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Miscanthus biomass quality composition and methods of feedstock preparation for conversion into synthetic diesel fuel

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Abstract

When developing various technologies designed for biomass conversion into biofuels, it is important to establish the suitability of raw material of lignocellulotic, non-food plants such as *Miscanthus*, whose biomass has a good energy potential. Biomass productivity, quality and its suitability for processing under more northern climatic conditions are important factors to be considered. Experiments were aimed to estimate quality and technological parameters of *Miscanthus* growing, harvesting and processing into synthetic diesel, to evaluate chemical, physical and mechanical properties of biomass and to determine energy consumption necessary for biomass preparation for conversion into synthetic diesel. The study object was biomass of *Miscanthus* (*Miscanthus* × *giganteus* Greef et Deu) produced under Lithuanian and German climate conditions.

Miscanthus harvested in the autumn produced up to 9.42 t ha^{-1} dry matter (DM) yield, which was significantly higher in the treatments fertilised with a higher nitrogen rate. The content of cellulose (413–456 g kg^{-1} DM) and hemicellulose (204–236 g kg^{-1} DM) was very similar at all fertilisation levels. The highest content of lignin (117 g kg^{-1} DM) was established in the treatments fertilised with 120 kg ha^{-1} N. The spring-harvested *Miscanthus* biomass had significantly lower moisture content and the yield was significantly lower, too. While preparing the biomass as feedstock for synthetic diesel the greatest reduction in moisture content (to 8.59 ± 1.38%) occurred when *Miscanthus* biomass was chopped, pre-dried and milled, and particles larger than 2 mm accounted for the largest share. The energy use for chopping of autumn-harvested biomass was lower and chopping efficiency was higher compared with the spring-harvested biomass. The composition of major components of synthetic fuel from *Miscanthus* biomass was very similar to that of mineral diesel.

Key words: biomass, harvesting time, *Miscanthus*, physico-mechanical properties, synthetic diesel.

Introduction

Nowadays biodiesel is regarded as an environmentally friendly fuel whose production is expected to grow in the near future, especially from lignocellulosic crops such as *Miscanthus* or other similar new energy crops which are not associated with food crops and which are considered to have energetic, economic and environmental advantages over food crops (Janaun, Ellis, 2010; Reijnders, 2010). Different biofuels are generated from diverse renewable resources and biodiesel is one of the most important transport fuels that can be obtained from biomass using different conversion processes (Demirbas, 2009; Cheng, Timilsina, 2011). Gasification of lignocellulosic biomass provides a way to produced different liquid fuels (Simmons, 2012), therefore biodiesel can be produced from all types of biomass that can be gasified, herewith technologies for converting biomass to biodiesel also are at various stages of development (Yousuf, 2012). When developing technologies for biomass conversion, several important aspects such as biomass feedstock potential and quality should be considered. Superior raw material is that which comes from crops which produce higher yields than food crops and have other advantages such as possibility to produce considerable quantity of biomass in less fertile soils (Carriquiry et al., 2011). Studies were done on the biomass of various energy plants and assessment of biomass suitability for processing was carried out. *Miscanthus* × *giganteus* is one of the benefited crops relevant as biomass feedstock especially in warmer and moderate climate zone countries (Clifton-Brown et al., 2004; Hastings et al., 2009; Anderson et al., 2011; Zub et al., 2011). Despite poor overwintering in the first year, *Miscanthus* has been indicated as an energy crop, which can be grown almost in all Europe (Clifton-Brown, Lewandowski, 2002; Clifton-Brown et al., 2004) and some experiments conducted in more northern countries concluded the same (Jezowski et al., 2011; Kryževičienė et al., 2011).

There are various considerations to improve the biomass quality of the recycling process to obtain a higher total energy. Lewandowski and Heinz (2003) reported that harvesting early in spring is recommended for *Miscanthus* for less moisture content. Harvesting time is important also for other quality composition characteristics (Lewandowki, Heinz, 2003; Hodgson et al., 2011; Zub et al., 2011). Morphological and mechanical properties, composition of feedstock at harvesting affect not only dry matter yield, but also the state of feedstock for subsequent conversion process and influence total energy efficiency (Kaack, Schwarz, 2001; Kaack et al., 2003; Mani et al., 2006; Igathinathane et al., 2008). Johnson et al. (2012) indicated that *M.* × *gigantheus* cutting process needs to be investigated in detail, which would help in developing more efficient harvesting and biomass particle size reduction equipment required for the introduction of *M.* × *gigantheus* as a bioenergy crop. Due to biomass processing technology imperfections, not all biomass is consumed, therefore in order to make the best use, it is necessary to look for ways to improve biomass feedstock preparation for processing (Robbins et al., 2012).

The aim of this study was to evaluate *Miscanthus* growing and harvesting and its biomass quality- technological parameters such as chemical and physico-mechanical characteristics (chaff humidity, bulk density and fineness) as well as biomass conversion into synthetic diesel.

Materials and methods

The object of this study was biomass of *Miscanthus* (*Miscanthus* × *giganteus* Greef et Deu) produced under Lithuanian climate conditions and German climate conditions (in the demonstrational department of the company "Alphakat GmbH", Germany), as a feedstock for the production of synthetic diesel. The *Miscanthus* biomass as feedstock for conversion into energy produced in Lithuania was analysed in more detail. The trials have been conducted since 2007 at Lithuanian Institute of Agriculture (currently – Lithuanian Research Centre for Agriculture and Forestry) in Dotnuva, Kėdainiai district (55º24′ N, 23º52′ E), in a reclaimed river bed territory. The soil is light, sand on sand with a small stone and gravel admixture, *Eutri-Cambic Arenosol* (*ARb-eu*). Nitrogen (N) fertilisation at three rates (0, 60 and 120 kg ha^{-1}) was applied in spring from the second growth season onward. The biomass was harvested once a year – either in autumn (autumn harvesting) or spring (spring harvesting). To estimate biomass yield, the plants were cut and fresh mass was immediately weighed. To calculate dry matter (DM) yield of biomass, 5–6 stems were taken from each treatment replication and chopped, the mass was weighed and dried at +105ºC to a constant weight, and weighed again. Chemical analyses were done on a composite chopped mass samples taken from three replications then dried at +65ºC and ground in a cyclonic mill with 1 mm sieve. The samples were subjected to the fibre component analyses: acid detergent fibre (ADF) and neutral detergent fibre (NDF) and acid detergent lignin (ADL) using a cell wall detergent fractionation method according to van Soest (Faithfull, 2002). The content of cell wall structural carbohydrates hemicellulose and cellulose was calculated as the following differences: cellulose = ADF − ADL and hemicellulose = NDF − ADF (Hindrichsen et al., 2006).

For the assessment of *Miscanthus* biomass physico-mechanical features for synthetic diesel and the energy consumption for preparation of biomass for production, the following treatments were used: 1st – the biomass grown and prepared for the production of diesel in Germany (the biomass was grown in Germany, growing conditions were similar to those of the 2nd treatment, biomass was harvested in autumn and chopped with a forage harvester-thresher "Maral 125" ("Fortshritt", Germany); 2nd – the biomass grown at the Lithuanian Research Centre for Agriculture and Forestry and fertilised at 60 kg ha^{-1} N harvested in autumn and chopped with a forage harvester-thresher "Maral 125"; 3rd – the biomass prepared in the same way as 2nd treatment and later this feedstock material was dried to 8% humidity; 4th – the biomass prepared in the same way as in 3rd treatment and milled with a hammer disintegrator "Retsch SM 200" ("Retsch", Germany); 5th – the biomass from the Lithuanian Research Centre for Agriculture and Forestry was harvested in spring and chopped with a forage harvester-thresher "Maral 125". For the calculation of the chaff humidity the standard methodology was used (Jasinskas, Zvicevičius, 2008). The thickness of the chaff was determined by the weighing method (Jasinskas et al., 2012).

The energy consumption, necessary for chopping of *Miscanthus* stems, was determined by calculating the loaded and non-loaded energy outlay (kWh) of the disintegrator's electric motor. A portable three-phase power quality analyzer "Power Q Plus" ("Metrel", Slovenia) was used for determination of energy consumption (kWh) of the disintegrator's electric motor. Cut stems samples weighing 1.5, 3 and 4.5 kg were fed into the chopper machine. The dried and chopped samples of the raw material were fed into the grinding-mill by 25, 50 and 75 g samples. The disintegrator working efficiency was measured using a stopwatch by determining the mass quantity of supply and duration of mass chopping.

Dry biomass of *Miscanthus* in Germany ("Alphakat GmbH") was processed into synthetic fuel (liquid hydrocarbons) by applying the CPD (catalytic pressureless depolymerization) technology. Physical and chemical characteristics of the synthetic diesel were compared to those of mineral diesel and compliance with the standard requirements for biodiesel was estimated

(1st treatment). During the tests we used the following methods and materials: density was determined according to the standard LST EN ISO 3675 requirements; viscosity – in accordance with BS EN ISO 3104 requirements; acid value – according to the requirements of BS EN 14104; iodine value – according to the requirements of BS EN 14104; water content – according to DIN EN ISO 12937 requirements; sulphur content – according to the requirements of BS EN 20846; flashpoint – according to BS EN ISO 2719 requirements; ignition temperature was defined according to the requirements of LST EN ISO 2719; limitary temperature of filtration and turbidity – by LST EN ISO 116 requirements. Fourier transformation infrared (FTIR) spectroscopy analysis was performed and infrared spectrums were marked by infrared radiation spectrometer FTIR Spectrum RX I ("Arcoptix", Switzerland).

The research results were processed using the statistical analysis software package *SELEKCIJA*, software *ANOVA* and *STAT* (Tarakanovas, Raudonius, 2003), and least significant difference (LSD) at significance level of $P < 0.05$ was used.

Results and discussion

Morphological traits, biomass yield and chemical composition of Miscanthus. Important factors for herbaceous energy plants are DM yield and harvesting time. In our research, autumn-harvested *Miscanthus* produced 9.42 t ha^{-1} of DM in the 5–6th year of growing (Table 1). The DM yield depended on the N fertilisation level. Significant differences were observed with the highest N_{120} fertiliser rate compared to lower N_{60} and non-fertilised during both harvesting periods. As reported in literature, *Miscanthus* can produce high yields with low N inputs (Lewandovski, Kauter, 2003). However, the harvesting timing is an important factor for DM amount of *Miscanthus* plants. During the winter time biomass loss ranged from 32.7% to 39.6% depending on the fertilisation level. Non-fertilised *Miscanthus* produced significantly lower DM yield and the loss of biomass during the winter was significantly higher compared to fertilised plants.

Table 1. Biomass moisture and dry matter yield of autumn-harvested (AH) and spring-harvested (SH) *Miscanthus*

Indicators	Fertilisation			LSD_{05}
	N_0	N_{60}	N_{120}	
Dry matter t ha^{-1} (AH)	4.63	5.45	9.42	1.81
Moisture content % (AH)	64.5	66.9	65.3	
Dry matter t ha^{-1} (SH)	2.79	3.56	6.34	1.33
Moisture content % (SH)	32.4	33.4	37.4	
Loss of biomass in winter %	39.6	34.7	32.7	4.31

Similar trends were observed in the DM structure (Table 2). The higher N_{120} fertiliser rate significantly increased weight per plant and tended to increase the share of stems compared to the N_{60} rate and non-fertilised *Miscanthus*. The proportion of leaves in the autumn-harvested biomass did not depend on fertiliser rates. Percentage of stems and leaves in the total biomass dried in autumn was approximately the same as in that dried in spring. At spring harvesting, DM weight per plant was lower by 17–20 g compared to that at autumn harvesting.

Table 2. Biomass structure of *Miscanthus* plants at harvesting

Indicator	Fertilisation			LSD_{05}
	N_0	N_{60}	N_{120}	
Autumn-harvested biomass				
Weight per plant g	41.8	42.1	49.0	6.34
Percent of leaves	54.5	47.4	48.7	5.41
Percent of stems	45.5	52.6	51.3	5.68
Spring-harvested biomass				
Weight per plant g	24.8	23.1	29.4	4.11
Percent of leaves	26.7	24.8	20.7	5.07
Percent of stems	73.3	75.2	79.3	2.91

Chemical composition of biomass is a very important parameter showing its suitability for bioenergy and how this composition could affect biomass conversion efficiency. *Miscanthus* accumulated 700–785 g NDF in kg^{-1} DM of biomass depending on the N fertilisation level (Table 3). Key polymers of biomass composition such as cellulose, hemicellulose and lignin are quality indicators showing feedstock suitability for different energy conversion pathways. The content of cellulose and hemicellulose was very similar at all fertilization levels. Lignin, a constituent of fibre, is undesirable in the biomass intended for biogas or biodiesel production. Its highest content was found in the biomass of *Miscanthus* fertilised with N_{120} rate. In this study, we investigated chemical composition of only autumn-harvested biomass as influenced by N fertilisation. Literature sources indicate the effect of other factors as well. At autumn harvest, the cell wall composition was very similar to that of the whole biomass at winter harvest. Thus no significant differences in lignin and polysaccharide contents were observed (Huyen et al., 2010). Hodgson et al. (2011) concluded that significant variation in cell wall composition was indentified not only between *Miscanthus* genotypes, but also between harvest times. An important trait is moisture content in biomass. When delaying harvest time until plants have fully senesced, moisture content may reduce from 564 to 291 g kg^{-1} (Lewandowski, Heinz, 2003). Variation in senescence is correlated with variation in moisture content in *Miscanthus* (Robson et al., 2012) and consequently optimising moisture content through harvest time and senescence is one low energy route to improved conversion process. In our case, moisture content in autumn-harvested biomass was 64.5–66.9% and in spring-harvested biomass it was 32.4–37.4% (Table 1). However, delaying of harvest time correlated not only with reduction in moisture content, but also with yield. As we noticed, previous yield losses in our experiments were more than 30%. Clifton-Brown and Lewandowski

(2002) observed that the effect of harvesting delaying and the longer period between autumn and winter harvests was greater yield losses. Therefore other possibilities to improve biomass composition have to be looked for.

Table 3. Chemical composition of the above ground biomass of autumn-harvested *Miscanthus* plants, g kg^{-1} dry matter

Treatment	Fibre		Lignin	Cellulose	Hemi-cellulose
	NDF	ADF			
N_0	743	507	84	423	236
N_{60}	700	495	82	413	204
N_{120}	785	573	117	456	212
LSD_{05}	3.60	23.2	7.1	19.4	23.7

NDF – neutral detergent fibre, ADF – acid detergent fibre

Physico-mechanical features of Miscanthus biomass. The moisture of *Miscanthus* biomass which grew in the climatic conditions of Germany and was prepared to produce synthetic diesel was 10.98 ± 0.18% (Fig. 1). Moisture content of Lithuania-grown *Miscanthus* biomass, harvested in the autumn and chopped was as high as 51.92 ± 0.90%. When the biomass harvested in autumn was chopped, dried up and milled, its moisture decreased to 8.59 ± 1.38%. Meanwhile, moisture content of *Miscanthus* biomass harvested in spring and chopped was 30.20 ± 4.67%, or 20% less than that of the biomass harvested in autumn and chopped.

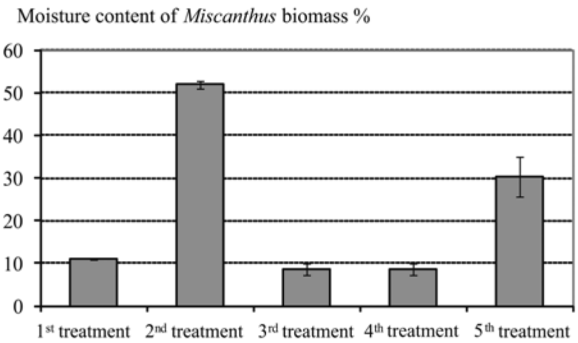

Figure 1. Moisture content of feedstock depending on the biomass preparation method

The density of *Miscanthus* biomass for synthetic diesel prepared in Germany was 0.184 ± 0.016 g cm^{-3} and the DM density was 0.164 ± 0.016 g cm^{-3} (Table 4). Meanwhile, density of *Miscanthus* biomass harvested in autumn and chopped was as low as 0.105 ± 0.008 g cm^3, and DM density was more than three times lower than that of the biomass prepared in Germany. The density of chopped and dried biomass was thrice as low as that of the material prepared in Germany. *Miscanthus* that was harvested in autumn, chopped, dried and milled had density and DM amount similar to that of the biomass prepared in Germany, 0.194 ± 0.013 and 0.177 ± 0.013 g cm^{-3}, respectively. Density of biomass harvested in spring and chopped was similar to that of biomass harvested in autumn and chopped.

Table 4. Physico-mechanical properties of *Miscanthus* biomass for synthetic diesel fuel production depending on biomass preparation method

Treatment	Chaff mass (g) in 500 ml vessel	Dry matter (g) of chaff mass in 500 ml vessel	Chaff bulk density g cm^{-3}	Bulk density of chaff dry matter g cm^{-3}
1	91.96 ± 9.31	81.88 ± 9.31	0.184 ± 0.016	0.164 ± 0.016
2	52.58 ± 4.82	25.27 ± 4.82	0.105 ± 0.008	0.051 ± 0.008
3	29.46 ± 3.68	26.93 ± 3.68	0.059 ± 0.006	0.054 ± 0.006
4	97.04 ± 7.36	88.70 ± 7.36	0.194 ± 0.013	0.177 ± 0.013
5	45.14 ± 5.73	31.51 ± 5.73	0.090 ± 0.011	0.063 ± 0.011

Fineness (fractional composition) varied considerably depending on the biomass preparation for synthetic diesel fuel production method (Table 5). The greatest amount of the particles larger than 2 mm were in the treatment where *Miscanthus* biomass was harvested in autumn, chopped and dried. Small difference of biomass fineness was between *Miscanthus* biomass harvested in autumn and chopped and biomass harvested in spring and chopped. Particles larger than 2 mm accounted for only 2.69 ± 0.91% in the biomass prepared in Germany (1st treatment); however, similar result was achieved in Lithuania, only when biomass was harvested in autumn, chopped, dried up and milled using a miller "Retsch SM 200" (4th treatment). In German feedstock dust accounted for 38.4 ± 7.11%, in Lithuanian feedstock dust content was almost three times as low – 14.01 ± 1.38% in the treatment where biomass was harvested in autumn, chopped, dried and milled. In other treatments there was almost no dust at all.

It is difficult to explain the significance of milling quality and particle size to the synthetic fuel production, quality or characteristics. Milling quality can be compared by the evaluation of fractional composition of milled biomass. Research evidence suggests that plant mass should be milled into particles smaller than 2–3 mm, 5 mm and bigger particles should make up not more than 5% and dust (smaller than 0.3 mm particles) should make up not more than 10–15% (Cheng, Timilsina, 2011; Yousuf, 2012). Our study showed too high content of dust (38.4%) in the feedstock from Germany, in Lithuanian samples dust content did not exceed the requirements and was below 15%.

Table 5. Influence of biomass preparation method on fineness (mill fractional composition) of biomass

Treatment	Fractional composition g and %					
	ø 2 mm	ø 1.25 mm	ø 1 mm	ø 0.5 mm	ø 0.3 mm	dust
1	1.62 ± 0.54 g	0.35 ± 0.13 g	1.48 ± 0.94 g	19.55 ± 4.38 g	13.97 ± 1.44 g	23.03 ± 4.30 g
	2.69 ± 0.91%	0.59 ± 0.29%	2.46 ± 0.71%	32.6 ± 7.32%	23.3 ± 2.31%	38.4 ± 7.11%
2	58.5 ± 1.43 g	0.60 ± 0.15 g	0.34 ± 0.14 g	0.47 ± 0.11 g	0.05 ± 0.01 g	0.02 ± 0.01 g
	97.5 ± 2.39%	1.0 ± 0.26%	0.57 ± 0.08%	0.79 ± 0.18%	0.08 ± 0.02%	0.03 ± 0.01%
3	58.5 ± 1.24 g	0.38 ± 0.17 g	0.48 ± 0.14 g	0.54 ± 0.20 g	0.09 ± 0.03 g	0.03 ± 0.02 g
	98.2 ± 3.17%	0.46 ± 0.14%	0.47 ± 0.07%	0.73 ± 0.25%	0.14 ± 0.05%	0.04 ± 0.01%
4	0.17 ± 0.04 g	0.88 ± 0.32 g	7.59 ± 2.62 g	31.4 ± 7.95 g	11.52 ± 2.71 g	8.41 ± 0.83 g
	0.28 ± 0.08%	1.46 ± 0.27%	12.65 ± 2.71%	52.4 ± 13.27%	19.21 ± 4.51%	14.01 ± 1.38%
5	57.8 ± 1.49 g	0.79 ± 0.03 g	0.56 ± 0.17 g	0.64 ± 0.24 g	0.14 ± 0.03 g	0.04 ± 0.01 g
	96.4 ± 1.04%	1.33 ± 0.04%	0.95 ± 0.29%	1.09 ± 0.15%	0.23 ± 0.08%	0.06 ± 0.02%

Energy consumption and efficiency. It was found that chopping of *Miscanthus* biomass harvested in autumn (2nd treatment) or harvested in spring (5th treatment) affected the efficiency and energy consumption of the drum chopper "Maral 125". The research data show that in spring-harvested biomass the energy used to chop *Miscanthus* is higher and productivity lower (Table 6). At a feeding load of 1.5 kg of *Miscanthus* biomass into the chopper, the difference in chopping efficiency between autumn and spring-harvested biomass was 4.4% and at 4.5 kg feeding load it was 14.7%.

Table 6. Labour efficiency and energy consumption of drum chopper "Maral 125"

Indicator and test conditions (biomass samples fed into the chopper)		Autumn-harvested biomass, 2nd treatment	Spring-harvested biomass, 5th treatment
Labour efficiency t h^{-1}	1.5 kg	0.90 ± 0.01	0.0054 ± 0.0016
	3 kg	1.30 ± 0.37	0.0118 ± 0.0037
	4.5 kg	1.97 ± 0.62	0.0166 ± 0.0044
Difference in labour efficiency between 5th and 2nd treatments %	1.5 kg	–	−4.4
	3 kg	–	−3.9
	4.5 kg	–	−14.7
Energy consumption kWh	15 kg	0.86 ± 0.32	0.0071 ± 0.0026
	3 kg	1.25 ± 0.37	0.0134 ± 0.0020
	4.5 kg	1.68 ± 0.45	0.0228 ± 0.0089
Difference in energy consumption between 5th and 2nd treatments %	1.5 kg	–	+31.5
	3 kg	–	+13.6
	4.5 kg	–	+37.4

Energy consumption for chopping of *Miscanthus* biomass harvested in spring (5th treatment) at 1.5 kg of feeding load was 31.5% greater and 37.4% greater at 4.5 kg feeding load compared with the biomass harvested in autumn (2nd treatment). We found that increasing sample weight from 1.5 to 4.5 kg, or three-fold, energy consumption used to chop it is increased by more than three times. It was found that the weight of chopped and dried *Miscanthus* biomass samples had an impact on the mill's efficiency and energy consumption (Table 7). When the mass of the *Miscanthus* supplied to the mill is increased from 25 to 75 g, the energy consumption used to mill it increased approximately twice and efficiency of the mill more than three times.

Table 7. Mill "Retsch SM 200" efficiency and energy consumption for milling of *Miscanthus* biomass

Indicator and test conditions (biomass samples fed into the mill)		Biomass, 4th treatment
Labour efficiency kg h^{-1}	25 g	2.9 ± 0.6
	50 g	5.6 ± 0.8
	75 g	8.9 ± 1.1
Increase in efficiency %, when the mill supply increased 3 times		307
Energy consumption Wh	25 g	1.5 ± 0.3
	50 g	2.6 ± 0.7
	75 g	2.9 ± 0.5
Increase in energy consumption %, when the mill supply increased 3 times		193

Evaluation of possibilities of Miscanthus biomass use for production of diesel fuel. Aiming to determine the possibilities to utilise the dried and properly prepared *Miscanthus* biomass for diesel fuel production as well as to determine the properties of synthesised fuel, biomass prepared in Germany was supplied as feedstock for the process of biomass liquefaction (liquid hydrocarbons production) by applying the CPD process. First trials were made seeking to prove that *Miscanthus* biomass could be effectively transformed into biofuel which meets the standard requirements and could be used in diesel engines. Test results of physical and chemical properties of liquid product produced from the *Miscanthus* biomass prepared in Germany and the requirements of standards for mineral diesel fuel LST EN 590 and standards for biodiesel LST EN 14214 are provided in Table 8.

For a more complex comparison of the composition of synthetic diesel fuel produced from *Miscantus* biomass with that of fossil diesel fuel, a Fourier transformation infrared spectroscopic analysis of both products was performed. The results are shown in Figure 2.

Table 8. Physical and chemical parameters of synthetic fuel and their compliance with the requirements of LST EN 590 and LST EN 14214 standards

Parameter	Requirements of LST EN 590		Requirements of LST EN 14214		Determined value
	min.	max.	min.	max.	
Density at 15°C kg m^{-3}	820	845	860	900	830
Viscosity at 40°C mm^2 s^{-1}	2.00	4.50	3.5	5.0	2.2
Acid value mg KOH g^{-1}	–	–	–	0.5	0.53
Iodine value g J_2 100 g^{-1}	–	–	–	120	19.2
Sulphur content mg kg^{-1}	–	10	–	10	98
Water content mg kg^{-1}	–	200	–	500	120
Flashpoint °C	~55	–	120	–	61
Ignition temperature °C	–	–	–	–	64
Pour point °C	–	−22 (arctic class 4)	–	–	−24
Cold filter plugging point °C	–	−44 (arctic class 4)	–	−44 (arctic class 4)	<−45

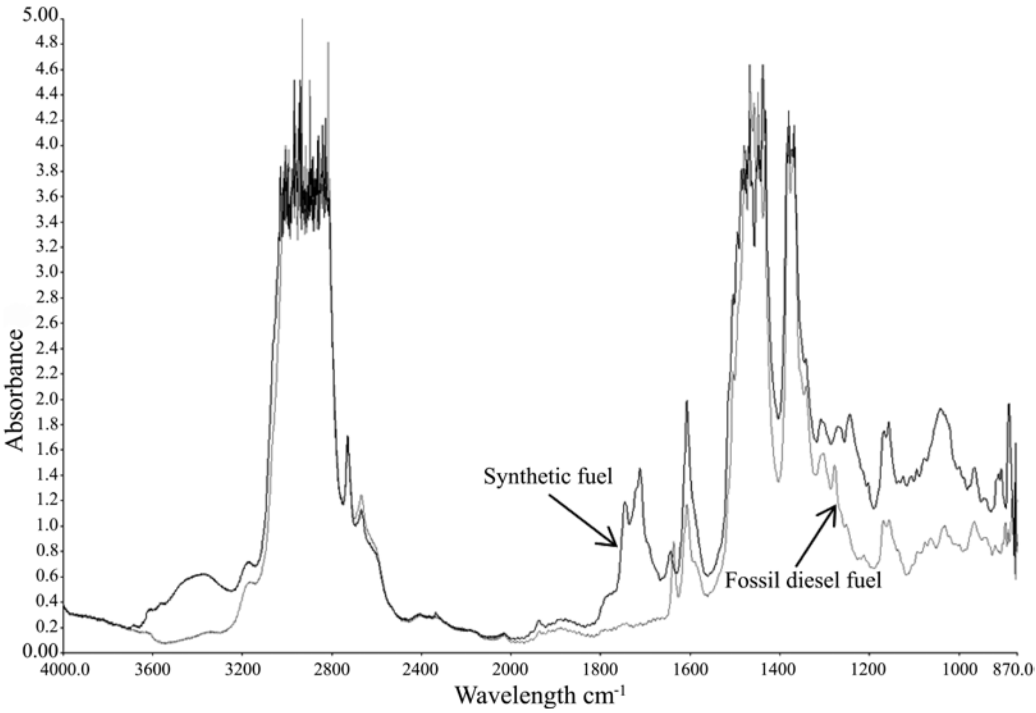

Figure 2. Fourier transformation infrared (FTIR) spectroscopy analysis of spectra of synthetic and fossil diesel fuel

Summarizing the results we can state that synthetic fuel is similar to fossil diesel fuel and meets the requirements of standard LST EN 590 for mineral diesel in respect to the properties that were analyzed. Synthetic fuel is flammable: flash point and ignition temperature are relatively low. The new fuel is characterised by very good low-temperature properties which are better than those of the arctic class 4 mineral diesel. Acidity of synthetic fuel is slightly above the maximum value specified in the biodiesel standard LST EN 14214; this indicates that fuel contains carboxylic acids, which can cause engine corrosion. Iodine value shows that the synthetic fuel contains a small amount (5–7%) of unsaturated hydrocarbons, as confirmed by the FTIR spectrum (3020–3080 cm^{-1} absorption area). Comparative spectral analysis demonstrates that in terms of composition, synthetic fuel is very similar to mineral diesel. Only a few parts of the spectrum have specific absorption areas not observed in the spectrum of fossil diesel fuel. Absorption area of 1600–1800 cm^{-1} indicates that the product may contain aldehydes, ketones and carboxylic acids, and their presence is confirmed by acidity measurements.

Our first experiments on fuel synthesis from *Miscanthus* biomass and analysis of fuel properties proved that *Miscanthus* biomass could be effectively used for synthetic fuel production. Further experiments need to be performed for the evaluation of the influence of biomass preparation methods and quality of prepared *Miscanthus* biomass on quantitative and qualitative parameters of synthetic fuel. It is necessary aiming to optimise the CPD process and to select the most effective biomass preparation methods for the production of synthetic fuel with the highest quality. In order to use such fuel in the transport sector, it is also necessary to carry out detailed tests on diesel engine operation and to analyse harmful components in the engine emissions.

Conclusions

1. *Miscanthus* can be expected to produce a promising biomass yield for growing for bioenergy purposes in Lithuania. Nitrogen fertilizer increased biomass yield of *Miscanthus*; however, delaying harvest until spring resulted in significant dry matter yield losses. Harvesting timing can be an important tool to ensure suitable biomass composition for conversion process and efficient production of energy.

2. *Miscanthus* harvesting time affects physico-mechanical properties of the biomass prepared for synthetic diesel production, machine use efficiency and energy consumption. The energy use for autumn-harvested biomass chopping was lower and the chopper efficiency was higher compared with spring- harvested biomass.

3. While preparing biomass as feedstock for synthetic diesel the greatest reduction in moisture content (to 8.59 ± 1.38%) occurred when *Miscanthus* biomass was chopped, pre-dried and milled, and particles larger than 2 mm accounted for the largest share.

4. Chemical assays and Fourier transformation infrared spectroscopic analysis were performed to compare in a more complex way the composition of liquid synthetic fuel produced from *Miscantus* biomass with that of fossil diesel fuel. The results of analyses demonstrate that in terms of composition, synthetic fuel is very similar to fossil diesel fuel.

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Miskantų biomasės kokybinė sudėtis ir žaliavos paruošimo konversijai į sintetinį dyzeliną metodai

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Santrauka

Plėtojant įvairias biomasės konvertavimo į biodegalus technologijas, yra svarbu nustatyti žaliavos tinkamumą tokių celiuliozinių augalų kaip miskantai, kurių biomasė turi gerą energinį potencialą ir jie nėra mitybiniai augalai. Didelės reikšmės turi tokių mažiau tyrinėtų ir rečiau auginamų augalų biomasės produktyvumas, kokybė ir jos tinkamumas perdirbti šiauresnio klimato sąlygomis. Eksperimentai atlikti siekiant įvertinti miskantų auginimo, derliaus nuėmimo ir perdirbimo į sintetinį dyzeliną kokybinius bei technologinius rodiklius, chemines, fizines bei mechanines biomasės savybes ir nustatyti energijos sunaudojimo kiekį, reikalingą biomasę ruošiant perdirbti į sintetinį dyzeliną. Objektas – miskantų (*Miscanthus* × *gigant*eus Greef et Deu), užaugintų Lietuvos klimato zonoje (analizuota išsamiau), ir miskantų, užaugintų Vokietijos klimato zonoje, biomasė. Gautas iki 9,42 t ha^{-1} miskantų sausųjų medžiagų (s. m.) rudeninis derlius, ir jie buvo esmingai derlingesni patręšus didesne norma azoto. Celiuliozės (413–456 g kg^{-1} s. m.) ir hemiceliuliozės (204–236 g kg^{-1} s. m.) kiekiai buvo labai panašūs esant visiems tręšimo lygiams, o didžiausias kiekis lignino nustatytas biomasėje, kai tręšta 120 kg ha^{-1} N – 117 g kg^{-1} s. m. Pavasarį miskantų biomasėje buvo žymiai mažesnis kiekis drėgmės, bet derlius taip pat buvo gerokai mažesnis. Biomasę ruošiant kaip žaliavą sintetiniam dyzelinui, drėgnumas labiausiai sumažėjo (iki 8,59 ± 1,38 %), kai miskantų biomasė buvo susmulkinta, iš anksto išdžiovinta bei sumalta ir buvo daugiausia didesnių nei 2 mm dalelių. Kapojant rudenį nuimtą biomasę energijos sunaudojimas buvo mažesnis, o kapojimo proceso efektyvumas buvo didesnis, palyginti su biomasės, nuimtos ankstyvą pavasarį, apdorojimu. Nustatyta, kad sintetinio kuro iš miskantų biomasės pagrindinių komponentų sudėtis yra labai panaši į mineralinio dyzelino.

Reikšminiai žodžiai: biomasė, fizinės ir mechaninės savybės, miskantai, nuėmimo laikas, sintetinis dyzelinas.