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Heating value of seeds of leguminous plants and their mixes with seeds of tussock-grass subfamily cereals

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Summary. The purpose of undertaken research was to determine and compare heating values for seeds of selected leguminous plant species and their mixes with cereal seeds. The tests were carried out using a calorimeter according to the applicable standard: PN-EN ISO 9831:2005. It has been observed that highest average heating value of 20.19 $MJ \cdot kg^{-1}$ is characteristic for yellow lupine seeds, and lowest – for field pea (17.91 $MJ \cdot kg^{-1}$). Moreover, the tests have proven that seeds of selected leguminous plants do not burn entirely, as a result of which deposit remains on crucible bottom.

Key words: seeds of leguminous plants, combustion heat, calorimetric method.

INTRODUCTION AND PURPOSE OF THE RESEARCH

Biomass will be more and more frequently used as fuel for heating purposes in houses and public facilities. Among other things, this is fostered by increasing prices of gas and heating oil, and the obligation imposed on Poland to increase the share of energy derived from renewable sources. In the world, grains of cereals, mainly oat and corn are used quite commonly for energy production purposes. Easier transport and storage are among the advantages of using this biomass type, as compared to straw or wood. Moreover, there are technical possibilities to fully automate the process of fuel feeding into boiler [5].

In Poland, using plant seeds or fruit for energy purposes is not widespread yet due to the fears of competitiveness regarding production of food and feeds. However, in case of energy production it is possible to use material of lower quality, not qualified for eating. In agricultural practice, material used for these purposes requires storing for shorter or longer time, while its quality is quite often deteriorating. This effect may result from activity of pests, which have adapted to feeding in closed rooms [9]. There are many reasons why fighting them is not easy. First, it is their high vitality and reproduction rate; moreover, development stages of some of them are hidden inside the seeds, thus limiting access for fumigants. Storage pests not only destroy materials, on which they feed, but also deteriorate their quality contaminating them with excreta, skins, and/or dead specimens. Moreover, they change physical properties of stored materials. Life-processes occurring in pest organisms (release of water, thermal energy) cause increase in material humidity and temperature, which in turn creates favourable conditions for growth of microorganisms, e.g. mildew fungi. Their metabolism products may be the reason for acute intoxications, and they also prove to have mutagenic, carcinogenic, teratogenic and estrogenic properties [8]. Cereal plantations captured by Fusarium genus fungi contaminated with mycotoxins may constitute another source of grain for energy production purposes [2].

The purpose of undertaken studies was to determine and analyse heating values for seeds of selected leguminous plant species and their mixes with cereal seeds.

MATERIAL AND METHOD

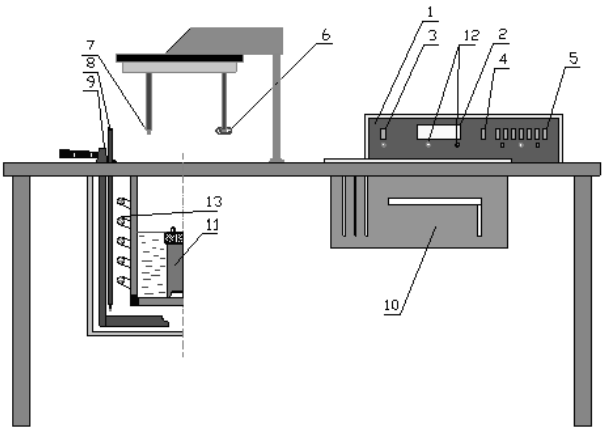
Material for tests was taken from a field experiment established using the method of randomly selected blocks in four repetitions. The experiment was carried out in soil with grain composition of strong clayey sand, belonging to good rye complex. White mustard was the forecrop. The tests covered seeds of the following leguminous plants: *Mister* variety yellow lupine, *Sonet* variety narrow-leaved lupine, *Titus* variety horse bean, *Eureka* variety field pea. Tested cereal-leguminous mixes include: seeds of *Mister* variety yellow lupine with seeds of *Kier* variety rye – ratio 1:1, seeds of *Eureka* variety field pea with *Furman* variety oat seeds – ratio 1:1.

The tests were carried out in the humidity of leguminous plant seeds close to 8.5 %, and cereal seeds: 10 %. Examined material humidity was determined using the dryer-weight method according to Polish Standard PN-R-65950 of December 1994 [12]. Samples were dried for 1 hour at the temperature of 130°C.

Heating value for seeds was determined using the KL-10 calorimeter (Fig. 1) according to applicable standard PN-EN [13-15].

The experiment involved complete combustion of samples weighing 1g (+/-0.0002) in oxygen atmosphere under pressure of 2.8 MPa in a bomb calorimeter, immersed in water (2.7 dm^3 in volume), in calorimetric vessel. Subsequently, water temperature rise was determined. Kanthal resistance wire was used to ignite samples.

Calorimeter operation is based on the measurement of characteristic thermal balance temperatures for the following setup: bomb calorimeter with combusted fuel and calorimetric vessel with water.



1. control device
2. digital display
3. power switch
4. start of measurement
5. read heat of combustion
6. mixer
7. thermometer
8. thermometer water jacket
9. mixer the water jacket
10. computerized measuring system
11. bomb calorimeter
12. LEDs
13. coil

Fig. 1. Calorimeter schematic diagram

Fuel sample heating value was computed automatically according to an internal device program using the following formula:

$$Q_s = K (T_3 - T_2 - k), \quad (1)$$

where:
K – calorimeter heat capacity [kJ/kg],
T_2, T_3 – characteristic balance temperatures [K],
k – allowance for heat exchange between calorimeter and environment,

$$k = 0.5 [0.2 (T_2 - T_1) + 0.2 (T_4 - T_3)] + 0.2 (n - 1) (T_4 - T_3), \quad (2)$$

where:
n – number of minutes in cycle no. 2 (main period),
T_1, T_4 – characteristic balance temperatures, [K].

The results were processed statistically with variance analysis method for significance level 0.05, using Statistica 9 application. Homogeneous groups were separated according to Duncan's test in case of occurrence of significant differences.

TEST RESULTS AND THEIR ANALYSIS

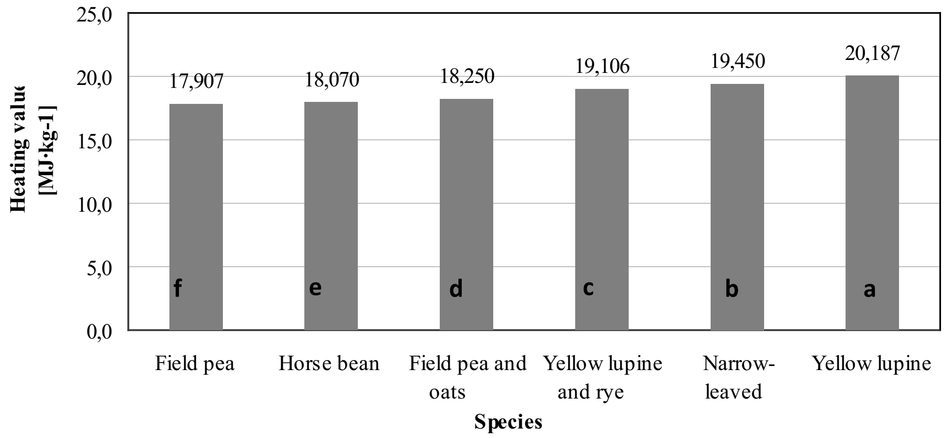
Currently, available literature includes studies on the subject related to using different plant biomass types for fuel purposes. However, most frequently they refer to vegetative organs of plants only. Whereas, relatively few concern seeds or fruit, while they mostly focus on cereal seeds and primarily refer to one species only – oats [7,10]. Completed studies included leguminous plants as well, in order to compare heating value of their seeds and determine the chances to possibly use them for energy production purposes through combustion.

Obtained heating values for seeds of leguminous plants and their mixes with seeds of tussock-grass subfamily cereals range from 17.9 to 20.2 $MJ \cdot kg^{-1}$. The highest heating value was shown by yellow lupine seeds, the lowest – by field pea (Fig. 2). Heating value for leguminous plants was higher compared to seeds of tussock-grass subfamily cereals, for which it was ranging from 16.2 to 18.6 $MJ \cdot kg^{-1}$ [19]. Probably, this is due to high protein concentration in leguminous seeds (in general 26.9% of dry matter), and in particular yellow lupine (on average 42.75% in dry matter) [6,11]. Protein is characterised by higher heating value (24 $MJ \cdot kg^{-1}$) than starch (17.5 $MJ \cdot kg^{-1}$), which prevails in chemical constitution of cereal seeds [3]. Heating values for cereal-leguminous mixes were ranging between the values obtained for leguminous seeds and cereal seeds used in these mixes.

As opposed to cereal seeds, during combustion of leguminous plant seeds, especially yellow lupine, the researchers observed a residue in form of hard, glassy substance on crucible bottom. This is probably due to higher ash content in leguminous plant seeds, compared to cereal seeds, on average 4.3% in dry matter (cereal grain: 2.4%) [6,17]. Moreover, leguminous plant seeds are characterised by high content of alkaline metals, especially potassium, (cereal grain: 0.5% of dry matter). Potassium reduces ash fusibility temperature. As a result of this, the mixture of chemical compounds characterised by low melting point generated during combustion process forms a good binder for all ash particles and unburned fuel particles. In practice, using fuels of this type makes boiler operation harder, since it leads to formation of hard and difficult to remove deposits inside combustion chamber. They disturb heat exchange process and accelerate high-temperature corrosion. It seems that good solution for this problem would be using co-combustion of leguminous plant seeds with other biomass type. This effect may be also partially prevented by adding to fuel those substances, which increase ash fusibility temperature, e.g. potassium-bonding silicon and aluminium compounds [4]. The first of the proposed solutions will also allow to use ashes as fertilisers, thus closing the entire cycle from agricultural production to energy production [1].

CONCLUSIONS

1. Among the examined leguminous plant seeds, the highest average heating value of 20.19 $MJ \cdot kg^{-1}$ was observed for yellow lupine seeds, and the lowest for field pea seeds (17.91 $MJ \cdot kg^{-1}$).



*a, b, c, d, e, f – homogeneous groups according to Duncan's test

Fig. 2. Heating values for leguminous plant seeds and their mixes with cereal seeds.

2. Heating values for cereal-leguminous mixes were within range limited by values obtained for individual species, for field pea and oats: 18.25 MJ·kg^{-1}, and for yellow lupine and rye: 19.11 MJ·kg^{-1}.
3. Seeds of leguminous plants do not combust entirely, leaving deposit on crucible bottom.

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CIEPŁO SPALANIA NASION ROŚLIN STRĄCZKOWYCH I ICH MIESZANEK Z ZIARNIAKAMI ZBÓŻ Z PODRODZINY WIECHLINOWATYCH

Streszczenie. Celem przeprowadzonych badań było określenie i porównanie wartości opałowych nasion wybranych gatunków roślin strączkowych i ich mieszanek z nasionami zbóż. Badania przeprowadzono za pomocą kalorymetru według obowiązującej normy: PN-EN ISO 9831:2005. Stwierdzono, że największą średnią wartością opałową 20,19 MJ · kg-1 charakteryzuje się żółte nasiona łubinu, a najniższą – groch zwyczajny (17,91 MJ · kg-1). Co więcej, badania wykazały, że nasiona wybranych roślin strączkowych nie palą się w całości, w wyniku czego pozostaje popiół na dnie tygla.

Słowa kluczowe: nasiona roślin strączkowych, wartość opałowa, metoda kalorymetryczna.