INTRODUCTION

The use of bioenergy is advantageous for reducing fossil energy dependence and greenhouse gas emissions, it is considered to be a substantial proportion of our future energy supply (Matzenberger et al., 2015). Bioenergy crops are a primary feedstock for bioenergy production, especially for liquid biofuel, as their photosynthetic efficiency is usually high and they have high biomass yields, high content of oils, sugars, starches, or cellulose. However, the ‘First-generation’ bioenergy from food and vegetable crops may conflict with food security and shows high energy input/output ratios, while the development of ‘second-generation’ bioenergy crops can help solve those problems (Boehmel, Lewandowski, & Claupein, 2008; Mohr & Raman, 2013; Naik, Goud, Rout, & Dalai, 2010). ‘Second-generation’ biofuels can be derived...
from the lignocellulosic biomass, including grasses such as switchgrass (Panicum virgatum), miscanthus (Miscanthus sinensis), and giant reed (Arundo donax) (Clifton-Brown et al., 2017; Corno, Pilu, & Adani, 2014; McLaughlin & Kszos, 2005; Pidlisnyuk, Stefanovska, Lewis, Erickson, & Davis, 2014). These grasses are usually easily adaptable species and have been introduced to different regions and countries; however, the presence of such plants may be detrimental to the regional ecosystems. The invasiveness of bioenergy crops has attracted widespread attention (Barney & Ditomaso, 2008; Smith et al., 2013). For instance, the giant reed has been named one of the 100 of the World’s Worst Invasive Alien Species (http://www.iucngisd.org/gisd/species.php?sc=112). Therefore, the use of native bioenergy crops attracts much interest (Dominguez, Montiel, Madejón, Diaz, & Madejón, 2017; Wang et al., 2014).

Some famous second-generation bioenergy crops such as miscanthus are derived from China (Clifton-Brown et al., 2017; Wang et al., 2014; Xue, Kalinina, & Lewandowski, 2015; Xue, Lewandowski, Wang, & Yi, 2016). Also, some other excellent native bioenergy grass has been identified in recent years, including the sweetcane (Erianthus arundinaceus) (Retzius) Jeswiet) (Dao et al., 2013; Zeng, Zhang, Liu, & Liu, 2013). Sweetcane is a warm-season, tall-growing perennial species native to much of southern China, and has traditionally been considered as a potentially important genetic resource for use in sugarcane breeding programs, thereby resulting in much research with respect to its biological characteristics and genetic resources. Recently, this species has been targeted for use as a bioenergy perennial because of its high fiber content and biomass yield. As a potential feedstock for bioethanol production, an increasing amount of research now focuses on its biomass characteristics and conversion technologies. Meanwhile, there are studies showing that the sweetcane has great potential for environmental restoration. The use of an environmentally stress-tolerant plant for energy production has been considered as a Win-Win paradigm (Robertson et al., 2017). Therefore, the purpose of this paper is to systematically summarize current knowledge on sweetcane: its biology, phenology, biogeography, agronomy and conversion, as well as analyze its potential in bioenergy production and environmental restoration.

2 | BIOLOGY

2.1 | Morphology and phenology

Sweetcane is a tall grass, forming large clumps that are approximately 0.3–6 m tall, with stem diameters of 1–3 cm, leave width of 1–4 cm, and leave length of 0.2–1.0 m (Figure 1) (Chen, & Phillips, 2006; Liang, 2011).

As a perennial grass, every year, the aboveground system of this species usually shoots in mid-March, the first month of spring in southern China, and the tillering occurs in late April. In late June, the first month of summer, it begins to joint. In late September, sweetcane heads, and flowers approximately 1 month later, the Caryopsis matures. In December, the first month of winter, the shoot system begins to wither (Figure 1) (Hou et al., 2015; Liang, 2011).

2.2 | Taxonomy and genetic diversity

Sweetcane belongs to the family Gramineae; however, its assignment at the genus-level is disputed between Saccharum and Erianthus. In literature, the commonly used Latin names of sweetcane are Saccharum arundinaceum Retz. and Erianthus arundinaceus (Retzius) Jeswiet. Both Saccharum and Erianthus belong to the Saccharum complex, which includes the genera Saccharum, Erianthus, Sclerostachya, Narenga, and Miscanthus, as they are thought to be involved in the origin of Saccharum (Daniels, Smith, Paton, & Williams, 1975; Mukherjee, 1958). Some species in this complex have been identified as promising bioenergy crops, such as M. sinensis, M. sacchariflorus, and S. officinarum.

Molecular phylogenetic analysis based on ITS sequences of some species in the Saccharum complex from Genbank indicated that sweetcane had a close genetic relationship with Erianthus (Figure 2). Moreover, other molecular classification methods, such as random amplified polymorphic DNA (RAPD) (Nair & Mary, 2006), amplified fragment length polymorphism (AFLP), microsatellites, and chloroplast genome analysis, all showed that sweetcane should be classified either as Erianthus or within a new genus (Feng, Wu, & Chen, 1997; Tsuruta, Ebina, Kobayashi, & Takahashi, 2017). Lignin gene-based TRAP markers also showed that sweetcane genotypes clustered as a distinct group that was highly divergent from the Saccharum (Suman et al., 2012). Thus, we use the Latin name Erianthus arundinaceus for sweetcane in this paper.
As sweetcane is of interest in sugarcane breeding programs and has a great potential in bioenergy production, a large number of wild germplasm resources have been collected by several research institutes (Table 1). These collections have covered almost all of the sweetcane distribution areas in China. Knowledge of the wild germplasm is important for efficient breeding programs because it provides the basis for development of desirable plants.

Sweetcane displays three cytotypes: \( 2n = 20 \), \( 2n = 40 \), and \( 2n = 60 \) (Cai, Wen, Fan, Wang, & Ma, 2002; Tagane, Misa, Ponragdee, Sansayawichai, & Sugimoto, 2011). Among them, \( 2n = 60 \) is the most common (Yang, Li, Xiao, & He, 1997). The genetic diversity of the sweetcane has been investigated with several molecular markers, such as AFLP (Tsuruta, Ebina, Kobayashi, Hattori, & Terauchi, 2012), simple sequence repeat (SSR) (Tsuruta et al., 2012), RAPD (Nair & Mary, 2006), and sequence-related amplified polymorphism (SRAP) (Zhang et al., 2013). Assessment of sweetcane genetic diversity showed that a high level of diversity exists within its distribution area. These genetic diversity studies provide useful information for introgression breeding and germplasm conservation.

### 2.3 Photosynthetic characteristics

Sweetcane is a \( C_4 \) plant with Kranz anatomy (Yang, Li, Yu, & Liu, 2011). Research showed that the daily variation in net photosynthetic rate \( (P_n) \) of sweetcane leaves had a bimodal curve and a ‘midday depression’ phenomenon (Zhang, Gan et al., 2017). The \( P_n \) of sweetcane was related to its altitude, with relatively high rates for populations distributed below 1,000 meters altitude (Yang, Pan, Yang, Li, & Xiao, 2006).

Preliminary field studies in southern China (Hubei Province) showed that the maximum \( P_n \) observed under field conditions of sweetcane was slightly lower than \( Pennisetum purpureum \), but higher than other bioenergy grass, such as \( M. floridulus \) and \( A. donax \) (Zeng, 2013). However, the differences between sweetcane genotypes were not considered in

---

**TABLE 1** Collection of wild sweetcane resources in China

| Collectors | Number of resources | Collection range | References |
|------------|---------------------|------------------|------------|
| Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences | 50 | Guangxi | Song et al., 2014 |
| Fujian Agricultural and Forestry University | 30 | Jiangxi, Guizhou, Yunnan, Sichuan, Fujian, Hainan, Guangxi, Guangdong | Zhang et al., 2004 |
| Sugarcane Research Institute, Yunnan Academy of Agricultural Sciences | 162 | Yunnan, Fujian, Guizhou, Hainan, Sichuan, Jiangxi, Giammgdong, Guangxi, Zhengjiang | Xu et al., 2015 |
| Sichuan Academy of Grassland Sciences | 49 | Yunnan, Guizhou, Sichuan, Shanxi, Gansu, Guangxi, Guangdong, Hainan | Dao et al., 2013 |

---

**FIGURE 2** Molecular phylogenetic analysis of ITS-1 sequences by maximum likelihood method. Open circles represent sweetcane, closed circles represent bioenergy crops, and no circles represent other species.
those studies; more research regarding the features of different genotypes could be conducted by following examples of other bioenergy crops (Kalinina et al., 2017; Lewandowski et al., 2016).

2.4 | Resistance

Sweetcane can adapt to a variety of environments, resist to abiotic and biotic stressors including drought, saline soils, cold, and disease, thus playing an important role in sugarcane breeding. This is also beneficial for its cultivation in different types of marginal land.

2.4.1 | Drought

Sweetcane has the agronomic trait of drought tolerance, which can be used for sugarcane improvement by hybridization. It has been proved that the drought resistance in hybrid offspring of sweetcane and sugarcane was significantly enhanced (Chen, Deng, & Guo, 2007). Moreover, different cultivars of sweetcane have distinct drought resistance. Two cultivars with remarkable drought resistance were identified in Hainan Province of China by Wu, Pan, Chen, and Zhang (2008).

Some genes related to drought resistance have been cloned from sweetcane (Kharte et al., 2016; Liu, Hu, Yao, Xu, & Xing, 2016; Zhang et al., 2007). The gene HSP70 from sweetcane had been shown to play an important role in Sugarcane (Saccharum spp. hybrid) in response to drought stress (Augustine, Cherian, Syamaladevi, & Subramonian, 2015). Overexpression of sweetcane EaDREB2 gene in sugarcane enhanced drought tolerance to a greater extent than the untransformed control plants (Augustine, Ashwin et al., 2015). Moreover, sweetcane was shown to develop arbuscular mycorrhizal fungi (AMF) association in their natural habitats, which could further enhance drought tolerance (Mirshad & Puthur, 2016).

2.4.2 | Salt

Sweetcane can also be tolerant to salt stress (Mirshad, Chandran, & Puthur, 2014). Under NaCl stress, sweetcane could maintain a dynamic balance of active oxygen metabolism (Guo, Guo, Guo, & Zhang, 2005). The potential of high NaCl tolerance made sweetcane an appropriate choice for growing in marginal lands, which was affected by high NaCl levels. Some genes related to drought resistance were shown to play a role in salt resistance (Augustine, Ashwin et al., 2015).

2.4.3 | Cold

Sweetcane is a warm-season perennial distributed in both tropical and subtropical regions, so its cold resistance, especially its ratoon cold tolerance, is not very strong (Burner et al., 2017). However, some accessions and breeding lines have demonstrated overwintering abilities in Nasushiobara, Japan, where the mean minimum air temperature in winter was −4.4°C (Matsumani et al., 2018). Moreover, the ability of hybrid sweetcane-sugarcane offspring to resist low temperatures was much stronger than that of sugarcane (Ram, Sreenivasan, Sahi, & Singh, 2001).

2.4.4 | Disease

Reports on sweetcane disease resistance were mainly focused on sugarcane-related diseases, such as Drechslera sacchari and Puccinia erianthi (Dai, 1993; Li, Huang, Fan, & Ma, 2005). Some disease-resistance genes of sweetcane have been cloned (Que et al., 2009), which could be inherited by intergeneric hybridization, thus improving the disease resistance of sweetcane-sugarcane hybrid offspring (Ram et al., 2001).

2.5 | Regeneration system

The reproduction system for sweetcane has been successfully established. Seeds, young leaves, and leaf sheaths were commonly used explants (Uwatoko, Tanaka, Saito, & Gau, 2011; Wu et al., 2012; Zhang, Yan et al., 2017). Calluses could be efficiently induced on Murashige and Skoog (MS) medium with 2,4-dichlorophenoxyacetic acid (2,4-D) and 6-benzyladenine (BA) (Li, Yang, Xiao, & He, 1998; Uwatoko et al., 2011; Wu et al., 2012; Zhang, Yan et al., 2017). Plantlets could be regenerated on MS medium with or without cytokinin, while very few genetic changes among the regenerated plants were observed (Uwatoko et al., 2011). However, a successful genetic transformation system for sweetcane has not yet been reported.

3 | HABITATS AND DISTRIBUTION

3.1 | Habitat diversity

Sweetcane can grow in a variety of habitats in southern China, such as roadsides, hill slopes, riversides, abandoned agricultural lands, courtyards, and even the rocks (Figure 3). Generally, this species favors areas with abundant sunlight.

The roadside, including highways and common roads, is the most common habitat of sweetcane (Dao et al., 2013; Fan, Wu, & Du, 2017; Hu, Wang, Yu, & Yang, 2015; Zhang, Lei, Zhen, Tao, & Yu, 2006). As a species that can thrive in barren landscapes, sweetcane is usually the first to grow along new roadsides. Furthermore, planting sweetcane on the roadside is conducive to soil and water conservation.

Sweetcane has a wide range of adaptability to water; it can grow on dry hill slopes as well as on wet riversides (Hao et al., 2016; Ou, Jin, Peng, Fang, & Fang, 1997). It can even be used in constructed wetlands (Jiang et al., 2005). Moreover, biomass from wetland plants is a good raw material for biomass energy production (Liu et al., 2012).
Sweetcane usually becomes a dominant species on abandoned agricultural lands in southern China (Du, Liu, Tu, & Ma, 2008), including contaminated land (Huang, Xu, Bai, Zhang, & Wang, 2011; Zeng et al., 2007).

3.2 | Distribution

3.2.1 | Distribution in China

The occurrence of sweetcane was mapped using records obtained from the Chinese Virtual Herbarium (http://www.cvh.org.cn/cms/en), the Specimen Resources Sharing Platform for Education (http://mnh.scu.edu.cn/new/), the Global Biodiversity Information Facility (www.gbif.org) and other references (Dao et al., 2013; Yan, Bai, Ling, & Chang, 2009; Zhang et al., 2013)(Figure 4). All sweetcanes were found in the tropical and subtropical areas of China, specifically in the regions east of the Tibetan Plateau, south of Huai River-Qinling Mountains line. Sweetcane was generally found below an altitude of 1,500 m; however, it could be distributed up to 2,350 m (Yan et al., 2016).

3.2.2 | Global distribution

As a warm-season species, sweetcane is mainly distributed in the subtropical to tropical areas of East Asia, South Asia, and Southeast Asia, including Bhutan, India, China, Myanmar, Thailand, Philippines, Laos, Sri Lanka, Vietnam, Indonesia, Malaysia, New Guinea, and Nepal (Chen, & Phillips, 2006; Peet, Watkinson, Bell, & Kattel, 1999). According to predictions using MAXENT species distribution modeling based on Global Climate Data WorldClim Version 2 (http://worldclim.org/version2), southern Japan, southern China, southern South Korea, the east coast of Australia, the Caribbean coast, and the southeast coast of Brazil are also suitable for sweetcane cultivation (Figure 5).

3.2.3 | Introduction and invasiveness

Sweetcane was introduced as an energy grass to Japan (Matsunami et al., 2018; Tagane et al., 2011; Uwatoko et al., 2011; Yamamura et al., 2013), as well as to Florida and North Carolina of USA (Fedenko et al., 2013; Palmer, Gehl, Ranney, Touchell, & George, 2014). The potential invasiveness of sweetcane in Florida was evaluated using the Australian Weed Risk Assessment system, and the results showed that sweetcane had a low probability of becoming invasive (Gordon, Tancig, Onderdonk, & Gantz, 2011).

4 | POTENTIAL FEEDSTOCK FOR BIOFUEL

4.1 | Biomass composition and calorific value

The composition of lignocellulosic biomass determines its utilization potential as energy crop. Higher levels of cellulose and hemicellulose are beneficial for biofuel production after enzymatic hydrolysis, whereas higher lignin content can negatively
affect the conversion efficiency. The amount of cellulose, hemicellulose and lignin of different sweetcanes are shown in Table 2. The cellulose contents of different sweetcanes range from 30.36% to 55.4%, while the hemicellulose amount ranges from 22.79% to 41.48%. Lignin content is generally from 5% to 10%, but a few can reach up to 17% (Table 2).

The biomass composition of sweetcane was comparable to that of other bioenergy crops, such as *P. virgatum*, *Miscanthus × giganteus*, *Pennisetum × purpureum*, and *M. floridulus* (Figure 6). When grown under the same conditions, sweetcane contained relatively higher cellulose content than other bioenergy crops (Hou et al., 2015). Furthermore, the cellulose content of tetraploid sweetcane was usually higher than hexaploid individuals, while the opposite was true for hemicellulose content (Yan et al., 2016).

The gross calorific value (GCV) of sweetcane ranged from 16.44 to 19.32 KJ/g (Liang, 2011). Under the same growth conditions, the GCV of sweetcane was equivalent to other energy plants, such as *Pennisetum × purpureum* and *M. floridulus*, whereas the ash free calorific value was slightly higher than other energy plants (Figure 7) (Ning, Chen, Wang, Zhang, & Qiu, 2010; Zeng, 2013).

As a perennial plant, the shoot system of sweetcane withers each winter. In a year’s growth cycle, the cellulose content increases from June to December. However, the contents of hemicellulose and lignin decrease in October. Accumulation of calorific value per unit area reaches its highest level in November (Figure 8) (Yan et al., 2014). This indicates that November is the optimal time for harvesting sweetcane as a bioenergy feedstock.

4.2 **Biomass yield**

Biomass yield is another important indicator of a grass’ efficiency as a bioenergy crop. Sweetcane had a relatively high
biomass yield when comparing with other bioenergy plants grown in the same environment (Singh et al., 2015; Zeng, 2013). The high yield of sweetcane corresponded to growth conditions, planting time, and harvest time (Palmer et al., 2014; Singh et al., 2015; Yan et al., 2014). For instance, sweetcane biomass yield reached a maximum of 43.76 t/ha in China, while its yield for the first year of growth in North Carolina, USA, was only 5.7 t/ha (Table 3). In the subtropical region of China, the highest sweetcane biomass yield was obtained in November (Yan et al., 2014).

There are also variations in dry biomass yield between sweetcane individuals. Analysis of 20 sweetcane individuals from Sichuan Province showed that the variation coefficient of dry matter production per plant was 25% (Liang, 2011). Hence, careful selection of individuals for bioenergy feedstock is required.

### 4.3 Conversion of sweetcane biomass into biofuels

Traditionally, sweetcane was collected in winter and directly burnt as fuel source in rural areas of southern China. The high calorific value of sweetcane allows for direct combustion to generate electricity or heat, as well as the production of solid...
molded fuel. More importantly, sweetcane has great potential as biomass feedstock for bioethanol and methane production (Hu et al., 2017).

4.3.1 Bioethanol production

The high cellulose content of sweetcane makes it possible to be converted into bioethanol. The practical ethanol yield of sweetcane reported by Zhang, Gan et al. (2017) was 0.17 L/kg (based on dry biomass), with broth ethanol concentration of 4.6% (v/v). Hu et al. (2017) gained a better ethanol yield of 0.19 L/kg by using other pretreatment method, but it was still lower than the ethanol yield of switchgrass (Schmer, Vogel, Mitchell, & Perrin, 2008). Therefore, the ethanol yield of sweetcane would be further increased with the improvement of pretreatment and fermentation technologies.

Pretreatment is a key step in the lignocellulose biorefinery with respect to both technology and economic aspects. Alkali pretreatment is one of the most commonly used methods for herbaceous feedstocks. Pretreatment with 2% NaOH for 1 hr, lignin content of sweetcane was reduced from 11.01% to 3.34%, while cellulose content was increased from 43.77% to 72.54% (Zhang, Xie, & Lin, 2011). Other similar pretreatments indicated that sweetcane pretreated with 1% NaOH (1 hr) resulted in the highest sugar yield of 467.9 mg/g from enzymatic hydrolysis (Panneerselvam, Sharma, Kolar, Clare, & Ranney, 2013). Ammonia based pretreatment is a type of alkali pretreatment catalyzed by ammonia under different thermodynamic states of ammonia-water mixtures and ammonia concentrations. Liquid ammonia treatment (LAT) of sweetcane could result in 70% glucan conversion and 83% xylan conversion, respectively, under the optimal pretreatment condition. The glucose and xylose yields were 573% and 1,056% higher than those of the untreated biomass (Liu et al., 2013). Furthermore, pretreatment with ozone could effectively de-lignify sweetcane with negligible sugar loss while achieving a 50% delignification and total fermentable sugar concentrations greater than 400 mg/g (Panneerselvam, Sharma, Kolar, Clare et al., 2013; Panneerselvam, Sharma, Kolar, Ranney, & Peretti, 2013).

4.3.2 Biogas production

Sweetcane can also be used as feedstock for biogas production. In rural areas of southern China, sweetcane was usually added into household biogas digesters as supplementary substrate. Potential biogas production of sweetcane was first investigated by Deren, Snyder, Tai, Turick, and Chynoweth (1991) and the results revealed that its methane yield was in the range of 0.28–0.31 L/g volatile solids (VS), which was comparable to other energy crops (Deren et al., 1991; Zhang et al., 2016). A recent study of methane production from sweetcane showed that the highest methane yield was about 83.5 L/kg (based on total solids) (Hu et al., 2017). Moreover, the yields could be further enhanced if suitable pretreatment
on the feedstock and optimization of anaerobic digestion parameters were conducted.

In India, the fibers produced by mechanical compression of sweetcane were used for paper production. The chemical oxygen demand (COD) of the resulting liquid was approximately 93,974 mg/L, indicating that 1 L of liquid can produce 40 m³ biogas (Jayabose et al., 2017).

### 5 | POTENTIAL FOR PHYTOREMEDIATION

#### 5.1 | Nutrient removal

Low nutrient input is an advantage for the second-generation bioenergy crops compared with the first-generation bioenergy crops (Holland et al., 2015). Some perennial bioenergy grasses such as switchgrass and miscanthus can gain high biomass yields under low-input conditions while having low nutrient removal (Casler et al., 2017; Yu, Ding, Huai, & Zhao, 2013). It has been found that sweetcanes grow well in barren lands in southern China (Dao et al., 2013). The other field study regarding four bioenergy grasses (Pennisetum, Miscanthus × giganteus, sweetcane, and P. purpureum) from Saccharum complex showed that sweetcane had the highest K utilization efficiency (106%) and the lowest K content (1.14%) (Li et al., 2012). This indicates that it has a low-input characteristic.

On the other hand, a field experiment in USA showed that the nitrogen (N), phosphorus (P) and potassium (K) removal capacity of sweetcane could reach up to 240 kg/ha, 65 kg/ha, and 390 kg/ha, respectively (Singh et al., 2015). The N content of sweetcane biomass, which was harvested 2 years after planting, was 309 kg/ha in Japan (Matsumani et al., 2018). Moreover, sweetcane exhibited the ability to accumulate N and P in constructed wetland, which was used to treat light eutrophic water in southern China (Jiang et al., 2005). This also proves the great nutrient removal ability of sweetcane. However, due to the ability to absorb N from deeper soil and store N in underground parts during winter for the next growing season, only 20% of N in sweetcane individual plant originated from fertilizer (Matsumani et al., 2018).

Genotype plays an important role in nutrient removal efficiency of perennials (Yu et al., 2013). Many low-input cultivars of switchgrass and miscanthus were selected (Casler et al., 2017; Xu, Gauder, Gruber, & Claupein, 2017), although some of those cultivars were also superior in high-input environments (Rose, Das, Fuentes, & Taliaferro, 2007). Unfortunately, so far few data are available for sweetcane in cultivars selection, even though many genetic resources have been collected in China (Table 1). A study on six sweetcane varieties showed that the N content and carbon (C) content of the harvested sweetcane were in the range of 0.37%-0.83% and 44.7%-45.8%, respectively (Hu et al., 2017). As a result, the C/N ratio of sweetcane was from 62.6 to 121.6, and the highest value was comparable with Miscanthus × giganteus (Michel et al., 2011; Wilk & Magdziarz, 2017). In addition, the harvest time also affects the nutrient removal efficiency of sweetcane. The removed N and K in biomass being harvested in late winter was 55% of that being harvested in autumn (Matsumani et al., 2018).

In summary, due to the high nutrient utilization efficiency, sweetcane can be planted on barren marginal lands as a sustainable biomass feedstock. In this case, low-input cultivars need to be selected in the future and the best harvest time should be winter. On the other hand, since sweetcane has the ability to accumulate nutrients from surroundings, it can be grown in buffer strips along surface waters and be used to block nonpoint source pollutants entering rivers or lakes. The aboveground parts of sweetcane could be harvested as the feedstock for bioethanol, biogas or power generation, while the fermentation residues and ash could subsequently be used as fertilizer. However, a suitable harvest time needs to be determined in further research.

#### 5.2 | Remediation of heavy metal

Sweetcane exhibited high bio concentration factors for Mn and Ni in constructed wetlands, which were used to treat wastewater from the pulp and paper industry (Arivoli, Mohanraj, & Seenivasan, 2015). In heavy metal contaminated mining areas, sweetcane could efficiently accumulate Cu, Zn, Pb, and Cd, with enrichment factors and transport coefficients greater than 1 for Zn, Pb, and Cd (Huang et al., 2012). This indicates that sweetcane can be used as a remediation plant for abandoned farmlands, which have been contaminated by these metals.

Approximately 1/6 of the cultivated land in China suffered from heavy metal pollution (Wei, Chen, & Lin, 2013). Sweetcane has a strong ability to absorb Cd and Pb, which are common pollutants in southern China. Therefore, cultivation of sweetcane in heavy metal contaminated farmlands will be helpful for land remediation. Moreover, the biomass obtained from these lands can also be used for energy production. However, the residues derived from anaerobic fermentation or direct combustion of sweetcane growing in heavy metal contaminated farmland cannot be further used as fertilizer, because the biomass contains heavy metals. Some post processing technologies like pyrolysis or thermal treatment are needed (Keller, Ludwig, Davoli, & Wochele, 2005; Sas-Nowosielska et al., 2004).

### 6 | FURTHER RESEARCH REQUIREMENTS

#### 6.1 | Germplasm resource exploitation and breeding

Although some sweetcane resources have been collected, relatively few works have been done on screening and
breeding of fine traits associated with biomass utilization. Further research is required to obtain varieties with low lignin and high cellulose content for the purpose of cellulosic ethanol production; this entails initially screening the collected germplasm resources and then improving it through traditional breeding or transgenic methods. Therefore, an efficient genetic transformation system in sweetcane is needed.

6.2 Cultivation management

Sweetcane is a potential bioenergy crop; however, there are few studies on cultivation management. Future research should focus on the management of pests, diseases, harvesting, and fertilization.

6.3 Comprehensive development and implementation of the technology

The cost of raw materials is one of the limiting factors affecting large-scale commercialization of bioenergy. Development of a multi-channel, comprehensive utilization strategy for bioenergy crops is important for solving this problem. At present, research of bioenergy products, such as ethanol produced from sweetcane, is still laboratory-based. Future studies need to include pilot-scale and large-scale implementation. Additionally, consideration must be given to the disposal or utilization of residues, as well as the development of high value-added products from sweetcane (Figure 9).

7 CONCLUSION

Sweetcane not only plays an important role in sugarcane breeding, but also has great potential in environmental remediation and as a biofuel feedstock. It can be planted in wastelands, abandoned farmlands, and roadsides below an altitude of 1,000 m in southern China. Sweetcane can adapt to a variety of growth environments due to its wide resistance to abiotic and biotic stresses. Compared with other bioenergy grasses under the same growth conditions, sweetcane usually has a higher photosynthetic efficiency, biomass yield, cellulose content and calorific value. Moreover, sweetcane could be a highly effective phytoremediator for wetlands, buffer strips along surface waters, and contaminated lands due to its highly efficient uptake of nutrients and heavy metals. Additionally, the subsequent biomass can be harvested for bioenergy production. However, the study of sweetcane as a bioenergy is still in its infancy. More works on breeding, cultivation, genetic transformation, biorefinery, and energy conversion technologies need to be done.

ACKNOWLEDGEMENTS

The study was supported by the Sichuan Youth Science & Technology Foundation (2017JQ0047), Fundamental Research Funds for Central Non-profit Scientific Institution (12017206030202203) and National Natural Science Foundation of China (31600013).

ORCID

Wenguo Wang https://orcid.org/0000-0002-7441-1887

REFERENCES

Arivoli, A., Mohanraj, R., & Seenivasan, R. (2015). Application of vertical flow constructed wetland in treatment of heavy metals from pulp and paper industry wastewater. *Environmental Science and Pollution Research*, 22, 13336–13343.

Augustine, S. M., Cherian, A. V., Syamaladevi, D. P., & Subramonian, N. (2015). *Erianthus arundinaceus* HSP70 (*EaHSP70*) acts as a key regulator in the formation of anisotropic interdigitation in sugarcane (*Saccharum* spp. hybrid) in response to drought stress. *Plant and Cell Physiology*, 56, 1–13.
Augustine, S. M., Syamaladevi, D. P., Premachandran, M. N., Ravichandran, V., & Subramoniam, N. (2015). Physiological and molecular insights to drought responsiveness in Erianthus spp. *Sugar Tech, 17*, 121–129.

Augustine, S. M., Ashwin, N. J., Syamaladevi, D. P., Appunu, C., Chakravarthi, M., Ravichandran, V., … Subramoniam, N. (2015). Overexpression of EaDREB2 and pyramiding of EaDREB2 with the pea DNA helicase gene (PDH45) enhance drought and salinity tolerance in sugarcane (*Saccharum* spp. Hybrid). *Plant Cell Reports, 34*, 247–263.

Barney, J. N., & Ditomasso, J. M. (2008). Nonnative species and bioenergy: Are we cultivating the next invader? *BioScience, 58*, 64–70.

Boehmel, C., Lewandowski, l., & Claupein, W. (2008). Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems, 96*, 224–236.

Burner, D. M., Hale, A. L., Viator, R. P., Belesky, D. P., Houx, H., Ashworth, A. J., & Fritschi, F. B. (2017). Ratoon cold tolerance of *Pennisetum*, *Erianthus*, and *Saccharum*, bioenergy feedstocks. *Industrial Crops and Products, 109*, 327–334.

Cai, Q., Wen, J., Fan, Y., Wang, L., & Ma, L. (2002). Chromosome analysis of *Saccharum* L. and related plants. *Southwest China Journal of Agricultural Sciences, 15*, 16–19.

Casler, M. D., Sosa, S., Hoffman, L., Mayton, H., Ernst, C., Adler, P. R., … Bonos, S. A. (2017). Biomass yield of switchgrass cultivars under high- versus low-input conditions. *Crop Science, 57*, 821–832.

Chen, S., & Phillips, S. M. (2006). *Saccharum* Linnaeus, Sp. Pl. 1: 54. 1753. In Wu, Z., Peter, H.R., Hong, D. *Flora of China*, 22, 576–581.

Chen, Y., Deng, Z., & Guo, C. (2007). Drought resistant evaluations of commonly used parents and their derived varieties. *Scientia Agricultura Sinica, 40*, 1108–1117.

Clifton-Brown, J., Hasting, A., Mos, M., McCalmont, J. P., Ashman, C., Awyte-Carroll, D., … Flavell, R. (2017). Progress in upscaling Miscanthus biomass production for the European bio-economy with seed based hybrids. *Global Change Biology Bioenergy, 9*, 6–17.

Corno, L., Pilu, R., & Adani, F. (2014). *Arundo donax* L.: A non-food crop for bioenergy and bio-compound production. *Biotechnology Advances, 32*, 1535–1549.

Dai, X. (1993). Studies on resistance of *Saccharum arundinaceum* Retz to Drechslera sacchari (Butler) Subran and Jain. *Journal of Yunnan Agricultural University, 8*, 143–145.

Daniels, J., Smith, P., Paton, N., & Williams, C. A. (1975). The origin of the genus *Saccharum*. *Sugarcane Breeding News, 36*, 24–39.

Dai, X., Liu, C., Yu, X., & Ma, K. (2008). Effects of shading on early growth of *Cyclobalanopsis glauca* (Fagaceae) in subtropical abandoned fields: Implications for vegetation restoration. *Acta Oecologica, 33*, 154–161.

Fan, T., Wu, X., & Du, H. (2017). Vegetation types and their distribution characteristics along the motorway from Chengdu to Yibin. *Journal of Sichuan Forestry Science and Technology, 38*, 45–49.

Fedenko, J. R., Erickson, J. E., Woodard, K. R., Sollenberger, L. E., Vendramini, J. M., Gilbert, R. A., … Peter, G. F. (2013). Biomass production and composition of perennial grasses grown for bioenergy in a subtropical climate across Florida, USA. *BioEnergy Research, 6*, 1082–1093.

Feng, D., Wu, Z., & Chen, R. (1997). The study on using random amplified polymorphic DNA (RAPD) in the classification of *Saccharum arundinaceum* Retz. *Journal of Guangxi Agricultural Biological Science, 91*, 360–364.

Gordon, D. R., Tancig, K. J., Onderdonk, D. A., & Gantz, C. A. (2011). Assessing the invasive potential of biofuel species proposed for Florida and the United States using the Australian weed risk assessment. *Biomass & Bioenergy, 35*, 74–79.

Guo, Y., Guo, Y., Guo, C., & Zhang, M. (2005). Analysis of the hardiness of the intergeneric hybrids between *Saccharum* L. and *Erianthus* Michx subjected to NaCl stress. *Chinese Journal of Tropical Crops, 26*, 46–51.

Hao, J., Yao, X., Huang, Y., Yao, J., Chen, Y., Xie, H., & Chen, R. (2016). Effect of different habitats on the species diversity of communities and modular biomass of riparian vegetation in the Wenjiang section of the Jinma river. *Acta Botanica Boreali-Occidentalia Sinica, 36*, 1864–1871.

Holland, R. A., Eigenbrod, F., Muggeridge, A., Brown, G., Clarke, D., & Taylor, G. (2015). A synthesis of the ecosystem services impact of second generation bioenergy crop production. *Renewable & Sustainable Energy Reviews, 46*, 30–40.

Hou, W., Xiao, L., Yi, Z., Qin, J., Yang, S., Zheng, C., & Chen, Z. (2015). Evaluation of the adaptability of bioenergy grasses in acidic red soil. *Acta Pratuculactinae Sinica, 24*, 237–244.

Hu, C., Wang, X., Yu, X., & Yang, Q. (2015). Investigation and botanical character analysis of wild sugarcane germplasm resources of southern Tibet. *Journal of Yunnan Agricultural University, 30*, 351–356.

Hu, Y., Zhang, L., Hu, J., Zhang, J., Shen, F., Yang, G., … J. (2017). Assessments of *Erianthus arundinaceus* as a potential energy crop for bioethanol and biomethane production. *Bioresources, 12*, 8786–8802.

Huang, H., Xu, J., Bai, Y., Zhang, W., & Wang, X. (2011). Soil animal community structure and diversity under different restoration vegetation in polluted abandoned farmland of Dabaoshan mine. *Chinese Agricultural Science Bulletin, 27*, 80–85.

Huang, H., Xu, J., Yin, B., Zhang, W., Fei, Z., Li, T., … An, C. (2012). Enrichment of heavy metals in *Saccharum arundinaceum* (Retz.) Jeswiet in different soil habitats. *Chinese Journal of Ecology, 32*, 961–966.

Jayabose, C., Arumuganathan, T., Amalraj, V. A., Rakkkipappan, P., Shanthy, T. R., & Kailappan, R. (2017). Compressive force profile of high biomass *Erianthus* clones. *Sugar Tech, 19*, 341–346.

Jiang, Y., Ge, Y., Yue, C., Dai, J., Wang, H., Tang, Y., & Chang, J. (2005). Characteristics of plants in constructed wetland treating light eutrophic water. *Journal of Zhejiang University (Science Edition), 32*, 309–313.
Kalinina, O., Nunn, C., Sanderson, R., Hastings, A. F. S., van der Weijde, T., Özgüven, M., … & J. C. (2017). Extending miscanthus cultivation with novel germplasm at six contrasting sites. *Frontiers in Plant Science, 8*, 563.

Keller, C., Ludwig, C., Davoli, F., & Wochele, J. (2005). Thermal treatment of metal-enriched biomass produced from heavy metal phyto-extraction. *Environmental Science & Technology, 39*, 3359–3367.

Kharte, S. B., Watharkar, A. D., Shingote, P. R., Chandrareshkaran, S., Pagariya, M. C., Kawar, P. G., & Govindwar, S. P. (2016). Functional characterization and expression study of sugarcane MYB transcription factor gene *PeaMYBASI* promoter from *Erianthus arundinaceus* that confers abiotic stress tolerance in tobacco. *RSC Advances, 6*, 19576–19586.

Lewandowski, I., Clifton-Brown, J., Trindade, L. M., van der Linden, G. C., Schwarz, K. U., Muller-Samann, K., … & Kalinina, O. (2016). Progress on optimizing Miscanthus biomass production for the European bioeconomy: Results of the EU FP7 project OPTIMISC. *Frontiers in Plant Science, 7*, 1620.

Li, F., Yang, Q., Xiao, F., & He, L. (1998). Tissue culture on the young leaf of *Saccharum arundinaceum* Retz. *Journal of Plant Resources and Environment, 7*, 63–64.

Li, Q., Ao, J., Lu, Y., Huang, Y., Chen, D., Zhou, W., … & Jiang, Y. (2012). Differences of potassium efficiency among different genotypes of sugarcane and its related genera. *Guangdong Agricultural Sciences, 21*, 29–32.

Li, W., Cai, Q., Huang, Y., Fan, Y., & Ma, L. (2005). Identification of sugarcane wild germplasm resources resistant to *Puccinia erianthi*. *Plant Protection, 31*, 51–53.

Liang, Z. (2011). Genetic diversity and evaluation of biomass energy of *Erianthus arundinaceus* (Retz.) Jeswiet. (MSc). Yaan, China: Sichuan Agricultural University.

Liu, D., Wu, X., Chang, J., Gu, B., Min, Y., & Ge, Y. (2012). Constructed wetlands as biofuel production systems. *Nature Climate Change, 2*, 190–194.

Liu, J., Peng, H., Zhao, X., Cheng, C., Chen, F., & Shao, Q. (2013). Optimization of liquid ammonia treatment (LAT) parameters for enzymatic hydrolysis of *Saccharum arundinaceum* to fermentable sugars. *Chinese Journal of Biotechnology, 29*, 333–341.

Liu, Y., Hu, X., Yao, Y., Xu, L., & Xing, S. (2016). Isolation and expression analysis of catalase genes in *Erianthus arundinaceus* and sugarcane. *Sugar Tech, 18*, 468–477.

Matsuami, H., Kobayashi, M., Tsuruta, S., Terajima, Y., Sato, H., Ebina, M., & Ando, S. (2018). Overwintering ability and high-yield biomass production of *Erianthus arundinaceus* in a temperate zone in Japan. *Bioenergy Research, 11*, 467–479.

Matzenberger, J., Kranzl, R., Tromborg, E., Junginger, M., Daiglou, V., Goh, C. S., & Keramidas, K. (2015). Future perspectives of international bioenergy trade. *Renewable and Sustainable Energy Reviews, 43*, 926–941.

McLaughlin, S. B., & Kszos, L. A. (2005). Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy, 28*, 515–535.

Michel, R., Rapagna, S., Burg, P., & Celso, G. M., Courson, C., Zimny, T., & Gruber, R. (2011). Steam gasification of Miscanthus × Giganteus with olive as catalyst production of syngas and analysis of tars (IR, NMR and GC/MS). *Biomass and Bioenergy, 35*, 2650–2658.

Mirshad, P. P., Chandran, S., & Puthur, J. T. (2014). Characteristics of bioenergy grasses important for enhanced NaCl tolerance potential. *Russian Journal of Plant Physiology, 61*, 639–645.

Mirshad, P. P., & Puthur, J. T. (2016). Arbuscular mycorrhizal association enhances drought tolerance potential of promising bioenergy grass (*Saccharum arundinaceum* retz.). *Environmental Monitoring and Assessment, 188*, 425–444.

Mohr, A., & Raman, S. (2013). Lessons from first generation biofuels and implications for the sustainability appraisal of second generation biofuels. *Energy Policy, 63*, 114–122.

Mukherjee, S. K. (1958). *Revision of the Genus Erianthus*. *Lloydia, 21*, 157–188.

Naik, S. N., Goud, V. V., Rout, P. K., & Dalai, A. K. (2010). Production of first and second generation biofuels: A comprehensive review. *Renewable & Sustainable Energy Reviews, 14*, 578–597.

Nair, N. V., & Mary, S. (2006). RAPD analysis reveals the presence of mainland Indian and Indonesian forms of *Erianthus arundinaceus* (Retz.) Jeswiet in the Andaman-Nicobar Islands. *Current Science, 90*, 1118–1122.

Ning, Z., Chen, H., Wang, Z., Zhang, Z., & Qiu, Y. (2010). A study on the dynamic change of gross caloric value and ash content of the several tall grasses. *Acta Prataturae Sinica, 10*, 164–169.

Ou, X., Jin, Z., Peng, M., Fang, B., & Fang, J. (1997). Distribution of vegetation in Mengyang Nature Reserve of Xishuangbanna and their ecological characteristics. *Chinese Journal of Applied Ecology, 8*, 8–19.

Palmer, I. E., Gehl, R. J., Ranney, T. G., Touchell, D., & George, N. (2014). Biomass yield, nitrogen response, and nutrient uptake of perennial bioenergy grasses in North Carolina. *Biomass and Bioenergy, 63*, 218–228.

Panneerselvam, A., Sharma, R. R., Kolar, P., Clare, D. A., & Ranney, T. (2013). Hydrolysis of ozone pretreated energy grasses for optimal fermentable sugar production. *Bioresource Technology, 148*, 97–104.

Panneerselvam, A., Sharma, R. R., Kolar, P., Ranney, T., & Peretti, S. (2013). Potential of ozonolysis as a pretreatment for energy grasses. *Bioresource Technology, 148*, 242–248.

Peet, N. B., Watkinson, A. R., Bell, D. J., & Kattel, B. J. (1999). Plant diversity in the threatened sub-tropical grasslands of Nepal. *Biological Conservation, 88*, 193–206.

Pildisnyuk, V., Stefanovska, T., Lewis, E. E., Erickson, L. E., & Davis, L. C. (2014). Miscanthus as a productive biofuel crop for phytoremediation. *Critical Reviews in Plant Sciences, 33*, 1–19.

Que, Y., Xu, L., Lin, J., Xu, J., Zhang, M., & Chen, R. (2009). Isolation and characterization of disease resistance gene analogs from *Erianthus arundinaceus* cDNA. *Acta Agronomica Sinica, 28*, 417–424.

Ram, B., Sreenivasan, T. V., Sahi, B. K., & Singh, N. (2001). Introggression of low temperature tolerance and red rot resistance from *Erianthus*, in sugarcane. *Euphytica, 122*, 145–153.

Robertson, G. P., Hamilton, S. K., Barham, B. L., Dale, B. E., Izaurralde, R. C., Jackson, R. D., … & Tiedje, J. M. (2017). Cellulosic biofuel contributions to a sustainable energy future: Choices and outcomes. *Science, 356*, eaal2324.

Rose, L. W., Das, M. K., Fuentes, R. G., & Taliaferro, C. M. (2007). Effects of high- vs. low-yield environments on selection for increased biomass yield in switchgrass. *Euphytica, 156*, 407–415.

Sas-Nowosielska, A., Kucharski, R., Małkowski, E., Pogrzeba, M., Kuperberg, J. M., & Kryński, K. (2004). Phytoextraction crop disposal-An unsolved problem. *Environmental Pollution, 128*, 373–379.

Schmer, M. R., Vogel, K. P., Mitchell, R. B., & Perrin, R. K. (2008). Net energy of cellulosic ethanol from switchgrass. *Proceedings of
the National Academy of Sciences of the United States of America, 105, 464–469.

Singh, M., Erickson, J., Sollenberger, L., Woodard, K., Vendramini, J., & Gilbert, R. (2015). Mineral composition and removal of six perennial grasses grown for bioenergy. *Agronomy Journal*, 107, 466–474.

Smith, A. L., Klenk, N., Wood, S., Hewitt, N., Henriques, I., Yan, N., & Bazely, D. R. (2013). Second generation biofuels and bioinvasions: An evaluation of invasive risks and policy responses in the United States and Canada. *Renewable and Sustainable Energy Reviews*, 27, 30–42.

Song, H., Zhang, R., Yang, H., Zhang, G., Luo, T., Gao, Y., … Fang, W. K. (2014). Genetic diversity analysis of *Saccharum arundinaceum* revealed by SCOT markers. *Southwest China Journal of Agricultural Sciences*, 27, 59–64.

Suman, A., Ali, K., Jie, A., Parco, A. S., Kimbeng, C. A., & Baisakh, N. (2012). Molecular diversity among members of the Saccharum, complex assessed using TRAP markers based on lignin-related genes. *Bioenergy Research*, 5, 197–205.

Tagane, S., Misa, Y. T., Ponragdee, W., Sansayawichai, T., & Sugimoto, A. (2011). Cytological study of *Erianthus procerus* and *E. arundinaceus* (Gramineae) in Thailand. *Cytologia*, 76, 171–175.

Tsuruta, S., Ebina, M., Kobayashi, M., Hattori, T., & Terauchi, T. (2012). Analysis of genetic diversity in the bioenergy plant *Erianthus arundinaceus* (Poaceae: Andropogoneae) using Amplified Fragment Length Polymorphism markers. *Grassland Science*, 58, 174–177.

Tsuruta, S., Ebina, M., Kobayashi, M., & Takahashi, W. (2017). Complete chloroplast genomes of *Erianthus arundinaceus* and *Miscanthus sinensis*: Comparative genomics and evolution of the Saccharum complex. *PLoS ONE*, 12, 1–18.

Uwatoko, N., Tanaka, M., Saito, A., & Gau, M. (2011). Establishment of plant regeneration system in *Erianthus arundinaceus* (Retz.) Jeswiet, a potential biomass crop. *Grassland Science*, 57, 231–237.

Wang, W., Tang, X., Zhu, Q., Pan, K., Hu, Q., He, M., & Bazely, D. R. (2014). Predicting the impacts of climate change on the potential distribution of major native non-food bioenergy plants in China. *PLoS ONE*, 9, 1–11.

Wei, S., Chen, B., & Lin, L. (2013). Soil heavy metal pollution of cultivated land in China. *Research of Soil and Water Conservation*, 20, 293–298.

Wilk, M., & Magdziarz, A. (2017). Hydrothermal carbonization, torrefaction and slow pyrolysis of *Miscanthus giganteus*. *Energy*, 140, 1292–1304.

Wu, S., Pan, S., Chen, Y., & Zhang, M. (2008). ITS identification and drought resistance of genuine hybrids from the cross of *Saccharum* and *E. arundinaceum*. *Acta Agriculturae Universitatis Jiangxiensis*, 30, 628–632.

Wu, Z., Liu, J., Lu, X., Zhang, M., Lin, X., Zhao, P., & Wu, C. (2012). Establishing high frequency regeneration system of related genera of *Saccharum* (*Erianthus arundinaceus*). *Sugar Crops of China*, 29(9–10), 14.

Xu, C., Lu, X., Ma, L., Liu, X., Liu, H., Su, H., … Cai, Q. (2015). Phenotypic traits and genetic diversity of *Erianthus arundinaceus* germplasm. *Journal of Hunan Agricultural University*, 40, 117–121.

Xu, J., Gauder, M., Gruber, S., & Claupstein, W. (2017). Yields of annual and perennial energy crops in a 12-year field trial. *Agronomy Journal*, 109, 811–821.

Xue, S., Kalinina, O., & Lewandowski, I. (2015). Present and future options for *Miscanthus* propagation and establishment. *Renewable and Sustainable Energy Reviews*, 49, 1233–1246.
Zhang, S., Gan, L., Li, H., Li, H., Pan, S., & Long, M. (2017). Utilization of *Saccharum arundinaceum* for alcohol production. *Fujian Journal of Agricultural Sciences*, 2, 555–559.

Zhang, S., Xie, Z., & Lin, Y. (2011). Cellulase production by solid-state fermentation and saccharification using the fibre of the energy plant *Erianthus arundinaceum*. *Chinese Journal of Tropical Crops*, 32, 2346–2351.

Zhang, Y., Kong, X., Li, L., Sun, Y., Yang, L., & Yuan, Z. (2016). Biogas production performance and dynamics of anaerobic digestion of different energy grasses. *Transactions of the Chinese Society of Agricultural*, 47, 191–196.

Zhang, Y., Yan, J., Mahai, T., Bai, S., Zhang, J., Zhang, J., … Li, D. X. (2017). Callus induction of mature seed of *Erianthus arundinaceus* and establishment of the regeneration system. *Hubei Agricultural Sciences*, 56, 1570–1576.

**How to cite this article:** Wang W, Li R, Wang H, et al. Sweetcane (*Erianthus arundinaceus*) as a native bioenergy crop with environmental remediation potential in southern China: A review. *GCB Bioenergy*, 2019;11:1012–1025. [https://doi.org/10.1111/gcbb.12600](https://doi.org/10.1111/gcbb.12600)