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UTILIZATION OF SPELT WHEAT HULL AS A RENEWABLE ENERGY SOURCE BY PELLETING

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Abstract

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Spelt wheat is an old crop, which is regaining its popularity with arisen interest for organic food. This crop is characterized by its hard hull, which must be removed in Spelt processing and utilization for food. Agricultural waste, such as spelt hull, which falls in the category of biomass, can be considered as renewable energy source and be used for energy generation. The percentage of waste in form of hull can rise up to 30 %. In order to achieve better conversion of biomass to energy, it is necessary to conduct a pre-treatment of the raw material. In this study, pelleting was used as a pre-treatment of raw material. Production of quality biomass pellets requires preparation of raw material, which implies milling and conditioning. Main goal of this study was to determine physical and chemical properties of pellets made from spelt hull, as well as specific energy consumption during pelletizing process in dependence of form of added water during conditioning process.

Spelt hull proved to be good raw material for production of fuel pellets, with some minor aberrations in comparison to the fuel pellet standards (ÖNORM M 7135, DIN 51731, SS 187120). Since these standards are manly for wood, and wood-residue pellets, lower criteria could be applied for agricultural biomass pellets, such as spelt pellets.

Steam conditioning did cause some reduction in energy consumption for pelleting of spelt hull, but from this study, it can be concluded that adding water as a preparation method can also be used, without significant looses in pellet quality and with savings in energy consumption for pellet production.

Key words: pelleting, conditioning, fuel pellets, specific energy consumption, biomass, Spelt wheat

Introduction

In accordance with new world trends, it is desirable to have a sustainable agricultural production and that implies utilization of waste, which originates from that production. Large quantities of agricultural crop residues, which are produced every year in the world, are not sufficiently utilized (Demirbas et al., 2009). Agricultural waste, which falls in the category of biomass, can be considered as renewable energy source and be used for energy generation.

Since energy consumption is continuously increasing due to rapid development of population and industrialization, the development of energy resources cannot keep up with the demand. For that reason, research and interests are aimed at developing technologies, which use renewable energy sources, like biomass (Gokcol et al., 2009).

In recent years an interest for organic food has risen, along with that some old crops are being put back to use. One of this crops is a variety of wheat, spelt (*Triticum aestivum* var. *spelta*) which can be grown without pesticides, and therefore is especially suitable for organic production (Belton and Taylor, 2002). Spelt is specific due to its hard hull, which helps in resistance to pathogens, but also creates a lot of waste during dehulling. The percentage of waste in form of hull is up to 30 % (Bodroza-Solarov et al., 2010). Thus, spelt hull can be efficiently used as a renewable energy source, and this assumption was inves-

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tigated in this study. Spelt is jet not widely investigated crop and there are no available data on utilization of spelt hull, neither on its chemical composition.

In order to achieve better conversion of biomass to energy, it is necessary to conduct a pre-treatment of the raw material. When biomass is used as a renewable energy source, pelleting is desirable as it increases energy density (Stelte, 2011) and enables more uniform combustion of pellets. In addition, it facilitates transport, storage and handling, as well as enabling automated feeding of the material. Production of quality biomass pellets requires preparation of raw material, which implies milling and conditioning. In the process of conditioning water is added to the material, which at the end influences pellet characteristics, as well as energy consumption during pelleting process itself (Vukmirovic at al., 2010). In the process of conditioning mixed mash of material is converting to a physical state, which is more suitable for compaction of material, with use of heat, water, pressure and time. Conditioning increases production capacity and, in the same time, affects physical quality of produced pellets *(*Sredanovic and Levic, 2000). Addition of heat and water leads to changes of components, such as starch and protein, in a way that binding property comes into effect. Applying too much heat or water has negative effect on production capacity and pellet quality and may lead to plugging of pellet press die (Winowiski, 1985; Thomas et al., 1997). Water can be added to the material in a form of liquid or steam. Steam conditioning requires more energy therefore, energy can be saved in some cases using liquid water conditioning instead. In that way, there is no energy consumption for conversion of water to steam and achieving elevated pressure. Main goal of this study was to determine physical and chemical properties of pellets made from spelt hull, as well as specific energy consumption during pelletizing process in dependence of the form of added water during conditioning process.

Materials and Methods

Material and processing

The spelt cultivar Nirvana was obtained at location Backa Topola, Serbia, in 2010. The samples were dehulled by passing the grains between coated rolls and aspiration was used to remove the hulls.

Technological processing of spelt hull was performed at pilot-plant facility of Institute of food technology in Novi Sad, Serbia.

In order to obtain better pelleting properties, spelt hull was grinded using hammer mill with 4 mm sieve openings. Decreasing particle size exposes more surface area per unit volume for absorption of water and condensing steam during conditioning process. Grinding was also used to improve pellet quality by reducing air spaces between particles and to reduce weak spots in the pellets (Köster, 2003).

Conditioning of the material was done in double-shaft pedal mixer/steam conditioner (Muyang SLHSJ0.2A, China). Before conditioning process, material was divided in four batches of 25 kg each. The first two batches were conditioned by injection of steam under pressure of 2 bars. In the first batch, (S-1) steam was added until material reached temperature of 50°C, which caused moisture content rise to 15.19%. Second batch (S-2) was steam conditioned until 80°C was reached and moisture content of conditioned material was 17.90%. Next two batches were conditioned only by addition of water. In the third (w-1) and fourth batch (w-2) water was added in order to reach similar moisture content to first and second batch, and achieved moisture contents were 15.60% and 17.77% respectively. Since spelt hull could not be pelleted without adding of water in a form or steam or liquid, there was no control batch, but the starting material was analysed for all the parameters except abrasion.

Material was pelleted on a flat die pellet press 14-175, AMANDUS KAHL GmbH & Co. KG (Germany), Diameter of pellet die openings was 6 mm, with die thickness of 30 mm. After pelleting, pellets were cooled and stored for 24 hours under room conditions.

Physical analysis

Sieving analysis of grounded material was performed in the range 125 to 3000 μm by method of Test sieving (ISO 1591-1 1988 (E)). Geometric mean diameter (d_{gw}) and geometric standard deviation of particle diameter (S_{gw}) were determined according to ASAE Standard (ASAE, 2003).

Bulk density of grounded and pelletized material was measured with a bulk density tester, Tonindustrie, West und Goslar, Germany.

"Pfost" abrasion test unit, Bühler, Switzerland (Pfost and Allen, 1962; Pfost, 1963), was used to analyze abrasion of pellets. It was determined by inducing fines trough abrasing action of pellets shearing over each other and over the wall of drums (tumbling can device). The procedure is standardized by using a drum with specified dimensions, in which 500 g of sieved pellets are inserted. After tumbling for 10 min at 50 rpm (rounds per minute), pellets are subsequently sieved and the amount of fines passing a sieve with a grid size of 0.8 x pellet diameter was determined and expressed in percentage.

Chemical analysis

Starting and pelletized material were analyzed for moisture content (NREL/TP-510-42621), crude ash (NREL/TP-510-42622), crude protein (Kjeldahl method, AOAC 978.04), crude fat (AOAC 920.39), crude fibre (AOAC 962.10). In material were also analyzed volatile mater (CEN/TS 15148:2005), fixed carbon (calculated by difference between 100 and the sum of volatile matter, ash and moisture), content of C, H, N (CEN/TS 15104:2005) and S (CEN/TS 15289:2006), higher heating value (HHV) and lower heating value (LHV) (CEN/TS 14918:2005).

Thermo-gravimetric analysis

A thermo-gravimetric analysis was also conducted for pellet samples, using TGA701, Leco. Pellets were ground, and amount of approximately 1 g was used. The analyses was conducted using a flow of air, at low rate, with heating rate of 20°C min^{-1}, up to 900°C. From the obtained data (weight loss, and temperature) combustion profile, and intensity of weight loss in respect to the temperature, were made.

Statistical analysis

Statistical Analysis System (Statistical, Tulsa, Oklahoma, USA) was used for analyzing variations (analysis of variance – ANOVA) and least significant differences (LSD). The level of significance was set at $p<0.05$.

Results and Discussion

Chemical composition of the ground spelt hull is shown in Table 1. It can be seen that the material is composed out of more than 50% of crude fibre. Substantial amount of starch can be assigned to parts of grain remained in the hull mass due to specific type of dehuller used in dehulling process.

Cumulative particle size distribution of spelt hull after grinding is presented in Figure 1. Approximately 35% of material is retained on sieve with aperture size of 1250 μm, 15% on sieves with aperture size of 1000 and 2000 μm, and 12% on sieves with aperture size of 250 and 630 μm. Geometric mean diameter (d_{gw}) and the geometric standard deviation (S_{gw}) of ground spelt hull were estimated to be 807.5 μm and 2.1.

Bulk density of pellets and starting material is shown in Figure 2, and it was significantly different between treatments. Highest value is obtained for the sample S-1. Swedish Standard SS 187120, for fuel pellets proscribes values for bulk density to be above 600 kg/m^3 which was in this study achieved only for s1 samples. Nevertheless obtained values are in accordance with previous investigations dealing with biomass pellets (Obernberger and Thek, 2004; Theerarattananoon et al, 2011).

Table 1
Chemical composition of the ground spelt hull

Component	Concentration, % (w/w)
Moisture	11.0
Crude ash	3.97
Starch	23.12
Crude protein	8.7
Crude fat	1.45
Crude fibre	51.76

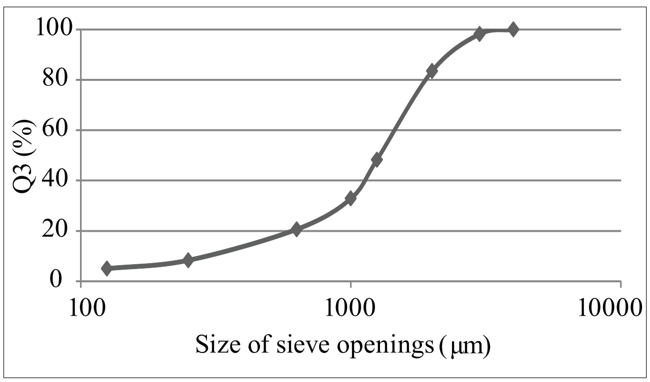

Fig. 1. Cumulative particle size distribution of ground spelt hull
Q3 - cumulative mass based distribution

Abrasion is a parameter which influences transportation and feeding of the combustion systems, where higher abrasion can cause malfunctioning of the feeding system as well as larger dust emissions (Obernberger and Thek, 2004). From the Figure 3 it can be seen that steam conditioned material (S-1 and S2) had lower abrasion. Conditioning with steam exposes the material to high temperatures, besides increased moisture content, which facilitates particle binding. Water and steam added in the material act as particle binder, due to forming of liquid bridges. On the other hand, they facilitate physical and chemical changes of main components such as fibre and starch, in this case (Thomas et al., 1997). All samples had abrasion values well below the barriers proscribed by norms for pellet fuels: < 2.3% (ONORM M 7135, DIN 51731), with the lowest abrasion for S-2 samples (0.86 %). Since there were no significant differences between treatments S-1 and w-2, it can be assumed that production of spelt-hull pellets can be done only by adding water in the conditioning process, but moisture content should be higher than in case of steam conditioned material. This results in saving of energy, necessary for steam production. The obtained results for pellet abrasion were lower than in previous studies for biomass pellets, where abrasion was around 10% (Fasina, 2008), and between 1.7 and 6.5% (Theerarattananoon et al., 2011).

Table 2 presents proximate and ultimate analyses results of starting material (labelled with “0”) and

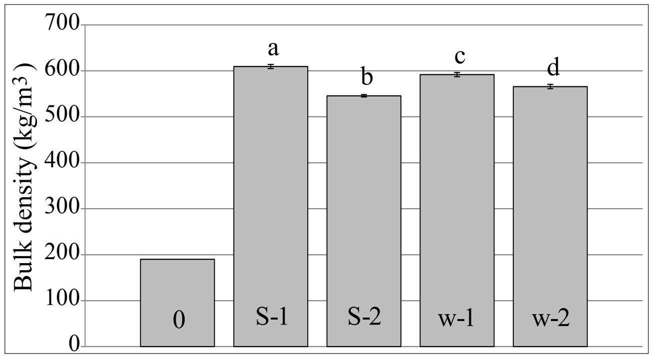

Fig. 2. Bulk density
Error bars present standard deviation.
[abcd]Means with different letters in the same row are significantly different at the 5 % level

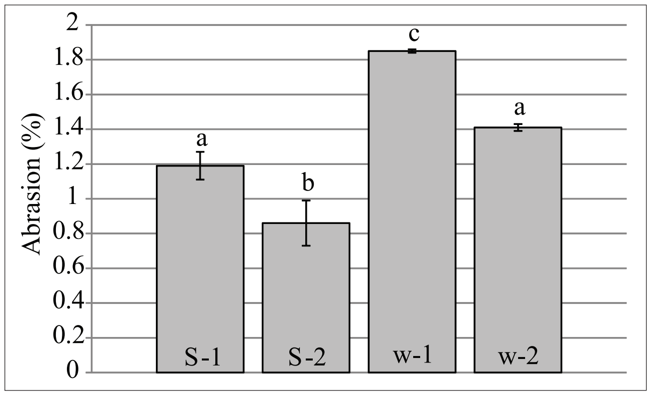

Fig. 3. Abrasion
Error bars present standard deviation.
[abcd]Means with different letters in the same row are significantly different at the 5 % level

Table 2
Results of the analyses

	0	S-1	S-2	w-1	w-2
Proximate analyses					
Moisture (%)*	8.13±0.02	8.12±0.02	8.97±0.04	8.56±0.01	8.57±0.05
Ash (% db)	3.43±0.01	3.82±0.01[a]	3.86±0.01[ab]	3.80±0.07[a]	3.92±0.02[b]
Fixed carbon (% db)	15.73±0.02	15.97±0.04[a]	15.84±0.37[a]	15.74±0.33[a]	15.85±0.32[a]
Volatile matter (% db)	80.54±0.02	79.84±0.04[a]	79.96±0.37[a]	80.10±0.33[a]	79.87±0.32[a]
Ultimate analysis					
C (% db)	45.97±0.06	45.75±0.06[a]	45.48±0.22[a]	45.17±0.11[a]	44.78±0.06[a]
H (% db)	6.81±0.07	6.71±0.04[a]	6.65±0.16[a]	6.84±0.12[b]	6.81±0.05[b]
N (% db)	1.41±0.04	1.41±0.06[a]	1.49±0.01[b]	1.55±0.05[b]	1.41±0.03[a]
S (% db)	0.105±0.010	0.111±0.031	0.099±0.018	0.102±0.026	0.095±0.06
HHV (MJ/kg)	18.594±0.028	18.678±0.028	18.665±0.076	18.952±0.046	19.068±0.070
LHV (MJ/kg. db)	17.114±0.028	17.220±0.028[a]	17.220±0.076[a]	17.466±0.046[b]	17.588±0.070[b]

* Determined after the pellets achieved equilibrium moisture content in the storage.
[abcd]Means with different letters in the same row are significantly different at the 5 % level; 0 Spelt hulls-not pelleted

all the treatments: S-1 (steam at 50°C), S-2 (steam at 80°C), w-1 (water to 15%) and w-2 (water to 18%). Statistical analysis was preformed for four treatments, to determine whether there were any differences between them.

Moisture content of cold pellets was around 8% for all samples (Table 2), which is below limit of 10%, as proscribed by European standards for fuel pellets (ONORM M 7135, DIN 51731, SS 18 71 20).

Ash content of all samples was slightly below 4% (Table 2), which is higher than proscribed by mentioned standards for fuel pellets, but in accordance with literature data for similar biomass (Obernberger and Thek, 2004; Masia et al., 2007; Saidur et al., 2011). One should keep in mind, that agricultural biomass has greater content of ash than wood, while it absorbs a lot of nutrients during its growth (Cuiping et al., 2004; Obernberger et al., 2006; Van Loo and Koppejan, 2008).

Volatile matter of samples was around 80% for all samples, with no significant difference among treatments, and the same is for fixed carbon, with values around 16% (Table 2). The data are in accordance with literature (Van Loo and Koppejan, 2008; Gil et al., 2010; Saidur et al., 2011).

Ultimate analyses, presented in Table 2, showed results which are common for biomass (Masia et al., 2007; Vassilev et al., 2010; Saidur et al., 2011). Nitrogen and sulphur are main parameters to be considered in terms of environmental protection, which is a primary reason of using bio-fuels. Nitrogen levels were above 0.3% (proscribed by ONORM M 7135, DIN 51731). This parameter is of great significance due to the nitrogen-oxide emissions, which occurs during combustion of pellets. Sulfur levels were low, but still just above the boundaries proscribed by fuel pellets standards (0.08 in DIN 51731 and SS 18 71 20). Sulphur causes emission of SO_2, which is a main component responsible for acid rains; therefore, this parameter needs to be determined for every biomass used as energy resource.

Heating values (Table 2) of samples were similar to the ones of wood (Saidur et al., 2011), and samples conditioned with adding water had higher heating values than the ones conditioned with steam. Pellets also had somewhat higher HHV and LHV values than original material.

Figure 4 presents weight loss intensity in relation to the temperature, which was obtained from the TGA results. All the samples showed the same profile, with no noticeable differences. The first peak presents weight loss due to the moisture evaporation, and this occurred at the temperature of 85°C. The ignition temperature, at which a rapid weight loss started, was 230°C. The highest percentage of weight loss was at the temperature of 300°C, with burnout temperature of 400°C .Biomass combustion is dominated by oxidation of volatile matter, which was present with around 80%, as mentioned above. These profiles are similar to the studies conducted on some different biomass pellets, such as blends of wood sawdust, coffee hulls, and grape pomace by Gil et al. (2010) and grape pomace in combination with oak by Miranda et al. (2011).

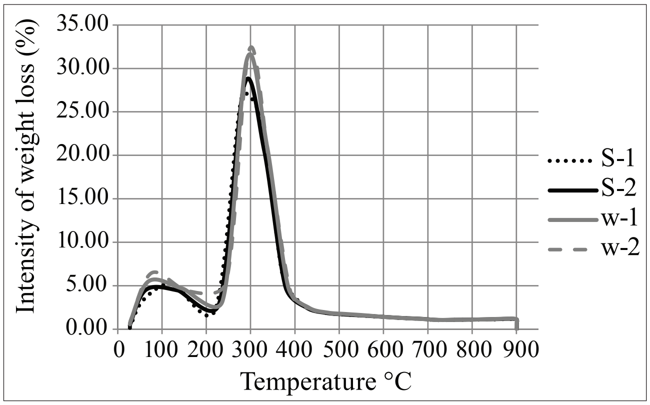

Fig. 4. Intensity of weight loss

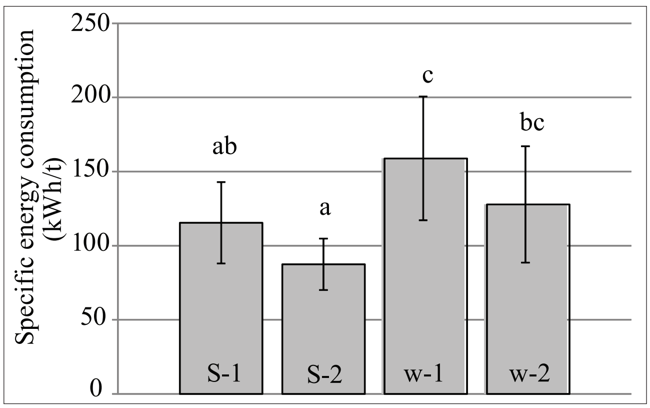

Fig. 5. Specific energy consumption for the pelleting process

Error bars present standard deviation.

[abcd]Means with different letters in the same row are significantly different at the 5 % level

Steam conditioning is believed to be a more effective way of preparing the material for pelleting, since water in a form of steam, can better incorporate in the material (Sredanovic and Levic, 2010). However, steam conditioning requires more energy, and therefore it is more expensive conditioning process in comparison to water addition. On the other hand conditioning with steam reduced specific energy consumption of pellet press, as can be seen from Figure 5. The lowest specific energy consumption was for the sample S-2, which was conditioned at higher temperature (80°C). No significant difference was found between the two steam conditioning treatments, as well as between the steam conditioning at 50°C (S-1), and water conditioning with achieving 18% of moisture (w-2). Less energy was consumed, when material had higher moisture content, due to the lubricant effect of water, which diminishes the friction between in the material and pellet press die (Kalyan and Morey, 2009).

Conclusion

Spelt hull could present a good raw material for production of fuel pellets. Physical and chemical properties of obtained pellets are similar to the properties of other biomass pellets. There were some aberrations in comparison to the fuel pellet standards, but it is important to mention that these standards are manly for wood, and wood-residue pellets, thus lower criteria could be applied for agricultural biomass pellets, such as spelt pellets.

Although steam conditioning reduced energy consumption for pelleting of spelt hull, and in general produces better quality pellets, from this study it can be concluded that adding water as a preparation method can also be used, without significant looses in pellet quality and with significant savings in energy consumption for pellet production. When adding water it is necessary to aim at higher moisture content, than it would be achieved when steam conditioning is used. In this case material with starting moisture of 18%, achieved with addition of water, showed equivalent energy consumption as did the one with starting moisture of 15%, which was achieved by steam conditioning at 50°C. Observing the main pellet quality properties, and comparing them to the European standards, it can be seen that there are no major differences between pellets obtained by preparing the material with water, and steam conditioning. All samples had similar proximate and ultimate analyses results, whereas there were some differences in physical properties. The burnout profiles were also similar for all pellets, which all supports the conclusion that water could be used instead of steam for preparing the material for pelleting of spelt hull.

An interesting possibility for further research could present pellet production of wood sawdust and spelt hull blend, since both materials present similar heating values. By doing so, content of nitrogen and sulphur in the mixture could be lowered, since wood as a material contains less of these elements than agricultural biomass, thus bringing the pellets closer to the fuel pellet standards boundaries.

Acknowledgements

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References

Belton, P. S. and J. N. T. Taylor, 2002. Pseudocereals and less common cereals: grain properties and utilization potential. *Springer-Verlag Berlin*, Heidelberg, pp. 153-173.

Bodroza-Solarov, M., F. Balaz, F. Bagi, B. Filipcev, O. Simurina and J. Mastilovic, 2010. Effect of hulls on grain mould infestation in *Triticum aestivum* ssp. *spelta* from organic trial. *Proceedings of 45th Croatian and 5th International Symposium on Agriculture, 15-19 February, Opatija, Croatia*, pp. 51-54.

Cuiping, L., W. Chuangzhi Yanyongjie and H. Haitao, 2004. Chemical elemental characteristics of biomass fuels in China. *Biomass Bio energy*, **27:** 119-130.

Demirbas, M. F., M. Balat and H. Balat, 2009. Potential contribution of biomass to the sustainable energy development. *Energy Convers. Manag*., **50:** 1746-1760.

Fasina,O. O., 2008. Physical properties of peanut hull pellets. *Bioresource Technology,* **99:** 1259-1266.

Gil, M. V., P. Oulego, M. D. Casal, C. Pevida, J. J. Pis and F. Rubiera, 2010. Mechanical durability and combustion characteristics of pellets from biomass blends. *Bioresour. Technol.,* **101:** 8859-8867.

Gokcol, C., B. Dursun, B. Alboyaci and E. Sunan, 2009. Importance of biomass energy as alternative to other sources in Turkey. *Energy Policy*, **37:** 424-431.

Kaliyan, N. and R. V. Morey, 2009. Factors affecting strength and durability of densified biomass products. *Biomass Bioenergy,* **33:** 337-359.

Koster, H., 2003. Improved animal performance through feed processing technology. AFMA's annual symposium, http://www.animate.co.za/articles/feedprocessing.pdf, (22.08.2011).

Masia, A. A.T., B. J. P. Buhre, R. P. Gupta and T. F. Wall, 2007. Characterising ash of biomass and waste. *Fuel Process. Technol.,* **88:** 1071-1081.

Miranda, M. T., J. I. Arranz, S. Roman, S. Rojas, I. Montero, M. Lopez and J. A. Cruz, 2011. Characterization of grape pomace and pyrenean oak pellets. *Fuel Process. Technol.,* **92:** 278-283.

Obernberger, I. and G. Thek, 2004. Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass Bioenergy,* **27:** 653-669.

Obernberger, I., T. Thomas, T. Brunner and G. Barnthaler, 2006. Chemical properties of solid biofuels—significance and impact. *Biomass Bioenergy,* **30:** 973-982.

Pfost, H. B., 1963. Testing the durability of pelleted feed. *Feedstuffs,* **23:** 66-68.

Pfost, H. B. and R. N. Allen, 1962. A standard method of measuring pellet durability. *Proc. Feed. Prod. School, 12-14 Nov., Midwest Feed Manuf. Assoc., Kansas City,* pp. 25-29.

Saidur, R., E. A. Abdelaziz, A. Demirbas, M. S. Hossain and S. Mekhilef, 2011. A review on biomass as a fuel for boilers. *Renewable Sustainable Energy Rev.,* **15:** 2262-2289.

Stelte, W., J. K. Holm, A. R. Sanadi, S. Barsberg, J. Ahrenfeldt and U. B. Henriksen., 2011. A study of bonding and failure mechanisms in fuel pellets from different biomass resources. *Biomass Bioenergy,* **35:** 910-918.

St. Joseph, M. I., 2001. American Society of Agricultural Engineers, pp. 573-576.

Skoch, E. R., K. C. Behnke, C. W. Deyoe and S. F. Binder, 1981. The effect of steam-conditioning rate on the pelleting process. *Anim. Feed Sci. Tech*., **6:** 83-90.

Sredanovic, S. and J. Levic, 2000. Conditioning – An important step in feed production. *Journal on Processing and Energy in Agriculture,* **4:** 82-84.

Theerarattananoon, K., F. Xu, J. Wilson, R. Ballard, L. Mckinney, S. Staggenborg, P. Vadlani, Z. J. Pei and D. Wang, 2011. Physical properties of pellets made from sorghum stalk, corn stover, wheat straw, and big bluestem. *Ind. Crops and Prod.,* **33:** 325-332.

Thomas, M. and A. F. B. van der Poel, 1996. Physical quality of pelleted animal feed: 1. Criteria for pellet quality. Thomas, M., van Zuilichem, D. J., van der Poel, A.F.B. 1997. Physical quality of pelleted animal feed: 2. Contribution of processes and its conditions. *Anim. Feed Sci. Tech.,* **64:** 173-192.

Vassilev, S. V., D. Baxter, L. K. Andersen and C. G. Vassileva, 2010. An overview of the chemical composition of biomass, *Fuel,* **89:** 913-933.

Van Loo, S. and J. Koppejan, 2008. The handbook of biomass combustion and cofiring. London-Sterling (VA): Earthscan.

Vukmirovic, D, D. Ivanov, R. Colovic, B. Kokic, J. Levic, O. Duragic and S. Sredanovic, 2010. Effect of steam conditioning on physical properties of pellets and energy consumption in pelleting process. *Journal on Processing and Energy in Agriculture,* **14:** 106-108.

Winowski, T., 1985. Optimizing pelleting temperature. *Feed Management*, **36**: 28-33.

Analytical methods:

AOAC Methods, In Official Methods of Analysis, 17th edn. Ed. W. Horwitz, AOAC Int, Arlington, VA (USA), 2000.

ASAE, 2003. Methods of Determining and Expressing Fineness of Feed Materials by Sieving. Standard no. S319.3. *American Society of Agricultural and Biological Engineers*, pp. 202–205.

CEN/TC 335. 2005. Biomass standards, Technical Specifications CEN/TS—Solid Biofuels.

NREL/TP-510-42622. Determination of Ash in Biomass.

NREL/TP-510-42621. Determination of Total Solids in Biomass and Total Dissolved Solids in Liquid Process Samples.

Pellet standards:

DIN 51731, 1996. Testing of solid fuels—compressed untreated wood, requirements and testing. Berlin, Germany: Deutsches Institut für Normung.

ONORM M 7135, 2003. Compressed wood or compressed bark in natural state, pellets and briquettes. Requirements and test specifications. Vienna, Austria: Österreichisches.

SS 187120, 1998. Biofuels and peat—fuel pellets—classification. Stockholm, Sweden: Swedish Standards Institution.

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