HEAT OF WINTER CEREAL CROPS

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Abstract
Heat is one of the most important types of energy at northern latitudes. In 2013 the total consumption of renewable energy resources (RER) in Latvia was 68 PJ. The heating systems can function on plant or other organic material, for example, wood chips or agricultural residues. By using local biomass resources it is possible to reduce the pollution of atmosphere caused by greenhouse gas emissions. Different variety of winter wheat (*Triticum aestivum*), triticale (*Triticosecale*) and rye (*Secale cereale*) were used in the research. The following aspects were determined during the research: dry matter yield, chemical composition and the higher heating value of grains and straw. The evaluation of grains and straw of winter cereals showed that the higher heating value (MJ kg^{-1}) was acquired from the straw of winter cereals, whereas the grains had the highest dry matter yield, thus the grains of winter cereals had the highest heating yield from one hectare (GJ ha^{-1}).
Key words: winter cereals, grain, straw, chemical composition, heating value.

Introduction

Heat is acquired from coal, gas, wood as well as from plant biomass – straw, grass, grains. The natural renewal process of fossil energy resources (coal, gas) takes a very long time whereas the plant biomass that accumulates solar energy, renews itself every year. Photosynthesis results in the production of structural and non-structural carbohydrates in the plant tissues. The components of biomass include cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starches, water, hydrocarbon ash, and other compounds (Jenkins et al., 1998).

According to the data of Central Statistical Bureau (CSB), in 2013 the total consumption of renewable energy resources (RER) in Latvia was 68 PJ. In comparison to year 2012 the RER consumption had decreased by 2.5%. It is related to the decrease of energy production in hydroelectric power stations. According to the data of CSB, the main types of RER in Latvia are firewood and hydro resources, in 2013 reaching 34.2% of the total energy consumption. Wind energy, biogas, biofuel, straw and other types of biomass were used to a smaller extent.

However, according to different scenarios the share of oil and natural gas in heating will not diminish. The use of biomass in heating systems makes up only a small part of the total amount of different resources (Barkāns, 2001). In order to produce heat, plant or other organic matter, for example, wood chips and agricultural residues can be used. Fossil fuels (gas, oil products, coal) can be replaced by local biomass resources. By using local biomass resources it is possible to reduce the pollution of atmosphere caused by greenhouse gas emissions, the consumer does not suffer from the fluctuating prices of fossil fuels and new jobs are created or the old ones are maintained in order to ensure the growing, processing and transportation of the raw materials (Biomass Heating .., 2005). Grains that are not suitable for food or fodder can be used in heating. They can be a high-value heating fuel. For the heating purposes a high-quality biomass needs: high yield; low ash content; low humidity level; high heating value; high bulk density (Fuel supply handbook .., 2010). Grains are like nature-made pellets. Straw can be used in heating either by being transformed into pellets or pressed into bales or coils.

The purpose of the study was to evaluate the suitability of winter cereals for heating, taking into account their yield, chemical composition and heating value.

Materials and Methods

The research was carried out in State Stende Cereal Breeding Institute in years 2009/2010 – 2011/2012. The trial fields were made in loam soil, Stagnic Retisol (Loamic) (World reference base for soil resources 2014) with the following characteristics: pH KCL 5.3–5.8, content of organic matter 19 – 24 g kg^{-1}, content of P_2O_5 readily available for plants 83 – 229 mg kg^{-1}, K_2O content 134 – 181 mg kg^{-1}. There were three rye varieties ('Matador', 'Placido', 'Dankowskie Nowe'), three triticale varieties ('SW Valentino', 'Dinaro', line 0002-26) and three winter wheat varieties ('Mulan', 'Skalmeje' and line 99-115) examined during the research. The field experiments were placed randomly in four replications. The grains were harvested by using a harvester, the grain yield (t ha^{-1}) was determined at 100% purity and 14% humidity after the grains were dried. As regards the straw yield, the samples were gathered from an area of 0.250 m^2 in each replication. The correlation between grains and straw was determined in the laboratory. The straw yield was calculated by using the acquired grain yield and the correlation between the amount of straw and grains.

The following quality indicators were determined from the acquired samples in the Laboratory of Grain Technology and Agrochemistry of State Stende Cereal Breeding Institute: humidity content (according to LVL EN ISO 721:2010), fiber (according to ISO 5498), crude ash (according to LVS 276:2000), N (according to LVS 277:2000), P (according to ISO 6492), K (according to LVS EN ISO 6969), Ca (according to LVS EN ISO 6869). The higher heating value of straw (kJ kg^{-1}) (according to ISO 1928) was determined in the Laboratory for Testing of Wood Chemistry Products at the Latvian State Institute of Wood Chemistry by using oxygen bomb calorimeter “Parr 1341” to manufacturing USA. The lower heating value is calculated by using the following formula (1):

$$Q_z = Q_{as} - 2454\ (W + 9H), \text{ where} \quad (1)$$

Q_z – lower heating value of the fuel weight, kJ kg^{-1}
Q_{as} – higher heating value of the fuel weight, kJ kg^{-1},
2454 – amount of heat necessary for evaporation of water at 20 °C, kJ kg^{-1},
9 – multiplier, as 1 part of hydrogen combines itself with 8 parts of oxygen,
W – humidity content in fuel, %,
H – hydrogen content in fuel, %
Dispersion analysis was used for the mathematical procession of data.

Results and Discussion

Dry matter yield of grains and straw. The dry matter yield from grains and straw of winter cereals was calculated in order to make the acquired data comparable. The average dry matter yield of winter cereals during the three years of research ranged from 7.71 to 8.38 t ha^{-1}. The species and variety of winter cereals as well as meteorological conditions had a significant ($p<0.05$) meaning for the yield formation in the individual years. The dry matter yield of winter wheat grains (7.97–8.36 t ha^{-1}) did not differ significantly among the examined winter wheat variety. As regards triticale during the three years of trial the highest dry matter yield was acquired from the variety ‘Dinaro’ – 8.08 t ha^{-1}. The most productive winter rye variety was ‘Placido’, that during two years of trial provided an average of 8.38 t ha^{-1} (Table 1). The dry matter yield of all cereal species was significantly affected by the meteorological conditions during the cultivation years.

The average dry matter yield that was acquired from straw of winter cereals was lower than the dry matter yield of grains – 6.39–6.81 t ha^{-1} (Table 2). From all the winter wheat varieties the highest dry matter yield was acquired from the straw of line 99–115 (7.63 t ha^{-1}), that had the lowest grain dry matter yield. Similar pattern was observed with rye variety where the highest dry matter yield was acquired from the variety ‘Dankowskie Nowe’ (7.38 t ha^{-1}).

Table 1

Grain dry matter yield, ash, lower and higher heating values, gross heating yield and energy values (2010 – 2012)

Species, variety	Dry matter yield, t ha^{-1}	Ash, g kg^{-1}	Bulk density, g L^{-1}	Lower heating values, MJ kg^{-1}	Higher heating value, MJ kg^{-1}	Higher heating value, GJ ha^{-1}	Energy values, MWh ha^{-1}
Winter wheat							
Skalmeje	8.17	16.0	769.0	14.10	15.99	130.47	36.29
99-115	7.97	16.4	772.8	13.92	15.79	142.33	34.96
Mulan	8.36	16.4	767.3	14.08	15.94	128.43	37.01
Average	8.16	**16.2**	**769.7**	14.03	15.90	133.74	36.08
$LSD_{0.05}$	0.46	0.7	19.3	0.39	0.39	14.43	-
Triticale							
SW Valentino	7.89	19.2	695.1	13.91	16.17	148.94	34.54
Dinaro	**8.08**	18.3	690.6	13.89	16.26	152.61	35.35
0002-26	7.62	18.2	696.7	14.22	**16.54**	146.49	33.99
Average	7.86	**18.6**	**694.1**	14.00	16.32	149.34	34.62
$LSD_{0.05}$	0.47	1.2	7.8	0.37	0.27	20.13	-
Rye							
Placido	**8.38**	15.4	747.1	14.14	15.99	155.83	37.20
Matador	7.41	15.7	745.3	14.14	16.02	137.60	32.98
Dankowskie Nowe	7.34	**16.4**	743.7	14.11	15.97	136.06	32.55
Average	7.71	**15.8**	**745.4**	14.13	15.99	143.16	34.24
$LSD_{0.05}$	0.51	0.6	4.9	0.42	0.37	24.31	-

Table 2

Straw dry matter yield, ash, lower and higher heating values, gross heating yield and energy values (2010 – 2012)

Species, variety	Dry matter yield, t ha^{-1}	Ash, g kg^{-1}	Lower heating values, MJ kg^{-1}	Higher heating value, MJ kg^{-1}	Higher heating yield, GJ ha^{-1}	Energy values, MWh ha^{-1}
Winter wheat						
Skalmeje	5.82	54.6	15.08	16.68	108.42	26.96
99-115	**7.63**	**46.8**	15.02	16.80	**142.33**	35.62
Mulan	6.75	**46.1**	15.40	17.05	128.43	31.93
Average	6.74	**49.1**	15.17	16.84	126.39	31.50
$LDS_{0.05}$	1.54	1.3	0.77	0.80	11.73	-
Triticale						
SW Valentino	6.51	**51.8**	14.99	16.64	124.16	30.12
Dinaro	5.92	49.5	14.75	16.39	108.97	27.19
0002-26	6.76	37.0	15.76	17.39	135.80	32.64
Average	6.39	**46.1**	15.17	16.80	122.98	29.98
$LDS_{0.05}$	1.02	1.3	1.18	1.15	55.13	-
Rye						
Placido	6.36	**49.3**	16.00	17.64	124.74	31.18
Matador	6.69	44.5	15.66	17.30	133.72	32.14
Dankowskie Nowe	**7.38**	44.5	15.65	17.29	145.73	35.45
Average	6.81	**46.1**	15.77	17.41	134.73	32.92

Chemical composition of grains and straw of winter cereals. Ash content in the biomass depends on its chemical composition. The amount of ash and the deposit formation in the heating boilers depend on the chemical elements K, P, Si, Na, S, Cl, Ca, Mg, Fe in the grains (Beidermann et al., 2005). Ash content in the grains of examined winter cereals was 15.4 – 19.2 g kg^{-1}. This amount is similar to the amount for winter cereals analysed in the scientific literature (Lewandowski et al., 2003, Beidermann et al., 2005; Wachendorf, 2008). The ash content of straw was 37.0 – 54.6 g kg^{-1}, which was significantly ($p<0.05$) higher than that of grains. As regards the highest ash content in grains, the highest level was observed in triticale grains: average 18.6 g kg^{-1} (Table 1). According to scientific literature, the ash content of wood biomass is 0.4 – 0.8% (4 – 8 g kg^{-1}) (Obernberg et al., 2004), however, the biomass of willows and poplars contains 1.71 – 2.7 % (17.1 – 27.0 g kg^{-1}) of ash (Jenkins et al., 1998). The ash content of coal is 5 – 20% (50 - 200 g kg^{-1}) depending on its quality (Biomass Energy...s.g.). The European Union member states have adopted standards for production of pellets for heating. One of the indicators is ash content in fuel. It has to be in the range from 0.7 to 1.5% (7 – 15.0 g kg^{-1}) (Garcia-Maraver et al., 2011). In the trial it was observed that the ash content of grains slightly exceeds the EU standards for pellets. The ash content of straw is significantly higher than envisaged in the standards and that encumbers the utilisation of heating boilers. The ash content differed significantly from one examined species to the other and depended on the chemical composition of the material (Table 2).

The quality of the fuel is affected by the chemical composition of the biomass. Biomass proteins contain nitrogen. During combustion it completely transforms into gaseous state. The researchers have observed that the amount of nitrogen correlates with the formation of nitrogen oxide (NO_x). (Wachendorf, 2008; Shcolz et al., 2002). Trials showed that the grains of winter cereals contained from 19.1 to 21.9 g kg^{-1} of nitrogen, but the amount of nitrogen in the straw of winter cereals was significantly lower, namely, 5.4 – 6.4 g kg^{-1} (Table 3). A significantly higher amount of nitrogen in the grains of winter cereals can be explained by higher levels of additional nitrogen fertilisation, that has also been described in the research of other authors (Shcolz et al., 2002). According to the standards of Austria, wooden briquettes and pellets must contain no more than 0.3% (3 g kg^{-1}) of nitrogen. Amount of nitrogen in straw pellets and bark briquettes must not exceed 0.6% (6 g kg^{-1}) (Obernberger et al., 2004). The research data show that the amount of nitrogen in grains of winter cereals is higher, but in straw it is close to the above mentioned standard.

The amount of potassium in biomass has an impact on the corrosion of heating boilers and lowers the melting temperature of ashes which causes slag formation (Shcolz et al., 2002). During the research it was observed that the grains of winter cereals contained from 4.06 to 5.04 g kg^{-1} of potassium, whereas the straw had a higher potassium content,

Table 3

Chemical composition of winter cereal grain and straw, g kg^{-1} (2010 – 2012)

Species	Nitrogen, g kg^{-1}		Phosphorus, g kg^{-1}		Potassium, g kg^{-1}		Calcium, g kg^{-1}		Magnesium, g kg^{-1}	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Winter wheat	21.9	6.0	2.62	**0.6**	**4.06**	**7.55**	0.47	**1.93**	0.96	0.60
Triticale	19.2	**5.4**	2.92	0.7	5.04	8.22	0.40	2.06	0.91	**0.57**
Winter rye	**19.1**	6.4	**2.57**	1.0	4.10	10.70	**0.36**	2.16	**0.73**	0.67
LDS $_{0.05}$	1.3	0.7	0.22	0.23	0.16	1.14	0.09	0.18	0.18	0.19

namely, 7.55 – 10.7 g kg^{-1} (Table 3). The potassium content in dry matter of forestry residues, fast-growing willows is lower than the one observed in the samples of cereals grains and straw (Beidermann et al., 2005).

No negative impact of phosphorus on the emission during the combustion has been observed, however, a high amount of phosphorus affects the melting temperature of ashes (Shcolz et al., 2002). The winter cereal grains contained 2.57 – 2.92 g kg^{-1} of phosphorus, while the winter cereal straw had 0.6 – 1.0 g kg^{-1} (Table 3). The wood contains less phosphorus than the grains of winter cereals (Wachendorf, 2008). It has to be noted that by fertilising the fields with ashes, potassium and phosphorus are returned to the soil.

Calcium and magnesium raises the melting temperature of ashes (Beidermann, et al., 2005). The winter cereal grains contained a smaller amount of calcium (0.36 – 0.47 g kg^{-1}), but the calcium content in straw ranged from 1.93 to 2.16 g kg^{-1}. The amount of magnesium in grains was 0.96 g kg^{-1}, but in straw up to 0.67 g kg^{-1} (Table 3). Amount of calcium and magnesium in wood is smaller than in straw and grains of winter cereals (Wachendorf, 2008).

An important indicator in the choice of fuel is fuel density or bulk density, as it affects the transportation and storage of the fuel. According to the standards elaborated in Sweden, the density of SS 187120 pellets for heating has to be from 600 kg m^3 (Obernberg et al., 2004, Garcia-Maraver et al., 2011). Density-wise the grain are similar to coal, their density is approximately 700 – 850 kg m^3 (Biomass Energy...s.g.). According to the research data, the bulk density of winter cereal grains ranges from 690.6 to 772.8 kg m^3. Looking at different species, winter wheat had the highest bulk density of grains, it was followed by rye and triticale (Table 1). No significant differences among the species were observed. The density of straw was not determined during the research.

Heating value is one of the most important indicators of heating quality. Higher heating value is energy amount per unit mass or volume released on complete combustion (Fuel supply handbook .., 2010). According to the data collected during the three years of trial, triticale grains had a significantly (p<0) higher heating value (MJ kg^{-1}) – 16.32 MJ kg^{-1}. The higher heating value of straw of the observed species, however, ranged from 16.81 to 17.41 MJ kg^{-1}, with no significant differences among species (Table 2). Similar data have been mentioned in the scientific literature (Wachendorf, 2008).

No significan substantial diferences in the higher heating value were observed among the investigated species. According to the data of European Association of Biomass Industry (European Biomass, s.g.), the higher heating value of coal ranges from 20 to 30 MJ kg^{-1}, that of wood – from 18 to 19 MJ kg^{-1}, and that of agricultural residues – from 15 to 17 MJ kg^{-1}. According to the data of Austrian researchers, the higher heating value of cereal grains was 18.61 MJ kg^{-1} (Friedel et al., 2005). Research data let us observe that, taking into account the heating value, the grains and straw of winter cereals are just as valuable fuel material as wood and other agricultural residues. Data of this research show a slightly smaller higher heating value than the one observed in the research of other authors.

Grains and straw contain a certain amount of humidity that affects their lower heating value. The lower heating value is amount of heat contained by a fuel unit and released when drying or burning the raw material. Thus, raw materials with a higher humidity content diminish the lower heating value (Fuel Supply Handbook, 2010). On average, the humidity of grains examined during the resarch was 10 – 11%, but the humidity of straw was 7 – 9%. Depending on the intended use the grains were dried after harvest, but the humidity content of straw was affected by the weather conditions during the harvest. The grain and straw samples of the examined species and variety did not differ significantly as regards the lower heating value. The average lower heating value of winter cereal grains for variety examined in the research was 13.89 – 14.14 MJ kg^{-1}, while the lower heating value of straw was 14.75 – 16.00 MJ kg^{-1}.

Energy value. An important indicator for heating isthe energy value. The energy acquired from the grains of winter cereals ranged from 34.24 to 36.08 MWh ha^{-1} (Table 1). According to the scientific literature, similar results were acquired in Germany (Nagel, 2000.). The energy acquired from the straw of winter cereals was slightly lower than that of grains, namely, 29.98 – 32.92 MWh ha^{-1} (Table 2). It was observed that neither for grains nor for the straw of winter cereals the energy value was affected by the choice of species or variety.

Conclusions

1. Having examined the grains and straw of winter cereals for their higher heating value (MJ kg^{-1}), the highest amounts were acquired from the **straw** of winter cereals, while the grains had a higher dry matter yield than straw, thus, the **grains** of winter cereals had a higher heating yield from one hectare (GJ ha^{-1}). From all the species the highest heating value both from mass unit and hectare (MJ kg^{-1}, GJ ha^{-1}) was acquired from **triticale** grains. As regards straw, the best results were acquired from the **rye**.
2. The highest energy value from one hectare was acquired from the winter cereal **grains**, it was slightly lower for the **straw** of the winter cereals which can be explained by the fact that straw has lower dry matter yield.
3. As regards the chemical composition of winter cereals, **rye** provided the most suitable grains for heating. The rye grains had the lowest ash, nitrogen, potassium and magnesium content. There were no significant differences in ash content of straw among species while, as regards the chemical composition, **wheat** and **triticale** straw were most suitable for heating.

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