about 60,000-65,000 hL. The exception is 2011, in which the volume of the produced bioethanol was much higher (almost 87000 hL), and the following year, in which only 525,000 hL was produced due to the supplies of the previous year. Nowadays, bioethanol is produced in significantly greater quantities compared to the period 1994-2004 (approximately 22000 hL per year), but also more than double less compared to the amount produced in the period 2005-2008 (about 145,000 hL per year), which indicates that part of the production capacity is currently underutilized. The possible reasons are the lack of suitable cost-effective raw materials, as well as the inadequate placement of bioethanol on the market in the Republic of Serbia, i.e. bioethanol is still limited to the promotion of traditional applications such as alcoholic drinks, as well as medical and pharmaceutical uses.

Serbia and other Balkan countries, which are interested in joining the European Union, have accepted the obligation to follow the EU policies and programs, including those that oblige them to introduce the production and usage of fuels from renewable energy sources. Analyzing the existing capacities and equipment for bioethanol production in Serbia, it is evident that the bioethanol facilities cannot meet the needs for bioethanol fuel production. With the reconstruction and modernization of the existing manufacturing plants, especially in the domain of new raw materials processing, they could be reconditioned for the production of bioethanol fuel (Dodić et al., 2009a; Nikolić et al., 2016). Nevertheless, the producing capacities are insufficient for meeting the needs of bioethanol as a supplement to motor fuels (Dodić et al., 2009b), so new facilities should be constructed based on the use of new, alternative raw materials.

Fig. 1. Map of facilities for the bioethanol production in the Republic of Serbia

Characteristics of raw materials for bioethanol production

On an industrial scale, bioethanol is produced in large-volume bioreactors (not less than 10000 L in Serbia and up to 500000 L in the world) (Lević *et al.*, 2007), which requires the consumption of a significant amount of water for the fermentation media preparation. For that purpose, in addition to the drinking water supplied from its own sources, industrial facilities also use cheap raw materials, which are usually intermediate products, by-products or effluents of various industries. These alternative raw materials are often simultaneously the source of water as well as various nutrients and compounds that are potentially useful medium ingredients (Balan, 2014). Moreover, the application of new raw materials and reuse of industrial effluents in bioethanol production are possible to some extent, and are mainly limited to the specific requirements of the selected producing strain (Prasad *et al.*, 2007). In this context, prior to the application of alternative raw materials in the bioethanol production, comprehensive considerations related to the biological availability and concentration of carbon sources, consistency of raw material, location where it is generated, seasonal availability, alternative application, as well as its local technological potential must be carried out (Smith, 2004).

The biological availability of carbon sources from the potential raw material implies that the identified sources of this nutrient are fermentable from the applied strain of *Saccharomyces cerevisiae*, or can be cost-effectively utilized for that purpose. The knowledge about carbon sources concentration and consistency of raw material should facilitate the management (e.g. transport and storage), and minimize the

possible changes in composition before usage (e.g. microbiological spoilage and layering). The location where the raw material is generated underscores the transport costs and the possibilities for their reduction. Provided the required quantities need to be collected from multiple locations, it is preferred that they be clustered (large generators in a limited area), and not scattered. The seasonal availability of alternative raw materials includes fluctuations in quantities and composition, which is a consequence of the nature of their production process. Therefore, it is important that the desired raw material is constantly available so that its seasonal availability can be compensated for by storage or cheap preservation. The possible solution is also the replacement of alternative raw material by another that is available at a given moment. It is necessary that selected raw materials have alternative usage in order to anticipate unwanted oscillations in the availability on limited markets. The local technological potential implies an estimation of the potential for generating the required quantities of alternative raw materials at present and in the future, so that the industrialized bioethanol production based on the fermentation of selected raw materials would be cost-effective over a long period.

In addition, it is also necessary to consider the following factors important for the bioprocess: the need for preliminary preparation of an alternative raw material, the consumption of energy and water, and the addition of other feedstock to complete the fermentation medium composition. The behavior of the medium ingredients during its preparation, sterilization, fermentation, as well as the separation of bioethanol from the fermented broth should not be neglected.

Intermediate and by-products of sugar beet processing as raw materials for bioethanol production

In the Republic of Serbia, sugar is exclusively produced from sugar beet grown domestically. Two decades ago, more than 110,000 ha was devoted to sugar beet in Serbia, and the areas devoted to sugar beet in Serbia at present are more than halved. Of the fifteen factories, which produced about 700,000 tons of sugar per year, only six sugar producing facilities have remained with an annual capacity between 400,000 tons and 550,000 tons. The locations of sugar beet cultivation area and the locations of sugar factories are given in Figure 2 (Serbian Business Registers Agency). It is obvious that all facilities for sugar beet processing are near the area where it is grown, and that all of them are located in the territory of AP Vojvodina. The equipment for sugar beet harvesting is adequate, the transportation methods to the factories are well established, and the sugar beet processing technology is entirely optimized.

The technological process of sugar production is continuous and carried out in the following interconnected stages: pretreatment of sugar beet, extraction of sugar from beet cossettes, beet juice purification, beet juice concentration, crystallization and finishing crystals. The raw, thin and thick juices are generated during sugar beet processing as intermediate products, whereas molasses, beet pulp and leaves represent by-products of sugar technology (Duraisam *et al.*, 2017).

As stated above, molasses is a commonly used raw material for bioethanol production. It is a stable feedstock during storage up to a year, without evident loss in commercial value. Therefore, the application of molasses is not restricted to the marketing season, and the advantages of its use include relatively simple preparation and minor equipment requirements (Lević *et al.*, 2008). Unfortunately, the available quantities of this non-standard raw material are unreliable (Baras *et al.*, 2002).

Fig. 2. Map of the sugar beet cultivation areas and sugar factories in the Republic of Serbia

Furthermore, molasses is obtained at the end of sugar beet processing, and hence its price is considerably higher compared to other intermediate and by-products of sugar technology (Ranković et al., 2008). Furthermore, the quantity of molasses in our market is very and indicates an decreasing trend due to sugar technology improvements with regard to generating smaller amounts of effluents and reducing the production capacities of sugar factories. Therefore, it is necessary to consider the characteristics of other effluents of sugar beet processing as raw materials for bioethanol production using *Saccharomyces cerevisiae*. The criteria for their selection are presented in Table 1. The data summarized in Table 1 indicate that intermediate products from sugar beet processing, i.e. raw, thin and thick juices, represent suitable raw materials for bioethanol production because all of them contain sucrose as a directly fermentable carbon source for *Saccharomyces cerevisiae* (Ranković et al., 2009). The concentration of sucrose in raw and thin juices are appropriate, whereas the thick juice must be diluted during the preparation of fermentation medium (Grahovac et al., 2011). The raw and thin juices feature low storability because the concentration of sugars is almost ideal for most microorganisms (Hinková and Bubník, 2001). Therefore, these effluents can be used directly either for bioethanol and sugar production during the sugar beet harvest season, or can be concentrated in an evaporator and stored for several months (Popov et al., 2010). Conversely, thick juice is a highly concentrated sugar solution that is obtained by the concentration and thickening of thin juice using evaporators. This eliminates problems with storability and inhibits microbial growth (Dodić et al., 2009c). However, the production of thick juice is very complicated and expensive, and it consequently influences the bioethanol price (Hinková and

Bubník, 2001). It is important to note that intermediate products of sugar beet processing do not have an alternative commercial use, but their local technological potential in Serbia is appropriate. As all the sugar factories (Figure 2) and distilleries (Figure 1) are located in a distance of 200 km, the transport of raw materials between existing facilities is fairly possible.

Table 1. Criteria for the selection of intermediate and by-products of sugar beet processing as raw materials for bioethanol production

Criteria	Intermediate products			By-products	
	Raw juice	Thin juice	Thick juice	Molasses	Beet pulp
Carbon source	sucrose	sucrose	sucrose	sucrose	cellulose hemicellulose lignin
Biological availability	ferment.	ferment.	ferment.	ferment.	not fermentable
Carbon source conc.	98 % from sugar beet	12-14 %	55-65 %	about 50 %	about 27 % about 29 % about 29 %
Consistency	liquid similar to water	liquid similar to water	thick liquid	syrupey consisten.	solid consistency
Generation location	short distance	short distance	short distance	short distance	short distance
Seasonal availability	in campaign	in campaign	in campaign	during all year	in campaign
Alternative application	-	-	-	widely used	widely used
Local technological potential	existing	existing	existing	existing	existing

Sugar beet pulp is an abundant by-product of sugar industry, obtained after the extraction of sugar with warm water, which contain cellulose, hemicellulose, and lignin as carbon sources (Duraissam et al., 2017). The extracted beet pulp is only available at the campaign due to high moisture content, and their drying provides the possibility of their long-term storage. This feedstock has a commercial value because it can be added to animal nutrition. However, the conversion of the lignocellulosic raw material to a form that is suitable for fermentation by yeasts is complicated, expensive and currently represents a major disadvantage for its use in bioethanol production (Grahovac et al., 2012a).

Possibility of the cogeneration of sugar and bioethanol in domestic factories

The increase of sugar production yield and efficiency has led to a reduction in required quantities of sugar beet. A cheaper production of sugar from sugar cane is an additional reason why most of the existing sugar factories in Europe have begun the co-production of bioethanol in additionally built refineries. Introducing the concept of sugar and bioethanol cogeneration is an attractive option for domestic sugar factories, as it provides flexibility in terms of the variation of produced quantities of sugar and bioethanol, depending on the market conditions. The cogeneration of sugar and bioethanol depends on several factors

such as the selected ratio of sugar and bioethanol production, the choice of raw material for bioethanol production (raw, thin and thick juices, molasses or beet pulp), the price of raw materials and products, etc. In addition, industrial facilities for sugar and bioethanol co-production have a spatial advantage due to the raw, thin and thick juices as intermediates and molasses and beet pulp as byproducts of sugar technology are available in the same place (Grahovac et al., 2012a).

Production of bioethanol from sugar beet is technically feasible in most sugar factories, with appropriate modifications to the facilities and equipment, as well as with some additions. The additional processes and operations required to produce bioethanol from sugar beet include fermentation, distillation, dehydration, storage, quality control and packaging of finished products (Grahovac et al., 2012a). As the composition of intermediate and by-products of sugar beet processing depends on the location and type of land where the crop is grown, as well as on the applied technological process, the optimization of the bioethanol production by the fermentation of these raw materials originating from the domestic sugar factories was done (Dodić et al., 2009; Grahovac et al., 2011; Grahovac 2012b; Popov et al., 2010). The determination of the yield, cost-effectiveness, technical requirements and optimal conditions of the bioethanol production using different intermediate and by-products of sugar beet processing is very important. It enables sugar factories to consider the cost-effectiveness of both sugar and bioethanol production, the optimal ratio between them, and the most suitable substrate for bioethanol production (raw juice, thin juice, thick juice or molasses).

CONCLUSION

This paper provides valuable information on the challenges of bioethanol production using intermediate and by-products of the sugar beet processing in the Republic of Serbia. The cogeneration of sugar and bioethanol in domestic factories can be beneficial to the sugar industry, which is facing threats of price and quota reduction in the market. At present, there are ideal conditions for the bioethanol production expansion owing to a significant role of bioethanol in meeting the future energy requirements in Serbia.

ACKNOWLEDGMENT: *This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia and Ministry of Science of Montenegro within the framework of the project 451-03-01414/2016-09/5 named "The potential application of agro-industrial waste from the territory of the Republic of Serbia and the Republic of Montenegro for the production of bio-fuels" (2016-2018) and the project TR-31002 named "Improving bioethanol production from products of sugar beet processing" (2011-2018).*

REFERENCES

- Bai, F.W., Anderson, W.A., Moo-Young, M. (2008). Ethanol fermentation technologies from sugar and starch feedstocks. *Biotechnology Advances*, 26 (1), 89-105.
- Balan, V. (2014). Current challenges in commercially producing biofuels from lignocellulosic biomass. *ISRN Biotechnology*, 2014, 1-31.
- Balat, M., Balat, Havva, Öz, Cahide (2008). Progress in bioethanol processing. *Progress in Energy and Combustion Science*, 34 (5), 551-573.
- Baras, J.K., Gačeša, J.K., Pejin, Dušanka J. (2002). Ethanol is a strategic raw material. *Hemijška industrija*, 56 (3), 89-105.
- Dodić, S.N., Popov, S.D., Dodić, Jelena M., Ranković, Jovana A., Zoltan, Z.Z. (2009a). Potential development of bioethanol production in Vojvodina. *Renewable and Sustainable Energy Reviews*, 13 (9), 2722-2727.
- Dodić, S.N., Popov, S.D., Dodić, Jelena M., Ranković, Jovana A., Zavargo, Z.Z. (2009b). Potential contribution of bioethanol fuel to the transport sector of Vojvodina. *Renewable and Sustainable Energy Reviews*, 13 (8), 2197-2200.
- Dodić, S., Popov, S., Dodić, Jelena, Ranković, Jovana, Zavargo, Z., Jevtić Mučibabić, Rada (2009c). Bioethanol production from thick juice as intermediate of sugar beet processing. *Biomass and Bioenergy*, 33 (5), 822-827.
- Duraisam, R., Salelgn, K., Berekete, A.K. (2017). Production of beet sugar and bio-ethanol from sugar beet and it bagasse: A review. *International Journal of Engineering Trends and Technology*, 43 (4), 222-233.
- Dziugan, P., Balcerek, Maria, Pielech-Przybylska, Katarzyna, Patelski, P. (2013). Evaluation of the fermentation of high gravity thick sugar beet juice worts for efficient bioethanol production. *Biotechnology for Biofuels*, 6 (158), 1-10.
- Grahovac, Jovana A., Dodić, Jelena M., Dodić, S.N., Popov, S.D., Jokić, A.I., Zavargo, Z.Z., (2011). Optimization of bioethanol production from intermediates of sugar beet processing by response surface methodology. *Biomass and Bioenergy*, 35 (10), 4290-4296.
- Grahovac, Jovana A., Dodić, Jelena M., Dodić, S.N., Popov, S.D., Vučurović, D.G., Jokić, A.I. (2012a). Future trends of bioethanol co-production in Serbian sugar plants. *Renewable and Sustainable Energy Reviews*, 16 (5), 3270-3274.
- Grahovac, Jovana, Dodić, Jelena, Jokić, A., Dodić, S., Popov, S. (2012b). Optimization of ethanol production from thick juice: A response surface methodology approach. *Fuel*, 93, 221-228.
- Hinková, Andrea, Bubník, Z. (2001). Sugar beet as a raw material for bioethanol production. *Czech Journal of Food Sciences*, 19 (6), 224-234.
- İçöz, E., Tuğrul, K.M., Saral, A., İçöz, Ebru (2009). Research on ethanol production and use from sugar beet in Turkey. *Biomass and Bioenergy*, 33 (1), 1-7.
- Jevtić-Mučibabić, Rada, Dodić, Jelena, Ranković, Jovana, Dodić S., Popov, S., Zavargo, Z. (2008). The valorization of the intermediates in the process of sugar beet as the alternative raw materials for the bioethanol production. *Food Processing, Quality and Safety*, 35 (2), 71-76.
- Lević, Lj., Lević, Jovanka, Sredanović, Slavica, Đuragić, Olivera, Kuljanin, Tatjana, Čolović, R. (2007). Bioethanol as fuel - statement, perspectives and technology of production. *Journal on Processing and Energy in Agriculture (former PTEP)*, 11 (4), 198-202.
- Lević, Lj., Razmovski, Radojka, Vučurović, Vesna, Koprivica, Gordana, Mišljenović, Nevena (2008). Appliance of sugar beet molasses after osmotic dehydration of apple for bioethanol production. *Journal on Processing and Energy in Agriculture (former PTEP)*, 12 (4), 219-221.
- Lin, Y., Tanaka, S. (2006). Ethanol fermentation from biomass resources: current state and prospects. *Applied Microbiology and Biotechnology*, 69 (6), 627-642.
- Nikolić Svetlana, Pejin, Jelena, Mojović, Ljiljana (2016). Challenges in bioethanol production: utilization of cotton fabrics as a feedstock. *Chemical Industry & Chemical Engineering Quarterly*, 22 (4), 375-390.
- Pătrașcu, Elena, Răpeanu, Gabriela, Bonciu, Camelia, Vicol, Constanța, Bahrim, Gabriela (2009). Investigation of yeast performances in the fermentation of beet and cane molasses to

ethanol production. Ovidius University Annals of Chemistry, 20 (2), 199-204.

Pavlečić, M., Vrana, Ivna, Vibovec, K., Ivančić Šantek, Mirela, Horvat, P., Šantek, B. (2010). Ethanol production from different intermediates of sugar beet processing. Food Technology and Biotechnology, 48 (3), 362-367.

Popov, S., Ranković, Jovana, Dodić, Jelena, Dodić, S, Jokić, A. (2010). Bioethanol production from raw juice as intermediate of sugar beet processing: A response surface methodology approach. Food Technology and Biotechnology, 48 (3), 376-383.

Prasad, S., Singh, A., Joshi, H.C. (2007). Ethanol as an alternative fuel from agricultural, industrial and urban residues. Resources, Conservation and Recycling, 50 (1), 1-39.

Ranković, Jovana, Dodić, S., Popov, S., Dodić, Jelena (2008). Intermediate products from sugar beet processing used for the biosynthesis of ethanol. Acta Agriculturae Serbica, 13 (25), 47-54.

Ranković, Jovana, Dodić, Jelena, Dodić, S., Popov, S. (2009). Bioethanol production from intermediate products of

sugar beet processing with different types of *Saccharomyces cerevisiae*. Chemical Industry & Chemical Engineering Quarterly, 15 (1), 13-16.

Smith, J.E. (2004). Biotechnology, 4th edition. Cambridge University Press, Cambridge, United Kingdom.

Šantek, B., Gwehenberger, G., Ivančić Šantek, Mirela, Narodslawsky, M., Horvat, P. (2010). Evaluation of energy demand and the sustainability of different bioethanol production processes from sugar beet. Resources, Conservation and Recycling, 54 (11), 872-877.

Zabed, H., Faruq, G., Sahu, J.N., Azirun, M.S., Hashim, R., Boyce, A.N. (2014). Bioethanol production from fermentable sugar juice. The Scientific World Journal, 2014, 1-11.

Serbian Business Registers Agency: <http://www.apr.gov.rs>
Statistical Office of the Republic of Serbia: <http://www.stat.gov.rs>

Received: 02. 25. 2018.

Accepted: 21. 03. 2018.