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Comparison of big bluestem with other native grasses: Chemical composition and biofuel yield

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ABSTRACT

Multiple entry selections of big bluestems and three native C4 grass species, including switchgrass, miscanthus, and Conservation Reserve Program (CRP) mixture grass, were evaluated for their chemical composition and ethanol yields via diluted sulfuric acid pretreatment following simultaneous saccharification and fermentation (SSF). Big bluestem and switchgrass had a similar glucan content that was significantly higher than miscanthus and CRP grass. Big bluestem had the highest average mass recovery (55.56%) after acid pretreatment, and miscanthus had the lowest mass recovery (46.3%). A positive correlation was observed between glucan recovery and mass recovery. No significant difference in average efficiency of SSF was observed among four native grasses, but ethanol yields from big bluestem entries, which averaged 26.2%, were consistently greater than the other three grasses. The highest ethanol yield among the 10 entries was from big bluestem cultivar KAW (27.7%). Approximately 0.26 kg ethanol with 9.4 g/L concentration can be produced from 1 kg of big bluestem biomass under current processing conditions. A negative relationship exists between lignin content and the efficiency of SSF with $R = -0.80$, and a positive relationship exists between ethanol yield and glucan content with $R = 0.71$.

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1. Introduction

The development of biofuels from lignocellulosic biomass could reduce our dependence on fossil fuel resources, reduce greenhouse gas emissions, and reduce competition between food and fuel [1]. Perennial herbaceous energy crops are abundant sources of lignocellulosic biomass, but they are not commonly recognized as important as traditional agricultural residues. In fact, perennial herbaceous energy crops may offer many economic benefits, including high yield, ability to grow easily in an annual cycle without pesticides or fertilizers and with low energy input, ability to increase wildlife biodiversity, ability to increase soil quality, ability to reduce soil nutrient losses and to promote nutrient recycling from municipal and agricultural wastes, ability to sequester soil carbon, and ability to mitigate greenhouse gas emissions [2]. The United States (US) Department of Energy (DOE) established the Herbaceous Energy Crops Research Program (HECP) in 1984 to develop data and information leading to commercially viable systems for production of herbaceous biomass for fuels and energy feedstocks [3]. Thirty-five potential herbaceous crops, 18 of which are perennial grasses such as big bluestem, switchgrass, and Conservation Reserve Program (CRP) mixture grass, were initially studied in the HECP [4].

Big bluestem (*Andropogon gerardii*), an ecologically dominant warm-season (C4) perennial native grass that comprises as much as 80% of plant biomass in the Midwestern prairies of North America, has been reported that the average and range of cellulose content, hemicellulose content, and biomass yield were 37.2% with a range of 33.5–49.8%, 23% with a range of 17.7–31.5%, and 7 Mg/ha with a range of 3.2–11.4 Mg/ha, respectively. The potential ethanol per hectare unit was calculated by multiplying yield data (kg/ha) bases on cellulose content (% of dry biomass), yielding a factor of 1.11 to

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account for weight gain during hydrolysis because of the addition of a water molecule. During glucose to ethanol fermentation, the resulting kilogram glucose per hectare data was multiplied by 0.5114 to account for the weight loss of two carbon dioxide molecules, and multiplied by 1.2764 to convert ethanol weight to volume (kilogram to liter). The average estimated ethanol yield of big bluestem calculated from a previous study was 1886 L/ha [5]. Big bluestem productivity is relatively high due to efficient utilization of nutrients; research has shown that big bluestem produces twice the biomass per unit of applied nitrogen compared with switchgrass or indiangrass [6]. Big bluestem also establishes easily from seed and spreads vigorously by vegetative growth of underground rhizomes with a robust root system [7]. In addition to low input costs and other economic considerations, bluestem prairie carries the advantage of serving a range of purposes in the ecosystem because it provides wildlife habitat, cattle grazing, and hay and pasturelands [8].

Switchgrass (*Panicum virgatum*) is another native C4 perennial grass on North America prairies that achieves biomass yield similar to or slightly higher than big bluestem [9]. Switchgrass has been selected as a “model” high-potential energy crop by Oak Ridge National Laboratory (ORNL) [4]. Switchgrass had the highest yields in DOE research trials in the mid-1980s, and breeding work was subsequently focused on switchgrass to the exclusion of other options [10]. Switchgrass has potential as a renewable fuel source but will necessitate large infrastructural changes, and even at maximum output, such systems could not provide the energy currently derived from fossil fuels [11]. Previous reviews have summarized switchgrass's potential as an energy crop in terms of historical study, biological and agronomical aspects, biofuel production via sugar and thermal platforms, and other utilizations and constraints [4,10,11].

Miscanthus (*Miscanthus sinensis*), originating from Asia, is a perennial non-wood rhizomatous tall grass native to subtropical and tropical regions. Miscanthus was first cultivated in Europe in the 1930s, when it was introduced from Japan [12]. Miscanthus has been used as a biofuel feedstock in Europe since the early 1980s and recently in North America for productivity trials [12–14]. Miscanthus, the European “model” herbaceous energy crop, was initially studied as a fuel source for steam and power generation. Research showed biomass yields of established miscanthus stands from 38.1 to 60.8 Mg/ha [12–14]. Miscanthus offers many advantages, such as low fertilizer and pesticide requirements, and some limitations, which are high establishment costs, poor overwintering, and insufficient water supply at some sites [12]. Miscanthus was recently identified as a promising energy crop for the Midwest, with yields exceeding those of switchgrass, the DOE model species, in U.S. side-by-side replicated field trials [15].

The Conservation Reserve Program (CRP) is a cost-share and rental payment program under the United States Department of Agriculture (USDA) [16] that is administered by the USDA Farm Service Agency (FSA) to prevent soil erosion and enhance groundwater recharge from highly erodible lands. CRP grasses comprise native perennial grasses such as big bluestem, indiangrass, little bluestem, switchgrass, sideoats grama, silver bluestem, sand lovegrass, bundleflower, sunflower, and Old World bluestem [17]. The percentage of each species within the grass mixture varies by location. CRP grass has a great biomass yield potential, with 38–63 million dry metric tons anticipated every year [18]. Research on CRP grass mixture has focused primarily on its impact on soil quality [19]. Linnebur recently studied the potential of CRP grass for biofuel production, focusing on effects of torrefaction as a pretreatment method on chemical and elemental compositions, thermal properties, and energy density of CRP biomass [20].

Although research data for big bluestem are less available than for switchgrass and miscanthus, natural pure stands of big bluestem are more common than switchgrass in Midwestern tallgrass prairies. In general, big bluestem is more palatable than hay and grass in the latter part of the season, so producers may prefer big bluestem as a long-term option [21]. Some landowners also consider switchgrass excessively invasive [22]. Production of ethanol and value-added chemicals via consolidated bioprocessing (a direct fermentation process) have indicated that big bluestem is a superior feedstock to switchgrass and eastern gamagrass [23]. Another advantage of big bluestem is that it can produce twice the biomass per unit of applied nitrogen than switchgrass or indiangrass [7]. In addition, big bluestem is the dominant species in the second year, whereas switchgrass dominates in the first establishment year [24], thus reinforcing that big bluestem increased significantly when grown in monoculture or with indiangrass and switchgrass in the second year [25]. Madakadze et al. reported that in southwestern Quebec, Canada, the list of average lignocellulose content ranked from high to low was cordgrass, big bluestem, switchgrass, sandreed, and indinagrass [26]. Waramit et al. reported that big bluestem tends to contain higher cellulose concentrations than switchgrass [27].

Our research has shown that big bluestem has favorable bioconversion characteristics and comparable bio-oil yield through hydrothermal conversion [28–30]. Few direct comparisons of the potential biofuel yield of big bluestem with other herbaceous perennial biomasses are available. Therefore, the objectives of this research were to compare the chemical composition of big bluestem and three other promising native herbaceous perennial biomass including switchgrass, miscanthus, and CRP grass, to study their potential on ethanol yield through sulfuric acid pretreatment following simultaneous saccharification and fermentation (SSF), and to provide useful insights for bioenergy industry and biomass producers.

2. Materials and methods

2.1. Materials

Three big bluestem ecotypes, including Cedar Bluffs (CDB), Top of the World (TOW), 12Mile (12 M), and the KAW cultivar, which are widely planted to restore marginal lands, were harvested in October 2013 from reciprocal garden plots at the Plant Materials Center in Manhattan, KS. Four switchgrass genotypes (three genotypes, SWG 2007-1, SWG 2007-2, and SWG 2007-3, were from Oklahoma State University's switchgrass breeding program and were provided by Dr. Yanqi Wu) and one switchgrass native (SWNT) were used in this study. The switchgrass field was established in 2010 by transplanting seedlings and thereafter harvesting annually in fall (October–November). The miscanthus field was established in 2009. Plant biomass samples for switchgrass and miscanthus were harvested from the Kansas State University Agronomy Farm in Manhattan, KS, in late October 2013 and used for further analyses. CRP grass was generously provided by an agricultural farm at Bison, KS. The grass samples were ground into powder using a Retsch cutting mill (Haan, Germany) with a 1-mm sieve. All chemicals used for this research were purchased from Sigma Chemical Co. (St. Louis, MO).

2.2. Composition analysis

Moisture content of ground biomass samples was determined by drying approximately 2 g of each sample in a forced-air oven at 105 °C for 4 h [31]. Extractives, glucan, and lignin contents of the biomass samples were determined by following NREL laboratory