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Giant reed: A competitive energy crop in comparison with miscanthus

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A B S T R A C T

Arundo donax L. (giant reed) is a perennial rhizomatous grass and a promising energy crop due to its high biomass yield, adaptation to different types of soils and weather conditions, lower tillage requirement than traditional crops, and phytoremediation properties. This review is a comprehensive comparison of giant reed with miscanthus, a well-known energy crop, in terms of biomass production and conversion to bioenergy and bioproducts. Compared with miscanthus, giant reed has higher biomass yield and can adapt to a broader range of environments, but it requires more energy input for planting. Giant reed has a higher invasive potential than *Miscanthus × giganteus*, necessitating ecological control, such as preventing cultivation sites from flooding, strict nutrient management in surrounding areas, and removal of giant reed from riparian ecosystems adjacent to fire prone shrub lands. Generally, giant reed showed comparable yields to miscanthus in bioenergy production, but achieved better performance than miscanthus in production of particle boards, paper, and xylo-oligosaccharides. Suggested future research on giant reed includes testing multiple harvests per year, assessing environmental benefits and reducing potential hazards, evaluating advanced pretreatment technologies, integrating processes for producing different bioenergy/bioproducts, and investigating effects of management practices on the production of fuels and products.

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1. Introduction

Concerns about fossil fuel depletion and environmental degradation have spurred great interest in renewable energy sources, which can reduce dependence on fossil fuels and mitigate climate change caused by carbon dioxide emissions [1]. As the largest potential source of renewable energy, biomass currently provides about 10% of world's primary energy supply, and is expected to contribute up to a third to meet the global energy demand in the future [1]. Different types of bioenergy, such as gaseous, liquid, and solid fuels can be produced from biomass [2–4]. Besides, many value-added bioproducts can also be derived from biomass, which can improve the sustainability of bioenergy production processes [2,3]. However, existing biomass feedstocks are very diverse and include energy crops, forestry and agricultural residues, and other organic wastes (such as organic municipal solid waste), creating processing challenges. In order to meet the increasing bioenergy demand, dedicated energy crops that can provide reliable and sustainable biomass feedstocks with high yields and low production costs are highly desirable, although other biomass sources can be alternatives.

Arundo donax L. (giant reed), is a perennial rhizomatous grass that belongs to the *Arundo* genus of the *Poaceae* family, *Arundinoideae* subfamily, and *Arundineae* tribe. It has recently been highlighted due to its high biomass yield and other advantages, such as adaptation to different types of soils and weather conditions, lower tillage requirement than traditional crops, and phytodepuration properties [2]. However, compared to many other candidate energy crops, giant reed has been less studied. Plants can be classified into three groups, i.e. C3, C4, and crassulacean acid metabolism (CAM), based on their photosynthetic pathways. So far, most of the studies on energy crops for bioenergy production have focused on C4 plants, which are generally more productive than C3 and CAM plants, and have higher water and nitrogen use efficiency than C3 plants. Miscanthus (a genus of the *Poaceae* family, *Panicoideae* subfamily, and *Andropogoneae* tribe) is a typical C4 perennial rhizomatous grass, and has been well studied and considered as one of the most promising energy crops [5]. Interestingly, although giant reed is a C3 plant, it has unusually high saturation levels in its photosystem compared to normal C3 plants. As a result, giant reed can achieve high biomass yields that could be competitive to those of C4 plants, such as miscanthus [2].

A number of aspects need to be considered when selecting plants as energy crops. Cultivation and harvesting practices may significantly affect biomass yields. Environmental impacts must be evaluated prior to farm scale application. Furthermore, suitable technologies and their performance for biomass conversion to bioenergy and bioproducts may vary for different crops. Based on studies of biomass production and conversion performance of giant reed and miscanthus that have been reported in the literature, giant reed has the potential to be competitive with miscanthus in these aspects. However, to date, there have been no reviews that systematically and comprehensively compare giant reed and miscanthus as feedstocks for production of bioenergy and bioproducts.

This paper reviews the current status in biomass production and conversion technologies for production of bioenergy and bioproducts from giant reed and miscanthus. The discussion on biomass production covers cultivation and harvesting, biomass yield, and environmental impacts. Following that, composition and theoretical energy potential, and production of liquid, gaseous, and solid fuels and various bioproducts are reviewed. Challenges and future approaches in giant reed-based bioenergy and bioproducts are also discussed.

2. Biomass production

2.1. Plant Propagation

A massive number of energy crops must be planted in order to meet the huge biomass demand for energy. For example, about 500 million of *Miscanthus* × *giganteus* plants (or 50,000 ha with a density of 10,000 plants per ha) would be needed to achieve 25% of the total requirement for renewable energy in the UK [6]. Giant reed and *M.* × *giganteus*, the miscanthus species most commonly studied for biomass production, are sterile plants that normally do not produce seeds. Alternatively, they can be propagated asexually from their vegetative parts, such as the rhizome and stem, or from axillary buds using *in vitro* propagation technologies.

2.1.1. Rhizome propagation

Rhizome propagation is the most commonly used method for establishing giant reed in field-plot experiments [7–9], and has also been well studied for establishing *M.* × *giganteus* [6]. Manual inspection and sizing of rhizomes is helpful to ensure their compatibility with planting equipment, but is unpractical and labor intensive for cultivation at farm scale. The estimated cost for traditional rhizome propagation was estimated to be about \$1.25 per plant in 2006 [8]. Assuming a density of 10,000 plants ha^{-1} and an average biomass yield of 40 t ha^{-1} per year for 10 years, the establishment cost would be \$31 t^{-1}, which is economically unfeasible considering the expected farm gate price of \$40 t^{-1}[10,11]. Another drawback of rhizome propagation is the limitation in the multiplication ratio, which is the increase in planting material over what is planted. For example, the multiplication ratio for *M.* × *giganteus* is typically about 1:3, allowing the planted area to increase by only three-fold annually [6]. In other words, about 33% of area is required for preparing rhizomes.

There have been few reports on mechanization of giant reed rhizome propagation. However, Assirelli et al. [12] demonstrated the viability of a mechanical method for on-site giant reed rhizome collection using a modified stump grinder. Mechanization of rhizome propagation (or macro-propagation) has been developed for cultivation of *M.* × *giganteus*. The mechanical method includes