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Algal biomass as a binding agent for the densification of Miscanthus

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Abstract

Purpose: Lignocellulosic biomass has been regarded as an important future energy source due to its excessive availability; however, the wide application of this material for many applications is restricted by the high costs associated with densification, transportation, thermo-chemical pretreatment and conversion. In order to increase the density of lignocellulosic biomass, it is typically compressed into pellets or briquettes. This frequently requires the addition of additives, which may negatively impact the economics of the process. Environmentally-friendly binding agents that can be obtained inexpensively are therefore desirable. This study examines the change in physicochemical properties of densified *Miscanthus* straw where algae were used as a binding agent. **Methods:** The algae (*Rhizoclonium* spp.) was obtained as a waste product from a local algal-based wastewater treatment system, dried and then added as a fine powder to milled *Miscanthus*. The material was then compressed into discs using a mounting press, which were then assessed for calorific value, compressive strength and sugar content. **Results:** We found that the algae-*Miscanthus* discs with blends of up to 30% algae had similar calorific values compared to *Miscanthus* alone (17.4 MJ kg^{-1}), with significantly reduced calorific values at higher blends. Furthermore, *Miscanthus* discs mixed with algae had significantly greater compressive strength at blends at or above 20% algae content compared to pellets made from 100% *Miscanthus* (39 N). The strength of the discs was directly proportional to the percentage of algae in the mixture, with a maximum strength of 189 N for blends with 90% algae. The glucose content of blends below 30% was not statistically different than 100% *Miscanthus*. **Conclusions:** These data provide support for the use of algae as a binding agent for biomass destined for bioenergy and bioproduct processes, and highlight an additional end use for algal biomass.

Keywords

algae, densification, lignocellulose, *Miscanthus*, pellets, wastewater

Introduction

Lignocellulosic biomass, particularly that from energy grasses, such as *Miscanthus*, is expected to contribute significantly to the future feedstock portfolio for second generation biofuels [1]. However, the wide application of this material is restricted by the high costs associated with densification, transportation, thermo-chemical pretreatment and conversion [2]. In order to increase the density of lignocellulosic biomass, it is typically compressed into pellets or briquettes [3]; however, the characteristics of compressed, low-density material, such as *Miscanthus* straw, has not been fully explored [4].

Previous research has shown that binding agents, such as lignosulfonates and gelatin, increase the durability and strength of pelleted biomass [5,6], yet are added expenses to densification strategies. An alternative strategy is to activate the inherent binding properties of lignin within the biomass; however, this strategy requires elevated temperatures and additional energy input [7]. Environmentally-friendly binding agents that can be obtained and utilized inexpensively are therefore desirable.

Alternatives to conventional wastewater treatment, such as algae-based treatment methods, have been explored for decades. Recently, the use of algae as biological agents for wastewater treatment has received wider acceptance due to an increase in operational cost of traditional wastewater system resulting from increased energy costs [8]. When algae are used for wastewater treatment, a “niche opportunity” is developed for the growth of algal biomass, which is by-product of the treatment system [9, 10]. The algal biomass produced as a waste product from the system could be used to generate biofuels, such as biogas, biodiesel or bioethanol [11]. At times, when extensive approaches for algal biofuel production are being investigated, integration of algal production with wastewater treatment systems seems logical [12].

Until recently, the solid biofuel potential of algal biomass and its potential role within the biomass densification industry has received little attention; particularly with respect to the binding ability of algal biomass. This study examines the change in physicochemical properties of densified *Miscanthus* straw where algal biomass from a biological wastewater treatment system was used as a binding agent. *Miscanthus* was chosen as a representative low-density lignocellulosic feedstock due to the widespread interest of this energy grass for future bioenergy strategies, particularly for the Midwest United States, which can be attributed to its high productivity ($15\text{--}40\text{ MT ha}^{-1}\text{ y}^{-1}$), low input requirements, and temperate growth range [2].

Materials and Methods

Biomass sources and preparation

Miscanthus (*Miscanthus x giganteus* cv. Illinois) was harvested from a farm near Pesotum, IL, and chopped into 20 mm segments for free-air storage. The algae (*Rhizoclonium* spp.) used for binding the *Miscanthus* pellets were obtained as a co-product from an algal-based wastewater treatment system from OneWater, Inc. (Indianapolis, IN) that uses Algaewheel[®] technology (Fig. 1). Air-dried *Miscanthus* and algae were milled with a Wiley mill (20 mesh) and *Miscanthus*-algae blends of different ratios ranging from 10% algae/90% (w/w) *Miscanthus* to 90% algae/10% (w/w) *Miscanthus* were prepared. Biomass blends were compressed using a 30 mm cylindrical die with a Simplimet 2 Mounting Press (Buehler, Lake Bluff, IL) at 1000 N for 5 s. A total of 6 g of material was used for each densified disc, which resulted in discs that were 30 mm in diameter and 10 mm thick.

Calorific value

Calorific value was measured using a 6200 Isoperibol Calorimeter (Parr Instrument Company, Moline, IL) according to standard procedures [13], and reported as the higher heating value (HHV). Approximately 1 g of material was used for each replicate. **Compressive strength**

Compressive strength was determined using a digital force gauge meter (DS2-220; Imada Incorporated, Northbrook, IL) and vertical wheel stand (HV-110; Imada) with 60 mm platens (AA60; Imada). Discs were compressed on their long axis between the platens until disc failure, which was measured using Force Data Acquisition Software (Imada).

Carbohydrate Analysis

Carbohydrate content was determined using a sulfuric acid hydrolysis method [14]. Approximately 300 mg of milled (20 mesh) algae and Miscanthus blends were treated with 3 mL of 72% sulfuric acid for 1 h, diluted to 87 mL with water, and then autoclaved (121°C) for 1 h. The mixture was then filtered through a medium porosity crucible to remove insoluble material. The resulting hydrolysate was neutralized with calcium carbonate, filtered (0.2 µm) and then analyzed using a Beckman System Gold HPLC (Beckman Coulter, Inc., Indianapolis, IN) with a refractive index detector (Jasco Inc., Easton, MD). Glucose and xylose were separated using a 300 x 7.8 mm Aminex HPX-87P column (Bio-Rad Laboratories, Inc., Hercules, CA) at 85°C with water as the mobile phase at a flow rate of 0.6 mL min⁻¹.

Ash and Moisture Content

The ash content was determined gravimetrically as the percentage of oven-dried (105°C) material remaining after heating to 550°C for 1 h using a muffle furnace according to Sluiter *et al.* [15]. The moisture content was calculated by comparing the mass of the material after heating to 105°C for 24 h to that of the material under ambient conditions.

Data analysis

Data were subjected to one-way ANOVA followed by Tukey or Bonferroni pairwise comparisons using Origin 8.1 (OriginLab, Northampton, MA).

Results and Discussion

Compressive Strength

The densification of biomass is often necessary for storage, shipping and end-use processes, and a number of tests have been developed to measure the strength of material that has been densified [5]. In the present study, the compressive strength (failure point) of discs prepared from blends of algae and *Miscanthus* were examined (Fig. 2). Other than those at 10%, all discs tested had compressive strengths that were significantly greater than *Miscanthus* alone, with compressive strength proportional to the percentage of algae in the discs. Direct comparisons with other forms of compressed biomass described in the literature are difficult due to differences in forming equipment and pressure, disc/pellet size and strength-testing equipment. The inability to directly compare the compressive strength data of the current study to existing studies further supports the need for a standardized method used to assess the characteristics of compressed biomass, which was recommended by Kaliyan and Morey [5].

Calorific Value

The calorific value of biomass is an often reported parameter that has a major impact on the utility of a particular feedstock, with a larger volume of material required for lower energy materials to produce the same amount of energy as high density materials [16]. It was therefore critical to assess the calorific value of algae and *Miscanthus* blends. Calorific values (reported as HHV) were generally inversely proportional to the amount of algae in the blend as a result of the difference between calorific values of pure *Miscanthus* (17.4 MJ kg^{-1}) and algae (11.0 MJ kg^{-1}). Despite this trend, there were no significant differences between *Miscanthus* alone and blends of

30% algae or lower (Fig. 2). This suggests that algal blends within a range of 0-30% can be used to increase compression strength of Miscanthus without significant loss in energy content.

Sugar Content

The carbohydrate composition of biomass is particularly important to a number of bioenergy processes. Of the sugars available from plant biomass, glucose and xylose are the most dominant and are particularly valuable for bioconversion (*e.g.* fermentation) to biofuels [17]. Accordingly, the glucose and xylose content was explored in each blend of algae and Miscanthus (Fig. 3). The data indicate that the amount of glucose liberated from Miscanthus by acid hydrolysis was not significantly different from blends with 10, 20 and 40% algal biomass. The glucose content of the 30% algae blend was not statistically different from these blends, but was significantly different than Miscanthus alone ($p=0.046$). In contrast, the xylose content determined by acid hydrolysis at a blend of 10% algae was 44% lower compared to pure Miscanthus. This is attributed to the relatively low level of xylose in pure algae compared to glucose (Fig. 3). Chen *et al.* [18] showed similarly low percentages of xylose in algae by dry weight (3.7%) compared to glucose (11.0%). As a result, xylose content is more adversely affected compared to glucose content with higher percentages of algae in blends with Miscanthus.

Ash and Moisture Content

Ash content is a key parameter for compressed biomass, especially when the material will be utilized with combustion technologies [16], where residual ash is a by-product that poses maintenance and/or disposal challenges. The ash content of algae and Miscanthus blends averaged $3.4 \pm 0.3\%$ by dry weight, with no significant changes between mixtures (data not shown), which is within the pellet fuels industry (PFI) utility standard for residential/commercial fuel of $<6\%$ [19]. The moisture content for Miscanthus ($9.0 \pm 0.3\%$) and algae ($8.0 \pm 0.1\%$)

under ambient conditions were significantly different ($p=0.009$), although both were within the PFI utility standard for moisture content [19].

Conclusion

Algal biomass has been shown to be an effective binding agent for *Miscanthus*, with significant increases in compressive strength with discs composed of at least 20% algae. At this same percentage, there is no significant decrease in calorific value or glucose content as measured by acid hydrolysis. Furthermore, this study highlights an additional potential end-use for algal biomass generated from bioenergy processes (*e.g.* biodiesel production) or other industrial activities, such as algae-based wastewater treatment.

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References

- [1] Somerville, C., Youngs, H., Taylor, C., Davis, S.C., Long, S.P.: Feedstocks for lignocellulosic biofuels. *Science* **329**(5993), 790-792 (2010)
- [2] Li, Y., Li, X., Shen, F., Wang, Z., Yang, G., Lin, L., Zhang, Y., Zeng, Y., Deng, S.: Response of biomass briquetting and pelleting to water-involved pretreatments and subsequent enzymatic hydrolysis. *Bioresource Technol.* **151**, 54-62 (2014)
- [3] Stelte, W., Clemons, C., Holm, J.K., Sanadi, A.R., Ahrenfeldt, J., Shang, L., Henriksen, U.B.: Pelletizing properties of torrefied spruce. *Biomass Bioenerg.* **35**, 4690-4698 (2011)
- [4] Lehmann, B., Schroder, H.-W., Wollenberg, R., Repke, J.-U.: Effect of Miscanthus addition and different grinding processes on the quality of wood pellets. *Biomass Bioenerg.* **44**, 150-159 (2012)
- [5] Kaliyan, N., Morey, R.V.: Factors affecting strength and durability of densified biomass products. *Biomass Bioenerg.* **33**(3), 337-359 (2009)
- [6] Kuokkanen, M., Vilppo, T., Kuokkanen, T., Stoor, T., Niinimäki, J.: Additives in wood pellet production - a pilot-scale study of binding agent usage. *Bioresources* **6**(4), 4331-4355 (2011)
- [7] Finney, K.N., Sharifi, V.N., Swithenbank, J.: Fuel pelletization with a binder: Part I - identification of a suitable binder for spent mushroom compost-coal tailing pellets. *Energ. Fuels* **23**(6), 3195-3202 (2009)
- [8] Pittman, J.K., Dean, A.P., Oundeko, O.: The potential of sustainable algal biofuel production using wastewater resources. *Bioresource Technol.* **102**(1), 17-25 (2011)
- [9] Park, J.B.K., Craggs, R.J., Shilton, A.N.: Wastewater treatment high rate algal ponds for biofuel production. *Bioresource Technol.* **102**(1), 35-42 (2011)

- [10] Ometto, F., Whitton, R., Coulon, F., Jefferson, B., Villa, R.: Improving the energy balance of an integrated microalgal wastewater treatment process. *Waste Biomass Valor.* **5**(2), 245-253 (2014)
- [11] Craggs, R.J., Heubeck, S., Lundquist, T.J., Benemann, J.R.: Algal biofuels from wastewater treatment high rate algal ponds. *Water Sci. Technol.* **63**(4), 660-665 (2011)
- [12] Singh, A., Nigam, P.S., Murphy, J.D.: Mechanism and challenges in commercialization of algal biofuels. *Bioresource Technol.* **102**(1), 26-34 (2011)
- [13] BS EN 14918:2009. Solid biofuels. Determination of calorific value.
- [14] Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D., Crocker, D.: Determination of structural carbohydrates and lignin in biomass. NREL/TP-510-42618 (2008)
- [15] Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D.: Determination of ash in biomass. NREL/TP-510-42622 (2008)
- [16] Carroll, J.P., Finnan, J.: Physical and chemical properties of pellets from energy crops and cereal straw. *Biosyst. Eng.* **112**(2), 151-159 (2012)
- [17] Wang, X., Jin, M., Balan, V., Jones, A.D., Li, X., Li, B.Z., Dale, B.E., Yuan, Y.J.: Comparative metabolic profiling revealed limitations in xylose-fermenting yeast during co-fermentation of glucose and xylose in the presence of inhibitors. *Biotechnol. Bioeng.* **111**(1), 152-164 (2014)
- [18] Chen, R., Thomas, B.D., Liu, Y., Mulbry, W., Liao, W.: Effects of algal hydrolyzate as reaction medium on enzymatic hydrolysis of lignocelluloses. *Biomass Bioenerg.* **67**, 72-78 (2014)
- [19] <http://pelletheat.org/wp-content/uploads/2011/11/standards-table.jpg> (May 22, 2014).

Figure Captions:

Fig. 1. Algaewheel[®] technology from OneWater, Inc. used to treat wastewater.

Fig. 2. Compressive strength and calorific value of pellets composed of varying blends of milled algae and Miscanthus. Letter differences indicate significant differences at the 95% level using pairwise comparisons, where bars sharing at least one letter indicates no significant difference.

Fig. 3. Glucose (gray) and xylose (dark gray) content of blends of algae and Miscanthus. Letter differences indicate significant differences at the 95% level using pairwise comparisons, where bars sharing at least one letter indicates no significant difference.

Fig. 1.

Fig. 2.

Fig. 3.