SUITABILITY OF CROP VARIETIES FOR ENERGY PRODUCTION

Aivars Kaķītis, Mareks Šmits[1], Ina Belicka[2]
[1]Latvia University of Agriculture, Faculty of Engineering, Institute of Mechanics,
[2]State Stende Cereal Breeding Institute
Aivars.Kakitis@llu.lv, Mareks.Smits@llu.lv, Ina.Belicka@stendeselekcija.lv

Abstract. Usage of herbaceous biomass as a fuel significantly increases during recent years. The main resources for solid biofuel in rural areas of Latvia are wood, residues of cereal crops, peat and emergent vegetation in lakes as common reeds (Phragmites australis). The share of biomass as a fuel in Latvia is 30.3 %, which is the highest percentage in the enlarged EU. Cereal grain is ready to use fuel which successfully can be applied for heat production in small scale boilers. The main problem of grain usage in furnaces is ash content and ash melting and slagging. The article describes grain burning properties for summer and winter cereal varieties grown in Stende State Cereal Breeding Institute. Energy production per hectare, ash content and ash melting temperature for different crop grain are described in the article.

Keywords: cereals, grain, ash melting, ash content.

Introduction

During the recent years the use of biofuels has been constantly expanding. The available modern biofuel production and combustion technologies enable effective utilization of practically all waste from the forest and wood processing industries. Also herbaceous biomass, for example, straw has found increasingly wider implementation as a fuel. The main resources for solid biofuel in rural area of Latvia are wood, residues of cereal crops, peat and emergent vegetation in lakes as common reeds (Phragmites australis). The Baltic Sea countries play an important role in the development and implementation of biofuel technologies.

According to Eurostat the renewables covered 5.7 % of the gross inland consumption in the EU 25 countries in 2002. Biomass gave almost two thirds of renewables-based energy (65.4 % or 3.7 % of gross consumption). In almost all of the Baltic Sea countries the share of biomass in the gross inland energy consumption is higher than the EU average while remaining lower of it only in Germany (2.1 %). Traditionally, biomass has been much used in Finland and Sweden. In Finland biomass gives almost one fifth (19.6 %) of the energy and about half of the required heat is produced from wood fuels. In Sweden biomass makes 16.1 % from the total energy demand. The share of biomass in Latvia is the highest in the enlarged EU and exceeds 30.3 % [1, 2].

Grain is a highly competitive ready-to-use fuel that has the potential to be applied in a range of situations provided the technical challenges associated with ensuring it is burnt efficiently can be addressed and the increased costs of installing a suitable system can be overcome.

The chemistry of grain combustion is different to that of straw and wood fuels and must be taken into consideration to design and install appropriate systems to overcome a number of technical difficulties which can be broadly categorised as follows:

- Ash content;
- Ash melting and slagging.

Ash content depends on the high potassium and silica content of fuel. It also means that ash residue after burning is higher than that of wood biofuels. In approximate terms, the ash content is as follows:

- Wood fuel 0.5 % ash;
- Cereal grains 3.5-6 % ash.

Ash is more than an issue of convenience for the user. The composition and quantity of combustion residue are the primary factors determining whether or not a feedstock can be burned effectively in a particular appliance.

Alkali metals, in combination with silica and sulphur, are primarily responsible for melting or sintering at relatively low temperatures. This undesirable process is facilitated by the presence of chlorine [3].

Slagging is caused when the ash residue of a fuel "melts" in a boiler during the combustion process. This can reduce the efficiency of operation and if not prevented will cause major operational problems. The issue affects cereals in particular because, when combusted, the potassium chloride and silicon dioxide contained in the grain ash mix to form a chemical that melts at 700 ˚C.

To avoid slag formation, fuel must be burnt in a two-stage process:

- Grain should be pyrolised on the grate at low temperature (less than 700 ˚C);
- Biogas produced from the pyrolysis must be burned in a separate combustion zone (secondary combustion can take place at much higher temperatures).

The separation of combustion zones is achieved by having a large combustion chamber and this allows differential temperature control which prevents slagging. Temperature control is maintained by regulating the flow of air to the primary and secondary combustion zones.

Materials and methods

The aim of the research project implemented at State Stende Cereal Breeding Institute in 2007 and 2008 was evaluation of the suitability of crop varieties for energy production. Field experiments were carried out to grow several new varieties of summer and winter crops. The grain yield was stated for all varieties of crops at moisture content 14 %.

Chemical analysis of grain and straw was done according to the standards existing in Latvia.

The gross calorific value was measured according to ISO 1928 using the oxygen bomb calorimeter "Parr 1341. Lower calorific value was calculated by formula (1) according to [4]:

$$Q_z = Q_a – 2454\,(W + 9H), \quad (1)$$

where Q_z – lower calorific value, kJ·kg-1;
Q_a – gross calorific value, kJ·kg-1;
2454 – heat for water evaporation at 20 ˚C, kJ·kg-1;
W – humidity, %;
H – content of hydrogen, %.

The main properties of grain and straw analyzing in this article are the energy value of cereals, ash content and fusibility characteristics of ash. Several standards are available for establishing the fusibility characteristics, including ASTM D 1857, ISO 540, and DIN 51730.

With the ASTM standard the changes in the shape of a standard ash cone by burning it in acidifying (oxidizing) environment are defined (see Fig. 1).

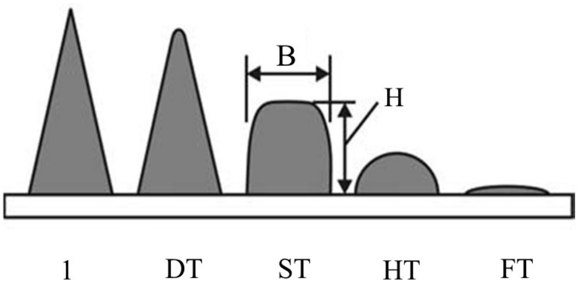

Fig. 1. **Changes in the shape of a standard ash cone by burning:**
1 – initial state: before heating the peak of ash cone is sharp; DT – initial point of deformation: the sharp peak is rounding; ST – softening temperature, the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter (H = B); HT – the point of formation of hemisphere or, the cone collapses and becomes dome-shaped (H = 0.5B); FT – flow temperature, the liquid ash dissipates along the surface

Fusibility of ash depends on its mineral composition and even minor differences in the composition may change the fusibility characteristics significantly. According to the fuel and ash composition, the fusibility characteristics of ash cannot be reliably predicted in practice.

The fusibility of grain and straw ash was stated at the company "Virsma" LTD according to the standard ISO 540.

Results and discussion

The grain yield and calorific value of grain are given in Table 1. The average grain yield of summer crops varies from 4.76 t ha^{-1} (oat) to 5.04 t ha^{-1} (summer wheat).

Table 1

Grain yield and calorific value of grain

Name	Grain yield* (t·ha^{-1})	Gross calorific value, (kJ k^{-1})	
		Grain	Straw
Oat, *aver.* *min-max*	**4.76** (3.51-5.28)	**16750** (16442-16994)	**16481** (16171 - 16840)
Barley, *aver.* *min-max*	**4.87** (4.40-5.37)	**15767** (15616-16013)	**16315** (16023-16671)
Summer wheat, *aver.* *min-max*	**5.04** (3.86-5.59)	**15591** (15475-17731)	**16204** (15788-16594)
Rye, *aver.* *min-max*	**6.82** (5.51-7.61)	**15667** (15421-15889)	**16423** (15764-16765)
Triticale, *aver.* *min-max*	**9.80** (8.35-12.69)	**15326** (15052-15404)	**16444** (16135-16702)
Winter wheat, *aver.* *min-max*	**8.79** (8.47-9.32)	**15437** (14655-15969)	**16287** (16158-16367)

* Moisture content -14%.

Depending on the soil properties, whether conditions, fertilizing and other conditions, the grain yield of summer crops varies from 3.51 t ha^{-1} to 5.59 t ha^{-1}. Summarizing the mentioned above the average grain yield of summer crops is approximately equal for all varieties.

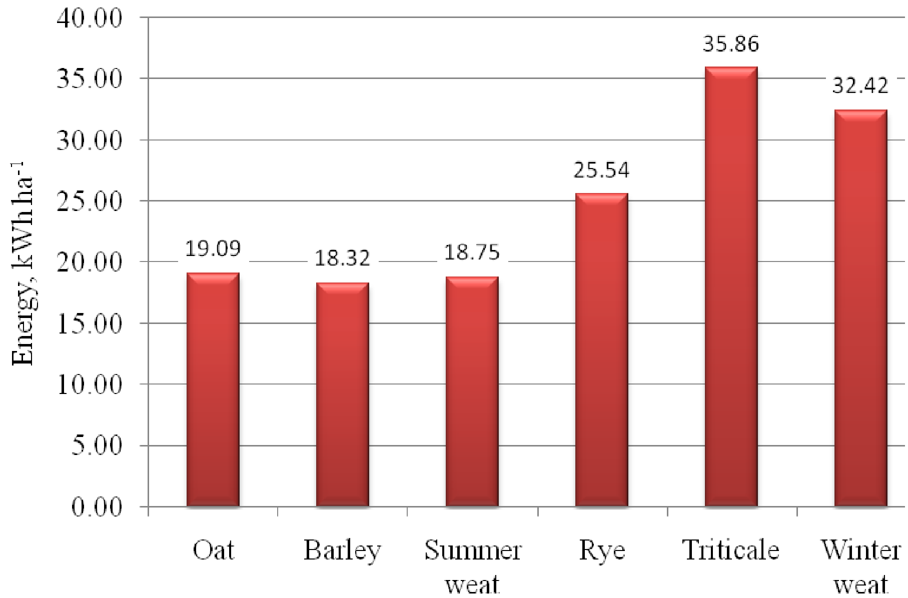

Fig. 2. **Total grain energy production per hectare**

The average grain yield of winter crops varies from 6.82 t·ha^{-1} (rye) to 9.80 t·ha^{-1} (triticale). The grain yield of triticale is 1.44 times bigger than the yield of rye. By comparison with the summer crops triticale gives approximately 2 times greater grain yield.

The gross calorific value of cereal grain varies from 15.33 MJ kg^{-1} (triticale) to 16.75 MJ kg^{-1} (oat). The gross calorific value of straw exceeds 16 MJ kg^{-1} for all crops and the difference between the crop varieties does not exceed 2 %. It is not significant and, from this point of view, straw of all cereals is suitable for energy production.

A significant parameter of grain as an energy source is total energy production per hectare. The energy production of triticale is 35.86 MJ ha^{-1} that approximately 1.96 times exceeds the energy production of barley (18.32 MJ ha^{-1}) and summer wheat (18.75 MJ ha^{-1}), (Fig. 2). From this point of view triticale and winter wheat are more suitable for energy production than summer crops.

The chemistry of grain combustion is different to that of straw and wood fuels. Ash melting and slagging can occur in the burning process and those must be taken into consideration to design and install appropriate furnaces. Ash is more than issue of convenience for the user. The composition and quantity of combustion residue are primary factors determining whether or not a feedstock can be burned effectively in a particular appliance.

The ash content had been determined during the experiments for all crops varieties. The ash content of winter crop grain is 1.5 % (average) for all varieties (Fig. 3.) It exceeds the ash content of wood fuels (0.5 %) approximately 3 times.

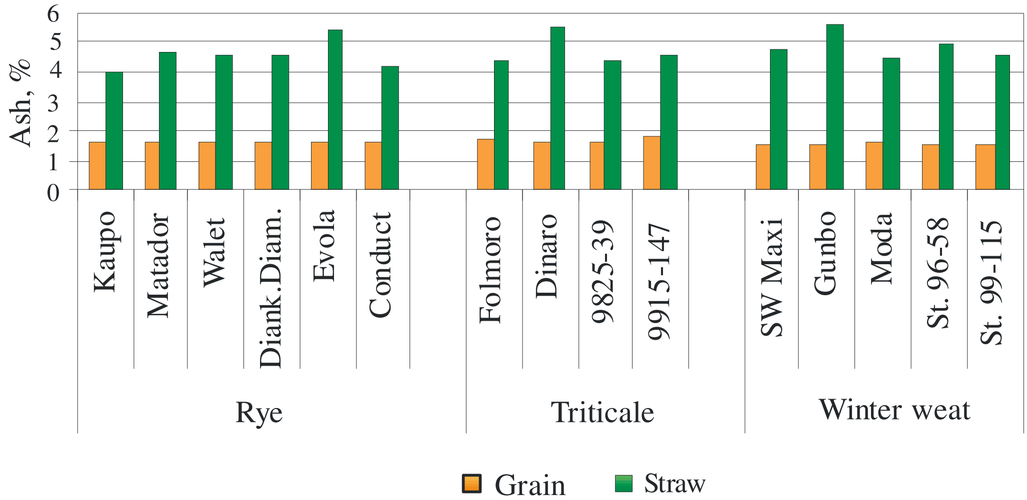

Fig. 3. **Ash content for winter crop varieties**

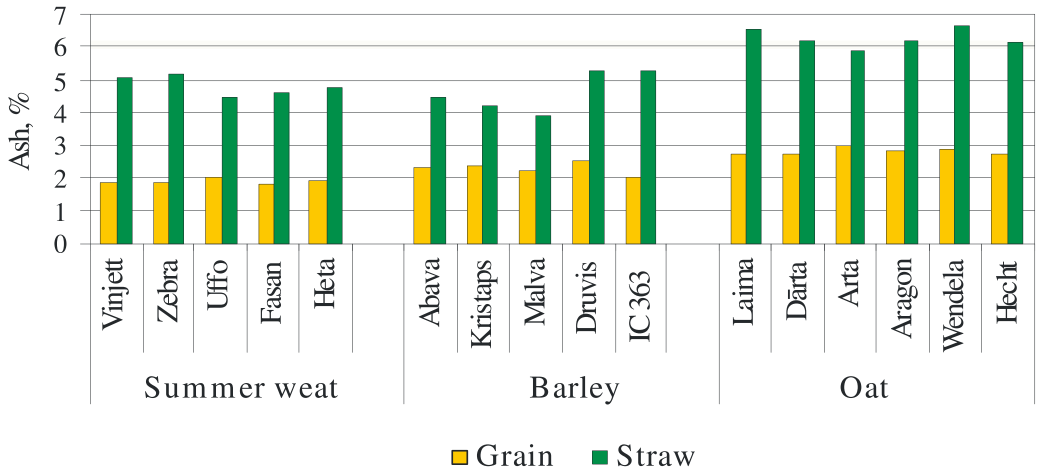

Fig. 4. **Ash content for summer crop varieties**

The ash content of summer crop grain varies from approximately 2 % (wheat, barley) to 2.7 % (oat). The ash content of straw for all crops is between 4 % and 5 %, except oat straw with the ash content approximately 6 %.

Table 2

Ash melting temperature of summer crops according to ISO 540

Sort	Variety	Ash melting temperature							
		DT, ˚C		ST, ˚C		HT, ˚C		FT, ˚C	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Summer wheat	*Vinjett*	510	938	650	1005	783	1060	820	1218
	Zebra	588	885	650	995	725	1033	790	1208
	Uffo	500	885	688	988	740	1033	805	1150
	Fasan	540	920	688	995	748	1045	805	1223
	Heta	618	1003	659	1055	718	1103	780	1213
	Abava	710	1025	790	1050	900	1070	1100	1145
Barley	*Kristaps*	900	935	940	985	998	1025	1113	1168
	Malva	1038	990	~1090	1050	1115	1078	1360	1168
	Druvis	-	988	-	1025	-	1075	-	1175
	IC 363	547	950	670	990	758	1018	805	1090
Oat	*Dārta*	**>1400**	**1010**	**>1400**	**1040**	**>1400**	**1093**	**>1400**	**1160**
	Laima	**~1388**	**1028**	**>1400**	**1055**	**>1400**	**1075**	**>1400**	**1133**
	Arta	**~1050**	**1050**	**~1065**	**1100**	**~1105**	**1125**	**~1145**	**1173**
	Aragon	**~1275**	**868**	**~1350**	**963**	**~1360**	**1063**	**~1375**	**1100**
	Wendela	**>1400**	**1013**	**>1400**	**1030**	**>1400**	**1068**	**>1400**	**1138**
	Hecht	**~1363**	**1035**	**>1400**	**1080**	**>1400**	**1098**	**>1400**	**1128**

Table 3

Ash melting temperature of winter crops according to ISO 540

Sort	Variety	Ash melting temperature							
		DT, ˚C		ST, ˚C		HT, ˚C		FT, ˚C	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Rye	*Kaupo*	625	950	650	970	850	980	960	1100
	Matador	625	870	650	1000	850	1060	960	1075
	Walet	570	870	600	890	780	940	850	1125
	Diankowskie Diament	625	950	650	1060	850	1075	960	1090
	Evola	625	960	650	980	850	990	960	1100
	Conduct	625	900	650	920	850	940	960	1175
Triticale	*Folmoro*	570	825	600	900	790	920	825	1125
	Dinaro	750	890	780	900	800	910	960	1100
	9710-4	750	840	775	860	800	900	830	1060
	9825-39	760	825	800	865	840	950	910	1100
	9915-147	700	870	730	890	740	910	800	1125
Winter wheat	*SW Maxi*	750	930	775	940	795	950	825	1125
	Gunbo	700	900	735	920	745	950	815	1100
	Moda	710	910	740	950	760	980	815	1125
	Stende 96-58	700	890	735	920	745	980	815	1125
	Stende99-115	750	880	775	920	785	950	850	1175

An important parameter characterising the burning properties of grain and straw is ash melting temperature. Low value of ash melting temperature leads to ash slagging and causes problems in boiler operation.

The ash melting temperature was stated for all varieties of summer and winter crop grain and straw (Table 2 and Table 3). The ash melting temperature (initial point of deformation DT) of winter crops lies between 625 ˚C and 750 ˚C. Summer wheat grain showed approximately the same temperature of the DT-point. Such low ash melting temperature leads to ash slagging and boiler operation disturbing.

The oat grain ash melting temperature (DT point) exceeds 1200 ˚C (except the variety Arta). Wood fuel has approximately the same ash melting temperature, which does not cause the problems with ash slagging in boilers. In this case oat grain can be recommended for heat energy production. The disadvantage of oat burning is significantly lower total energy production per hectare in comparison with triticale and winter wheat. Three years long grain burning experience at State Stende Cereal Breeding Institute showed that oat grain burning does not create ash slagging in the furnaces. Burning of other cereals brought to ash slagging and caused problems in moving grates operation. To avoid slag formation further recommendations can be applied:

- fuel must be burnt in a two-stage process;
- mixtures of biomass fuels must be used (for example, grain with wood chips);
- non-organic chemicals (baking soda or lime) should be added to fuel.

Conclusions

1. The gross calorific value of cereal grain varies from 15.33 MJ kg^{-1} (triticale) to 16.75 MJ kg^{-1} (oat). The difference of the gross calorific value between varieties of cereals does not exceed 9 %.
2. The energy production of triticale is 35.86 MJ ha^{-1} that approximately 1.96 times exceeds the energy production of barley (18.32 MJ ha^{-1}) and summer wheat (18.75 MJ ha^{-1}). From this point of view triticale and winter wheat are more suitable for energy production than summer crops.
3. The oat grain ash melting temperature (DT point) exceeds 1200°C. In this case oat grain can be recommended for heat energy production.

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