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A COMPARISON OF THE COSTS OF BIOETHANOL PRODUCTION FROM TRITICALE, WHEAT AND MAIZE

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ABSTRACT

Bioethanol is one of the most promising biofuels from renewable resources. The selection of the most appropriate feedstock for bioethanol production strongly depends on the local conditions. The present work compares the costs of the biotechnological production of fuel bioethanol from triticale, wheat and maize.

The first part of the study was concerned with the cultivation of four varieties of triticale and wheat and four maize hybrids under optimum agro-ecological conditions. The grain yield data and the data for the yield of bioethanol obtained under laboratory conditions from these raw materials were used in the second part of the study. Namely, these data served as the basis to calculate the costs of bioethanol production from triticale, wheat and maize grown on 26 privately-owned farms in the Autonomous Province of Vojvodina, Serbia. Based on the obtained results it can be concluded that the main factor that influences the price of bioethanol is the cost of the raw material. On the other hand, the price of particular raw materials depends on the grain yield per hectare. The results of the economic analysis showed that the expenses of bioethanol production from triticale were the lowest, somewhat higher from maize, and the highest from wheat.

Key words: bioethanol, cost, maize, triticale, wheat.

INTRODUCTION

A consequence of industrial development and population growth is a remarkable increase in the energy demand. There is an estimate that the world's energy consumption has increased 17-fold in the last century (Demirbas, 2007). However, conventional energy resources, like fossil fuels, cannot meet the increasing energy demand. Therefore, the use of biofuels as alternative energy sources has many advantages, such as the contribution to the reduction of CO_2 emission, higher employment opportunities, and the development of rural communities.

Biofuels are easily available from common biodegradable biomass sources, and their use contributes to the economic and environmental sustainability (Baras et al., 2002). Bioethanol is one of the most promising biofuels from renewable resources. When is used as oxygenate, it has certain advantages: Firstly, it has a higher oxygen content that implies less amount of required additive. The increased content of oxygen allows a better oxidation of the gasoline hydrocarbons with the consequent reduction in the emission of CO and aromatic compounds (Sánchez and Cardona, 2008). Fuel bioethanol production has increased remarkably because many countries look for reducing oil imports, boosting rural economies and improving air quality. Among biofuels, bioethanol is currently considered the most appropriate solution for short-term gasoline substitution. For example, in 2007, roughly 45 megatons of bioethanol was produced in the world for automotive purposes, three-quarters of which was generated in the United States and Brazil by means of first-generation technologies (Cardona and Sánchez, 2007). The selection of the most appropriate feedstock for bioethanol production strongly depends on the

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local conditions. North American and European countries have based their ethanol industry mostly on starchy materials, due to their agro-economic conditions.

For better competitiveness, bioethanol production cost should be lowered. For current technologies employed at commercial level, the main share in the cost structure corresponds to the feedstocks (Cardona and Sánchez, 2007). The current world bioethanol research is driven by the need to reduce the cost of production. Maize is considered the most suitable feedstock for industrial bioethanol production. It was reported that the average maize production in Serbia in 2009 was about 6.5 million of metric tons (calculated domestic needs for maize are only 4.0-4.5 million metric tons) (Nikolić et al., 2009). This means that there is enough maize for other purposes besides food or feed; therefore significant amounts can be used for bioethanol production. These are the reasons why we used maize as a feedstock for bioethanol production. Wheat is very good feedstock for bioethanol production and is considered as a primary commodity for bioethanol production in Europe and Australia (Miedl et al., 2007). To complete gelatinisation of wheat starch, a temperature of about 65°C is required. Wheat kernels contain native amylolytic enzymes capable of degrading the starch contained in the grain (Senn and Pieper, 2001). Miedl et al. (2007) have concluded that this cereal could be used in United Kingdom and other northern European countries for the production of bioethanol.

Recently, it has been reported that triticale is cultivated in more than 30 countries worldwide (Mergoun et al., 2004) on around 3.7 million ha in total, yielding more than 12 million metric tons a year. Triticale has agronomic advantages as it can be grown on more marginal land (arid, acidic, etc.) and requires less agricultural chemicals (fertilizers, herbicides, etc.). The size, quality and content of the seed are similar to that of wheat, although certain agronomic features make it less desirable for crop growers such as its longer stem and subsequent susceptibility to lodging and also a higher susceptibility to certain diseases such as Ergot, though it does have a better resistance to other diseases such as rust, smuts and mildew and also a lower nutrient requirement. Therefore, the overall inputs are lower than those of wheat (Deverell et al., 2009).

The main factor affecting the cost, and therefore competitiveness, of bioethanol is the cost of the feedstock, which generally constitutes some 60-85% of the total production cost (Kwiatkowski et al., 2006; Mojović et al., 2009). Grain growth conditions related to location and nitrogen fertilization level had the most noticeable effect on grain starch content, while grain yield per hectare has the most significant effect on ethanol productivity (Obuchowski et al., 2010). The price of bioethanol from starchy sources depends on a number of factors. Franceschin et al. (2008) verified that bioethanol production is nowadays a profitable investment; however, cost and profitability indexes are very dependent on the price of corn, fluctuations in the ethanol selling price, and government subsidies. The production and supply of bioethanol is of interest to governments, industry and agricultural community as it benefits to national energy security, to the reduction of greenhouse gas emission, and to rural economies (Deverell et al., 2009).

In view of the fact that the price of raw material is the main component in the costs of bioethanol production, the objective of this study was to compare the economic suitability of triticale, wheat and maize for this purpose. To this end, the data about the grain yields of these cereals obtained under optimum cultivation conditions and the data on the yield of bioethanol produced under laboratory conditions were used to estimate the costs of bioethanol production based on the grain yields of triticale, wheat and maize obtained on 26 privately-owned farms in the Autonomous Province of Vojvodina, Serbia.

MATERIAL AND METHODS

Raw materials. In order to calculate the economic parameters and price of bioethanol produced from triticale, wheat and maize, these cereals were grown under optimum conditions and the grain yields were determined. Then, they were used as raw materials for the bioethanol production under laboratory conditions.

Four varieties of triticale (Oganj, Odisej, Jutro and NST 21) and wheat (NS 40S, Dragana, Rapsodija and Renesansa), and four maize hybrids (NS 640, NS 6030, NS 6010 and NS 5043), were grown on the experimental fields of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The data on grain yields and data on bioethanol yields obtained in the laboratory experiments were used to calculate the technological parameters of the energy consumption in the phases of grain milling, thermal degradation, fermentation, and distillation. Based on the amounts of energy consumed in the particular phases of production, it was possible to calculate the overall energy demand in the technological process of bioethanol production.

Wheat and triticale were milled in a dry mill MIAG-BRAUNSCHWEIF, Type: DOXY 71 b/4, mill motor power 0.22 kW at 1375 r/min, yielding the meals consisting of 90% of particles of average size less than 700 μm. The energy consumption in the milling of triticale and wheat was 0.031 kWh/kg. The maize samples were milled in a dry mill CONDUX-WERK Wolfrang bel Hanan Typ LS 10 K No 1596, mill motor power 0.84 kW, and the meal consisted of 86% particles with average size lower than 700 μm. The corresponding energy consumption was 0.046 kWh/kg. These data on the electricity used in the milling agree with those reported by Pieper and Bohner (1985).

Analytical methods. The content of the main components in triticale, wheat and maize meals was obtained by chemical analysis determining starch content by standard polarimetric method after Ewers and expressed on dry matter basis, whereas the moisture content was determined by standard method of drying at 105°C to the constant mass.

Enzymes. All enzymes were kindly provided by Novozymes (Denmark), and they were handled and stored strictly following the manufacturer's recommendations.

Thermamyl 120 L, a heat-stable α-amylase from Bacillus licheniformis, was used for wheat and maize meal liquefaction. Its activity was 120 KNU per gram (KNU, kilo novo units α-amylases – the amount of enzyme which breaks down 5.26 g of starch per hour according to Novozyme,s standard method for the determination of α-amylase). SAN Super 240 L from Aspergillus niger, glucoamylase, activity 240 AGU per gram (AGU is the amount of enzyme which hydrolyses 1 μmol of maltose per minute under specified conditions) was used for wheat and maize meal saccharification.

Thermamyl 120 L and SAN Super 240 L were added to the wheat and maize mashes as recommended by the manufacturer (Novozymes, Denmark).

Yeast strain. Instant dry active baker's yeast *Saccharomyces cerevisiae* provided by Alltech Fermin, Senta, Serbia, was used as a producing microorganism. Prior to each experiment, the yeast was activated by suspending in 0.1% sterile peptone water pre-warmed to 38°C. The yeast cell count was determined in Neuberger's counting chamber. The amount of inoculum needed to obtain 30-35 × 10^6 CFU/mL in the fermentation medium was taken from the yeast solution (Wang et al., 1999).

Pretreatment of cereal samples for fermentation. Mashing of milled samples was carried out using an automated mashing water bath (Glasbläserei, Institut für Gärungs Gewerbe, Berlin). In the case of triticale, this was performed without addition of technical enzymes, whereas mashing of wheat and maize samples was performed with the addition of technical enzymes (Thermamyl 120 L and SAN Super 240 L). Four parallel tests were set at three different temperatures: 60°C for triticale (Senn and Pieper, 2001); 65°C for wheat (Pejin et al., 2009), and 95°C for maizr (Goslich, 1981). Mashed samples were mixed with water pre-warmed to 50°C in metallic jars, keeping the sample to water ratio at 1:3. After mixing with water, the enzyme Thermamyl 120 L was added to the wheat and maize samples. The jars were held in a water bath with stirring (150 r/min) for 30 min at 50°C. After that, the mashed samples of triticale, wheat and maize were heated to 60, 65 and 95°C, respectively, and incubated at the corresponding temperature with constant stirring for 60 min. Then, the temperature was lowered to 53-55°C, and bacterial glucoamylase SAN Super 240 L was added to wheat and maize samples. These samples were held at this temperature for 30 min, and after that the temperature was lowered to 30°C.

Fermentation. Mashes were transferred to 1 L glass bottles and the prepared yeast was added; the bottles were closed with foam burgs to allow venting of the CO_2 produced during fermentation. Fermentation was conducted in a thermostat at 30°C. After the fermentation, 250 mL of the fermented mash was centrifuged for 15 min at 10 000 r/min at 4°C in a refrigerated centrifuge (Sorvall RC 24), and the supernatant was used for ethanol determination (Miedl at al., 2007). The bioethanol concentration was determined based on the density of bioethanol distillate at 20°C and expressed in weight % (w/w). Four measurements were made for each sample of triticale, wheat and maize, and the data were given as mean values.

Comparison of the prices of bioethanol produced from triticale, wheat and maize. The complete analysis of the cost effectiveness of using triticale, wheat and maize as raw materials for bioethanol production was based on the expenses incurred in particular phases of production. The production cost of the raw material was calculated on the basis of the analysis of data for the privately-owned sector in the Republic of Serbia, encompassing 26 individual farms from the territory of the Autonomous Province of Vojvodina for the last five years. The selected producers were representative of intensive farming. The calculation of the bioethanol production costs was based on the production costs, which encompassed only the basic variables: the costs of raw material, other material costs, and energy costs. The other costs (amortization, labor, maintenance, interests, insurance, etc.) were not included in the calculation, because they greatly depend on the size and concrete constructive and technological characteristics of the plant for bioethanol production. In Serbia, there is no obligation of bookkeeping for private farms, except for those which are encompassed by the VAT system, which are at the present only a very small number. Also, there is no established system for regular collection of economic data, like in the FADN (Farm Accounting Data Network) system operating in the EU countries (Vukoje and Maletić, 2007). However, the cooperation between the Faculty of Agriculture in Novi Sad and the counselling service of the AP Vojvodina has resulted in an appropriate methodology and the corresponding software for collecting "the basic production-economic indicators for farm estates" (Vukoje and Koči, 2007). The model has already been in function for three years in the agricultural stations of the AP Vojvodina. Each year, data are collected and analysed for the most important products. The calculations used in this work to determine the production costs of triticale, wheat and maize are just the result of the mentioned investigations.

RESULTS AND DISCUSSION

Table 1 gives the grain yields (t/ha) obtained for four varieties of triticale and wheat and four maize hybrids, grown on the experimental fields of the Institute of Field and Vegetable Crops, Novi Sad. These yields may be considered as very high. They were obtained on a very good, fertile soil and under optimum cultural practices.

Table 1. Grain yields of varieties of triticale and wheat and maize hybrids

Triticale		Wheat		Maize	
Variety	Grain yield t/ha	Variety	Grain yield t/ha	Hybrid	Grain yield t/ha
NST 21/06	10.58	NS 40S	10.40	NS 640	10.50
Odisej	8.58	Rapsodija	9.20	NS 6030	11.60
Jutro	9.10	Renesansa	8.68	NS 6010	11.00
Oganj	8.76	Dragana	8.59	NS 5043	11.12
Mean value	*9.25*		*9.21*		*11.30*

As can be concluded from the presented data, the grain yields of triticale and wheat are on average by 18.58 % lower than those of maize.

By analysing the data given in Table 2, one can see that bioethanol yields were lowest in the case of triticale and highest in the case of maize.

These results are in agreement with the mean contents of starch of 66.67% in triticale, 68.75% in wheat, and 73.25% in maize (Pejin et al., 2009).

Among triticales the variety NST 21/06 gave the highest grain yield (Table 1) and also the highest yield of bioethanol (Table 2). Rosenberger et al. (2002), using the triticale Modus obtained a bioethanol yield of 463 L/t, so that it can be concluded that the triticale varieties used in the present work are suitable for bioethanol production.

Table 2. Bioethanol yields from triticale, wheat and maize

Triticale		Wheat		Maize	
Variety	Bioethanol*	Variety	Bioethanol*	Hybrid	Bioethanol*
NST 21/06	485.8	NS 40S	504.7	NS 640	538.0
Odisej	443.6	Rapsodija	472.7	NS 6030	528.4
Jutro	476.8	Renesansa	483.5	NS 6010	520.0
Oganj	477.4	Dragana	519.4	NS 5043	522.7
Mean value	*470.9*		*495.0*		*527.2*

* Litres of absolute bioethanol/tonne of dry matter.

The grain yields of triticale, wheat and maize obtained on the experimental fields of the Institute of Field and Vegetable Crops in Novi Sad (Serbia) location can not serve as the basis for calculating bioethanol price because the yields are location dependent. Hence, to obtain more realistic data about the production of these raw materials, we used data obtained in 26 privately-owned farms, i.e. from 26 different locations. The costs of production of the cereals were calculated per hectare, i.e. per tone of the main product (Table 3). By applying the appropriate conversion factor it was possible to calculate the costs per tone of dry matter, assuming the maximum grain humidity of 14%. The total costs of triticale production were the lowest (483.16 €/ha) and those of maize highest (674.36 €/ha).

The total costs of triticale production in Serbia are by 26% lower compared to those of wheat and maize. A comparison of the data presented in Tables 1 and 3 shows significant variations in the yields of the investigated crops. For triticale, this difference in grain yield is 3.65 t/ha, for wheat 3.85 t/ha, and for maize 3.38 t/ha. These differences between the high grain yields achieved on the experimental fields and on privately-owned farms may be a stimulus to the farmers to grow best varieties of triticale, wheat and maize, applying the measures of intensive farming. For the production of bioethanol, of essential importance is the cost of dry matter of the raw material. It was the highest for wheat (112.96 €/t) and lowest for maize (99.01 €/t).

Table 3. Calculation of the costs of production (€) of triticale, wheat and maize per hectare

Description	Unit of measure	Triticale	Wheat	Maize
Material	€/ha	248.88	267.73	342.75
Fuel	€/ha	65.25	69.98	87.92
Production services	€/ha	72.82	80.80	94.06
Labor costs	€/ha	23.33	24.20	32.59
Fixed charges	€/ha	88.84	92.97	117.03
Total costs	€/ha	**499.11**	**535.67**	**674.36**
By-product value	€/ha	15.95	14.98	0.00
Cost price	€/ha	**483.16**	**520.69**	**674.36**
Grain yield	t/ha	**5.60**	**5.36**	**7.92**
Cost price	€/t	**86.28**	**97.14**	**85.15**
Conversion factor	-	1.16279	1.16279	1.16279
Dry matter price	€/t	100.32	112.96	99.01

The basis for the calculation of the bioethanol production costs from the investigated raw materials is represented by the expenses incurred in the particular phases of the production. The first production phase is the grain milling, which in the case of triticale and wheat was performed by conventional dry procedure at an energy expenditure of 31 kWh/t, whereas in the case of maize this was done using a hammer mill, and the corresponding energy expenditure was 46 kWh/t. The milling costs were calculated based on the average electricity price comparable with those in the EU countries (0.085 €/kWh) (Table 4).

As is evident from the data given in Table 4, the energy consumed in the milling of triticale and wheat was by 32% lower compared to that of maize, which is in concordance with the findings of Offer and Haldenwanger (1988).

Table 4. Calculated expenses of the energy consumed in the milling

Description	Unit of measure	Triticale	Wheat	Maize
Consumed electricity/t	kWh	31.00	31.00	46.00
Electricity price	€/kWh	0.085	0.085	0.085
Total expenses	€	2.64	2.64	3.91

Next phase in the production of bioethanol is the thermal treatment of the milled material. The corresponding costs consist of the costs of purchasing the appropriate enzymes for degradation of the starch contained in the wheat and maize samples (Table 5) and costs with the energy consumed in the thermal degradation of all the investigated raw materials (Table 6). The triticale varieties did not require the use of enzymes since their kernel contains higher amounts of amylolytic enzymes (Kučerova, 2007; Pejin et al., 2009).

The amount of enzymes needed for wheat starch conversion to bioethanol is by about 50% lower compared to maize, because wheat kernel contains some amylolytic enzymes (Table 5). This finding is in agreement with that reported by Miedl et al. (2007).

Thermal degradation in the process of bioethanol production is realized by heating the mixture of milled raw material with water to the given temperature. The thermal treatment temperature depends on the nature of the raw material, and it was 60°C for triticale, 65°C for wheat, and 95°C for maize (Senn and Pieper, 2001).

Table 5. Calculation of the expenses of using the degradation enzymes

Description	Consumption norm	Triticale	Wheat	Maize
Thermamyl	kg/t	0	0.20	0.50
Thermamyl price	€/kg	0	5.50	5.50
Value	€	0	1.10	2.75
SAN Super 360	kg/t	0	0.60	1.00
Price of SAN Super 360 preparation	€/kg	0	7.50	7.50
Value	€	0	4.50	7.50
Total expenses	€	0	5.60	10.25

The amount of energy needed for thermal treatment of triticale was by 44.43% smaller compared to maize (Table 6).

Table 6. Calculation of the energy costs of thermal treatment

Description	Unit of measure	Triticale	Wheat	Maize
Heating temperature	°C	20 - 60	20 - 65	20 - 90
Energy consumed	MJ/t	563.00	633.00	1,013.00
Energy value of natural gas	MJ/m^3	33.34	33.34	33.34
Volume of consumed gas	m^3	16.89	18.99	30.39
Gas price	€/m^3	0.42	0.42	0.42
Total expenses	€	7.13	8.01	**12.83**

The thermally treated mixtures are cooled to the fermentation temperature of 30°C and the production microorganism *Saccharomyces cerevisiae* is added. In the present work, dry active *Saccharomyces cerevisiae* was added in an amount of 1.25 kg/t of raw material (Ingledew, 1999).

Table 7 presents the calculation of the costs for the dry active yeast *Saccharomyces cerevisiae* application, needed for the fermentation process in the bioethanol production. The costs of dry active yeast are the same for all investigated raw materials because the efficient fermentation of all the investigated raw materials requires approximately the same number of viable yeast cells.

Table 7. Calculation of the expenses for using dry active yeast *Saccharomyces cerevisiae*

Description	Unit of measure	Triticale	Wheat	Maize
Dry active yeast	kg/t	1.25	1.25	1.25
Yeast price	€/kg	5.78	5.78	5.78
Total expenses	€	7.23	7.23	7.23

Besides, in the phase of the medium manipulation prior, during, and after the fermentation a certain amount of electric energy is needed, and the calculation of these expenses is given in Table 8.

Table 8. Calculation of the costs of electricity consumed in the fermentation process

Description	Unit of measure	Triti-cale	Wheat	Maize
Specifc energy consumption	kWh/L bioethanol	0.01	0.01	0.01
Electricity consumption	kWh	4.71	4.95	5.27
Electricity price	€/kWh	0.085	0.085	0.085
Total costs	€	0.35	0.37	0.40

The next phase, requiring the largest amount of energy, is the phase of distillation and dehydration. The corresponding calculation of the energy costs is based on the use of natural gas as fuel (Table 9).

Table 9. Calculation of the costs of energy consumed in the process of distillation and dehydration

Description	Unit of measure	Triticale	Wheat	Maize
Distillation and dehydration	MJ/L bioethanol	3.72	3.72	3.72
Total gas consumption	m^3	1,749.65	1,839.45	1,958.99
Energy value of natural gas	MJ/m^3	33.34	33.34	33.34
Volume of the gas consumed	m^3	52.48	55.18	58.76
Gas price	€/m^3	0.42	0.42	0.42
Total costs	€	22.15	23.29	24.80

Based on all the presented calculations it was possible to derive the price of bioethanol production in Serbia (Table 10). The main factor that influences the price of bioethanol is the cost of the raw material. On the other hand, the price of particular raw materials depends on the grain yield per hectare (Kwiatkowski et al., 2006).

Table 10. Calculation of the costs of raw material and energy for bioethanol production

Description	Unit of measure	Triticale	Wheat	Maize
Raw material	€/t	100.32	112.96	99.01
Milling	€/t	2.64	2.64	3.91
Thermal treatment	€/t	7.13	13.61	23.08
Cooling	€/t	0.00	0.00	0.00
Fermentation	€/t	7.58	7.60	7.62
Distillation and dehydration	€/t	22.15	23.29	24.80
Material and energy costs	€/t	**139.82**	**160.09**	**158.42**
Costs of the production of 1000 L of absolute bioethanol	€/1000 L	**296.91**	**323.37**	**300.46**

The price of maize for bioethanol production was the lowest because of the fact that the mean grain yield obtained on 26 privately-owned farms was by 2.32 t/ha higher than of triticale, and by 2.56 t/ha than that of wheat. Based on the yields of the investigated cereals obtained on the experimental fields of the Institute of Field and Vegetable Crops, Novi Sad and average yields obtained on 26 privately-owned farms, the farmers can be advised to grow the varieties and apply crop management that give higher grain yields.

CONCLUSIONS

Based on the presented results it can be concluded that in bioethanol production, triticale is advantageous compared to wheat and maize. As first, the overall costs of its cultivation are lower by 26%. Further, in the process of bioethanol production, the milling expenses are by 32% lower compared to those for maize; there is no need for technical enzymes (provided an appropriate triticale variety is used), and its thermal treatment requires 44% less energy compared to maize. In this work, all production costs are ascribed to the bioethanol, which means that the value of the by-products, CO_2 and silage, was not deducted from the costs of bioethanol production. Since the values of these by-products are generally proportional to the amount of produced bioethanol, the taking of these parameters into account would not change the relations between the established prices of bioethanol.

The lowest production price of bioethanol per production unit was obtained for triticale, insignificantly higher for maize, and highest for wheat. In order to increase grain yield of triticale, and thus lower the bioethanol price, farmers can be advised to grow triticale varieties that give higher yields, like, for example, the variety NST 21/6. The differences in the bioethanol price derived on the basis of data for 26 privately-owned farms in Serbia are not significant, but if one takes into account the overall advantages of bioethanol production from triticale and potential rise of energy prices, it is possible to conclude that triticale has a great potential as a raw material for the production of bioethanol.

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