CEREAL GRAIN AS ALTERNATIVE FUEL IN LATVIA

Inga Jansone[1;2], **Zinta Gaile**[2]
[1]State Stende Cereals Breeding Institute,
[2]Institute of Agrobiotechnology, Latvia University of Agriculture
inga.jansone@e-apollo.lv

Abstract
Thermal energy is one of the most important energy types in Latvia. Thermal energy is acquired from coal, gas, wood as well as plant biomass – straw, grass, grain. Low quality grain which is not suitable for the use in either food or feed production could be used for heating. Technologically, the grain is suitable for the heating systems with automatic fuel feed. During the field trial that took place in State Stende Cereals Breeding Institute in years 2009/2010 and 2010/2011, the possibility of using grain of winter wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.) and triticale (*Triticosecale* Wittm) in heating was examined. The content of C, O, and H of the grain was determined as well as the content of fibre, ash, phosphorus, potassium, and calcium. The grain yield was determined at the humidity of 14%. The higher heating value of grain (kJ kg^{-1}) was also determined, whereas while the lower heating value was calculated. Out of all the examined species of winter cereals the winter wheat was the most suitable for heating, taking into account its grain yield, heating values and ash content. Having examined the chemical composition of the dry matter of winter cereal grain, it was determined that it has a higher amount of phosphorus and potassium than the wood as mentioned in relevant scientific sources. These chemical elements negatively affect the ash melting temperature due to which the slag is formed in the heating boilers.
Key words: grain yield, higher and lower heating values, chemical composition, ash.

Introduction

It is important for Latvia to ensure an independent energy system. One of the most significant energy types in our latitude is thermal energy. Thermal energy can be acquired from coal, gas, wood as well as plant biomass — straw, grass, grain. It takes a long time for the fossil fuel resources (coal, gas) to replenish, while this process happens much faster for the plant biomass that renews every year by accumulating solar energy. The main characteristics of high-quality biomass are high biomass yield, low ash content, low humidity level and good combustibility. Due to the unpredictable weather conditions in Latvia there are certain years when the harvested grains cannot be used for either food or feed production (for example, because the grains have sprouted before harvesting, they are polluted with mycotoxines excreted by *Fusarium* etc. or because of other similar reasons). Grain that cannot be used for either food or feed is one type of biomass that could be used for heating. The choice of energy plants in a certain agricultural territory is determined by species and the technical facilities for cultivation. The energy plants have to be suitable for the climate of the territory, they have to fit into the rotation of crops in the farm and their yield level has to be appropriate. The most suitable energy plants are those that use the solar energy most efficiently, that need the least amount of chemical fertilisers and that have low humidity content at the time of the harvest (Venturi, Venturi, 2003). Technologically, the cultivation of cereals has been developed to a very good level, and grains are suitable for heating systems with automatic fuel feed.

The objective of the trial was to evaluate the possibility of using the grain of winter wheat (*Triticum aestivum* L.), rye (*Secale cereale* L) and triticale (*Triticosecale* Wittm) for heating.

Materials and Methods

Field trial

The field trial was carried out in the State Stende Cereals Breeding Institute in the autumn of 2009 and 2010. The conditions of soil were averagely suitable for growing winter cereals due to slightly diminished reaction of soil (Table 1).

Both years the white mustard was grown as a previous crop in the trial site. It was used as a green manure, and it was chopped and worked into the soil when the soil was ploughed in the autumn. The sowing rate was 450 germinating seeds per 1 m^2 for winter wheat, 400 germinating seeds per 1 m^2 for population rye (‘Matador’, ‘Dankowskie Nowe’) and triticale, and 200 germinating seeds per 1 m^2 for hybrid rye (‘Placido’). The sowing was carried out on 18 September 2009 and on 14 September 2010. Complex fertiliser was used as a basic fertiliser, ensuring the total amount of 12-15 kg N ha^{-1}, 45-60 kg P_2O_5 ha^{-1} and 60-90 kg K_2O ha^{-1} in the autumn depending on the year.

For top-dressing, ammonium nitrate (N 34%) was used in the spring of each year:

- upon the renewal of vegetation process:
    - for winter wheat – 90 kg N ha^{-1};
    - for triticale and rye – 60 kg N ha^{-1};
- during the GS 31-32 of plant development for all examined species of winter cereals – 60 kg N ha^{-1}.

Table 1

Soil characteristics at the site of field trial

Year of trial	Soil	Granulometric composition of soil	pH KCL	Content of organic substance, g kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}
2009/2010	Podzolic soils Pv	sM	5.8	24	229	181
2010/2011	Podzolic-gley soils PG	sM	5.8	23	187	134

Source: made by authors

Both years the winter cereals were harvested with the experimental harvester WINTERSTEIGER DELTA (on 8 August 2010 and 4 August 2011). The harvester is equipped with weights and grain humidity meter for evaluation of the harvest. After the samples were dried on the platform driers, the grains were cleaned using the facility MINI PETKUS MP100. The harvest of winter cereals was recalculated in t ha^{-1} at the 14 % humidity and 100% purity.

Methods of chemical analysis

The following indicators – fibre (according to ISO 5498), crude ash (according to LVS 276:2000), P content (according to ISO 6492), K content (according to LVS EN ISO 6969), and Ca content (according to LVS EN ISO 6869) – were determined with appropriate standard methods at Laboratory of grain technology and agrochemical research of State Stende Cereals Breeding Institute. The content of C, O, and H was determined by using *Macro Elemental Analyzer-vario* MACRO CHNS (according to LVS CEN/TS 1504:2005). The higher heating value of grain (kJ kg^{-1}) (according to ISO 1928) was determined by using the oxygen bomb calorimeter "Parr 1341", but the lower heating value - by making calculations with the formula (1) in the Laboratory for test of Wood Chemistry Products at Latvian State Institute of Wood Chemistry:

$$Q_z = Q_a - 25(9H+W) \quad (1)$$

where

- Q_z – the higher heating value of the fuel weight, kJ kg^{-1};
- Q_a – the lower heating value of the fuel weight, kJ kg^{-1};
- 25 – the amount of heat needed for the evaporation of water, kJ kg^{-1};
- H – the amount of hydrogen in the solid fuel, % ;
- W – the amount of humidity in the solid fuel, % (Nagla et al., 1982).

Knowing the amount of grain yield and the amount of energy in MWh which can be obtained from 1 t of grains, the energetic value of the higher heating value in MWh as obtained from 1 ha was calculated. The mathematical processing of data was carried out by using the analysis of variance.

Results and Discussion

Grain that are not used for food or feed production can be used as a high-quality fuel. The biomass is considered to be of high-quality for heating purposes, if it corresponds to the following criteria: high yield; low ash content; low humidity content; higher heating values; high volume weight (Fuel supply handbook .., 2010).

The average grain yield for all the species of winter cereals, taking into account both years of cultivation, was 8.08 to 8.89 t ha^{-1} at 14% humidity. There was a difference in productivity of various species and varieties of winter cereals (Table 2), and a substantial ($p<0.05$) influence of meteorological conditions for crop formation was noted each year. The level of grain yield (8.83 – 8.99 t ha^{-1}) (Table 2) for the examined winter wheat varieties was very similar ($p>0.05$). For triticale the highest average yield ($p<0.05$) during two years of trial was provided by variety 'Dinaro' – 8.93 t ha^{-1}, while the highest yield during the entire trial period was provided by winter rye variety 'Placido' with the average yield of 9.24 t ha^{-1} (Table 2). The yield of all winter cereal species was substantially affected by the weather conditions during the trial years.

One of the most important indicators of fuel quality is heating value. The higher heating value is the amount of heat one fuel unit provides when it is fully burnt (Fuel supply handbook .., 2010). The net calorific value depends on the humidity content of the fuel (in this case – grain). Winter wheat and rye reached the highest level of the higher heating value – on the average 16084 and 16104 kJ kg^{-1} respectively (Table 2). According to the data acquired during two years of the trial it was slightly lower for triticale - 15975 kJ kg^{-1}(Table 2). Similar data are mentioned in the literature (Wachendorf, 2008). No substantial differences in higher heating values were observed among the examined species. According to the data

Table 2

Average grain yield, higher and lower heating value of winter cereals

Species, variety	Grain yield, t ha^{-1}	Higher heating value, kJ kg^{-1}	Lower heating value, kJ kg^{-1}
Winter wheat			
Skalmeje	8.83	16185	14258
99-115	8.84	16003	14085
Mulan	8.99	16065	14145
Average	8.89	16084	14162
RS/LSD $_{0.05}$	0.66	938	893
Triticale			
Valentino	8.24	15890	14008
Dinaro	**8.93**	15921	14006
0002-26	8.20	16114	14206
Average	8.46	15975	14073
RS/LSD $_{0.05}$	0.66	572	636
Winter rye			
Placido	**9.24**	16089	14195
Matador	7.53	16128	14194
Danskovij Nova	7.46	16095	14168
Average	8.08	16104	14186
RS/LSD $_{0.05}$	0.33	990	1124

Source: made by authors

of European Biomass Industry Association (European Biomass..., s.a.), the higher heating value of coal ranges from 20 to 30 GJ t^{-1}, of wood – from 18 to 19 GJ t^{-1}, while that of waste matter of agricultural products – from 15 to 17 GJ t^{-1}. According to the data acquired by Austrian researchers, the average higher heating value for grain of all cereals was 18610 kJ kg^{-1} (Friedel et al., 2005). According to the data of our research, the higher heating value of grain is lower than the one acquired by other researchers.

The chemical composition of biomass affects the quality of the fuel. The protein of biomass contains nitrogen. In the combustion process it completely transforms into a gas. The researchers have found that there is a correlation between the amount of nitrogen and the formation of nitric oxides - NO_x (Wachendorf, 2008, Shcolz, Ellerbrock, 2002). In our research, the amount of nitrogen in the grain of the examined winter cereals was in the range from 20.4 to 22.6 g kg^{-1} (Table 3) (2.04 – 2.26%). A substantially higher ($p<0.05$) amount of nitrogen in the winter wheat can be explained by a higher amount of used nitrogen fertiliser as it is also described in the research of other authors (Shcolz, Ellerbrock, 2002). According to the standards of Austria, the wood briquettes and granules should contain less than 0.3% of nitrogen. The amount of nitrogen in straw granules and bark briquettes has to be less than 0.6% (Obernberger, Thek, 2004). The research data shows that the grain of winter cereals contains a significantly higher amount of nitrogen.

The potassium in the biomass fuel causes corrosion of the heating boilers and lowers the ash melting temperature, resulting in slag formation (Shcolz, Ellerbrock, 2002). During the research it was found that the amount of potassium in the grains of winter cereals ranges from 3.92 g kg^{-1} (0.39%) to 5.08 g kg^{-1} (0.51%) (Table 3). The potassium amount in the forestry waste matter and dry matter of fast growing willow is lower – from 0.015 to 0.03% (1.5-3.0 mg kg^{-1}) (Beidermann, Obernberger, 2005). Phosphorus has not been found to negatively affect the emissions during the combustion process; however, elevated amount of phosphorus lowers the ash melting temperature (Shcolz, Ellerbrock, 2002). Our research the phosphorus content in the grain of winter cereals ranged from 2.52 to 2.98 g kg^{-1} (0.25 – 0.29%) (Table 3). There are data in the literature that amount of phosphorus is lower in wood than in grains of winter cereals, namely 0.03 – 0.10% (Wachendorf, 2008). It has to be noted that potassium and phosphorus is returned to soil when the ash is used for fertilisation of fields.

Calcium and magnesium increases the ash melting temperature (Beidermann, Obernberger, 2005). In our research, the amount of calcium in the grain of winter cereals was 0.37-0.48 g kg^{-1} (0.037-0.048%),

Table 3

Average grain chemical composition of winter cereals from the two-year trial period, g kg^{-1}

Species	N	P	K	Ca	Mg
Winter wheat	22.6	2.52	3.92	0.48	0.96
Triticale	20.4	2.98	5.08	0.43	0.83
Winter rye	20.9	2.78	4.06	0.37	0.55

Source: made by authors

Table 4

Grain ash and fibre content, and volume weight of winter cereals

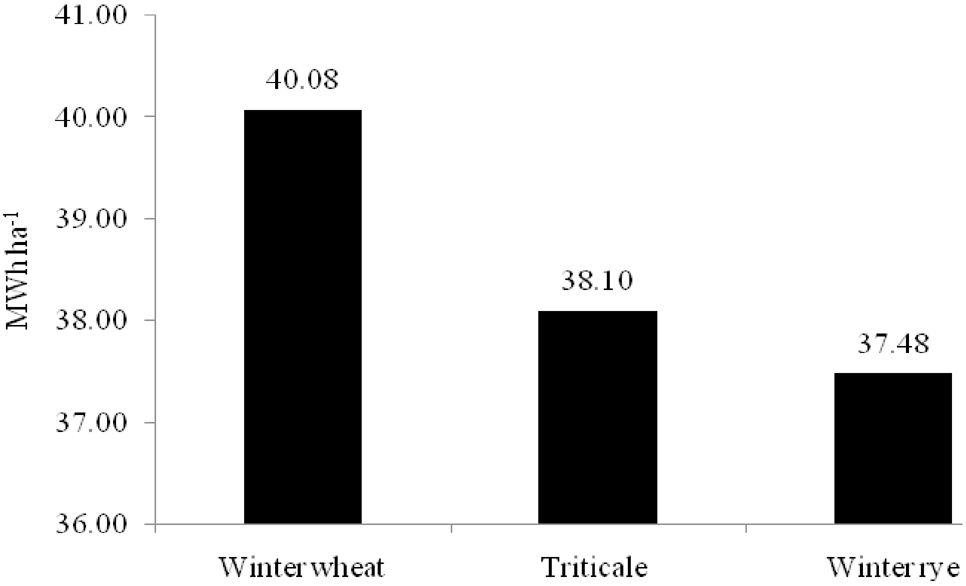
Species, variety	Ash, g kg^{-1}	Fibre, g kg^{-1}	Volume weight, kg m^{-3}
Winter wheat			
Skalmeje	16.20	25.38	771.0
line 99-115	16.48	28.75	778.3
Mulan	16.27	28.43	774.9
Average	**16.31**	**27.52**	**774.7**
RS/LSD $_{0.05}$	**0.29**	**1.32**	**11.19**
Triticale			
SW Valentino	19.87	27.43	683.5
Dinaro	18.63	24.91	688.9
line 0002-26	18.43	25.25	687.8
Average	**18.98**	**25.86**	**686.7**
RS/LSD $_{0.05}$	**1.16**	**1.15**	**7.19**
Winter rye			
Placido	15.70	21.73	732.1
Matador	16.23	22.86	725.6
Danskovij Nova	17.30	20.53	724.3
Average	**16.41**	**21.71**	**727.3**
RS/LSD $_{0.05}$	**0.73**	**2.36**	**4.63**

Source: made by authors

and the amount of magnesium was 0.55-0.96 g kg^{-1} (0.06-0.10%) (Table 3). The wood biomass contains more calcium (0.29 – 0.70%), while the amount of magnesium is lower (0.04 – 0.08%) (Wachendorf, 2008).

The ash content in biomass depends on its chemical composition. The chemical elements K, P, Si, Na, S, Cl, Ca, Mg, and Fe that are found in the grain, affect the ash content and the slag formation in the heating boilers (Beidermann, Obernberger, 2005). We determined that the ash content in the grain of winter cereals was 16.31 – 18.98 g kg $^{-1}$ (1.63- 1.89%). This indicator is similar to the results of other researchers obtained in trials with winter cereals (Lewandowski, et al. 2003; Beidermann, Obernberger, 2005; Wachendorf, 2008). The highest amount of ash content was found in the grain of triticale: 18.98 g kg $^{-1}$ (1.89%) on average. The ash content in the grain of winter wheat and rye was 16.31 and 16.41 g kg $^{-1}$ respectively (1.63-1.64%) (Table 4).

According to the data found in the scientific literature the ash content of wood biomass is 0.4-0.8% (Obernberg, Thek, 2004); however, the biomass of willows and poplars contains 1.71-2.7% ash (Jenkins et al., 1998). The ash content of coal is 5 – 20%, depending on its quality (Biomass Energy..., s.a.). The European Union member states have elaborated standards for production of granules for heating. One of the indicators is the ash content of fuel. It has to be 0.7 – 1.5% (Garcia-Maraver, et al., 2011). The ash content obtained during the research slightly exceeded the EU standards for granules (Table 4). The ash content of examined varieties differed significantly ($p<0.05$). The varieties 'Skalmeje' and 'Mulan' had the lowest ash content among the winter wheat varieties – 16.20 and 16.27 g kg^{-1} (1.620 – 1.627%). For triticale



Source: made by authors

Fig.1. **The energy value of the heating value of winter cereal grain.**

the lowest ash content was observed in the grains of the variety 'Dinaro' and the line 0002-26, whereas for the winter rye it was 'Placido' (Table 4).

An important indicator for the choice of fuel is the volume weight that impacts the transportation and storage of fuel. According to the standards SS 187120 that have been elaborated in Sweden, the volume weight of the heating granules has to be from 600 kg m^{-3} (Obernberg et al., 2004; Garcia-Maraver et al., 2011). The volume weight of grains is similar to that of coal, namely, around 700 – 850 kg m^{-3} (Biomass Energy..., s.a.). According to our research data the volume weight of the grain of winter cereals was from 686.7 to 774.7 kg m^{-3}. Evaluating individual species, winter wheat has the highest grain volume weight, followed by rye and triticale (Table 4). No substantial differences were observed among the varieties.

An important indicator in the heating is energy value of the heating values. Out of all the species the winter wheat had the highest average energy value – 40.08 MWh ha^{-1}. The energy value of triticale and rye was slightly lower (for 4.9 and 6.5% respectively) (Fig. 1).

According to the data of literature, similar results have been obtained in the research in Germany (Nagel, 2000). The energy value of heating value, calculating from 1 ha, was different among the varieties of one species, depending on the grain yield. There was no substantial difference in the amount of yield acquired from different winter wheat varieties, while as regards triticale the variety 'Dinaro' provided the highest grain yield – 8.93 t ha^{-1}; thus the energy value acquired from 1 ha also increased up to 40.14 MWh ha^{-1} and was similar to the energy value ensured by wheat. As regards the winter rye, a substantially higher grain yield was acquired from the variety 'Placido' – 9.24 t ha^{-1}, thus the energy value from 1 ha was also high, namely, 42.87MWh ha^{-1}.

Conclusions

Evaluating different aspects related to the suitability of the grain of winter cereals for heating, it was found that winter wheat had the most appropriate indicators: highest average grain yield – 8.89 t ha^{-1}, heating value – 16084 kJ kg^{-1}, volume weight – 774.7 kg m^{-3}, energy value – 40.08 MWh ha^{-1}, and the lowest ash content – 16.31 g kg^{-1}. These indexes show that the grain of winter wheat provides a high-quality biomass for the heating purposes. However, good results were also acquired from certain winter rye and triticale varieties. As regards the chemical composition of the grain of winter cereals, a higher content of chemical elements (P, K) was found after the combustion in comparison to other types of plant biomass. The presence of these elements negatively affects the ash melting temperature that according to the scientific data results in slag formation in heating boilers. The research has to be continued.

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