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China's crop wild relatives: Diversity for agriculture and food security

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ABSTRACT

The potentially devastating impacts of climate change on crop production and food security are now widely acknowledged. An important component of efforts to mitigate these impacts is the production of new varieties of crops which will be able to thrive in more extreme and changeable environmental conditions. There is therefore an urgent need to find new sources of genetic diversity for crop improvement. Wild plant species closely related to crops (crop wild relatives) contain vital sources of such genes, yet these resources themselves are threatened by the effects of climate change, as well as by a range of other human-induced pressures and socio-economic changes. The flora of China comprises more than 20,000 native higher plant species, a proportion of which have known or potential value as gene donors for crop improvement. However, until now, the full range of these valuable crop wild relative species had not been identified. In this paper we present a methodology for creating a checklist of, and prioritizing China's crop wild relatives, and reveal that 871 native species are related to crops that are of particularly high socio-economic importance in China—including rice, wheat, soybean, potato, sweet potato, millet and yam—crops which are also of notably high value for food and economic security in other parts of the world. Within this list we have identified species that are in particular need of conservation assessment based on their relative Red List status and potential for use in crop improvement programs. Endemic species that have particularly high economic value potential in China and that are under severe threat of genetic erosion and thus in need of urgent conservation action include wild relatives of tea (*Camellia fangchengensis* S. Yun Liang et Y.C. Zhong and *C. grandibracteata* H.T. Chang et F.L. Yu), apple (*e.g.*, *Malus honanensis* Rehder, *M. ombrophila* Hand.-Mazz. and *M. toringoides* (Rehder) Hughes), and pear (*Pyrus pseudopashia* T.T. Yu). We provide recommendations for developing a systematic and comprehensive national CWR conservation strategy for China, highlighting the challenges and requirements of taking the strategy forward to the implementation phase.

1. Introduction

1.1. The value of crop wild relatives for climate change mitigation

Crop wild relatives (CWR) are species closely related to crops that have the potential to contribute traits for crop improvement (Maxted et al., 2006). They have been used increasingly in plant breeding since the early 20th century and have provided vital genetic diversity for crop improvement—for example, to confer resistance to pests and diseases, improve tolerance to environmental conditions such as extreme temperatures, drought and flooding, and to improve nutrition, flavor, color, texture and handling qualities (Maxted and Kell, 2009). CWR have contributed significantly to the agricultural and horticultural industries, and to the world economy (Maxted and Kell, 2009; Maxted et al., 2008) and have long been recognized as a critical resource with a vital role in food security and economic stability (Hajjar and Hodgkin, 2007; Hoyt, 1988; Maxted et al., 1997a, 2012, 2014; McCouch et al., 2013; Meilleur and Hodgkin, 2004; Prescott-Allen and Prescott Allen, 1986; Stolton et al., 2006).

Today, crop production is significantly affected by the impacts of climate change and the future holds much uncertainty in terms of productivity both in the short and long term. In the Fifth Assessment Report of the Intergovernmental Panel on Climate

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Change (IPCC, 2014), Porter et al. (2014) note that climate trends over the past 50 years have had a negative impact on wheat and maize production in some regions and an overall negative impact on aggregate global production of these two crops. Impacts have been minor on rice and soybean yields, both in major production regions and globally and increasing temperatures have had a beneficial impact on crop production in some high latitude regions (Porter et al., 2014), including northeast China (Chen et al., 2010). Reported small or beneficial impacts of climate trends should however be interpreted with care. For example, Hijioka et al. (2014) cite a study of the response of rice yields to climate change in the period 1981–2005 in China (Zhang et al., 2010) which showed positive correlation between yield and temperature in tandem with increased solar radiation. However, in some localities lower yields were correlated with higher temperatures, with yield increases being positively correlated with rainfall.

Critically, projected impacts of climate change on rice production in China indicate that increasing temperatures will result in lower yields due to shorter growing periods (Hijioka et al., 2014). The authors also report (citing Wassmann et al., 2009a,b) that current temperatures are approaching critical levels in terms of increasing heat stress during the susceptible developmental stages of the rice plant. A study showing reduced rice yields throughout Asia under different climate change scenarios concluded that one of the most vulnerable regions is eastern China (Masutomi et al., 2009). On the other hand, Hijioka et al. (2014) highlight that winter wheat yields in China are projected to increase throughout the 21st century in the Huang-Huai-Hai Plain, China's most productive wheat growing region (Thomson et al., 2006), and in the North China Plain (Tao and Zhang, 2013). However, in the latter region, maize yields are projected to substantially decrease (Tao et al., 2009).

The studies cited above relate to long-term climate trends and do not take account of the potential impacts of extreme climate events on crop production which the IPCC (2012) reported are expected to have a negative effect. For example, rice crop yields may be lower in response to extreme rises in temperatures (Mohammed and Tarpley, 2009; Tian et al., 2010) and crop production can also be negatively impacted by periods of high rainfall causing flooding (Handmer et al., 2012). An additional potential pressure on agriculture in China is insufficient water caused by demand for non-agricultural uses (Xiong et al., 2010, cited in Hijioka et al., 2014).

While reported potential future increases in crop production in some areas for some major crops is positive, the overall trend is for climate change impacts to negatively affect crop production, as well as introducing higher levels of uncertainty with regard to the stability of environmental conditions. Climate change will also lead to changes in the occurrence of crop pests and diseases, as well as in production areas (Lane and Jarvis, 2007; FAO, 2011). Furthermore, studies of the impacts of climate change have only been undertaken on a limited number of crops. Therefore, the future of productivity for many crops is unknown. The potential ramifications are far-reaching, impacting the entire value chain, from farmers to consumers. Major crop losses may lead to local food and economic insecurity, as well as impacting global food supplies and market values. China is a major producer and exporter of several staple crops, including rice, wheat and maize. The potential for substantial decreases in productivity and even severe crop losses will not only impact on China's food and economic security but may potentially have a marked effect in other regions as well.

One option for mitigating the impacts of climate change on food production is to develop crop varieties with increased resistance to elevated temperatures, drought, pests and diseases (Easterling et al., 2007). The authors comment that the many climate change adaptation studies on wheat, rice and maize crops indicate that this option alone, or combined with other adaptations such as changes in planting times and locations and improved water management, has the potential to provide an average of 10% increase in yield across all regions, all crops and different temperature regimes. The cultivation of high temperature tolerant varieties of maize in the North China Plain for example, combined with adaptations in planting regimes, could have a significant increase in yields, while no adaptation interventions may result in yield reductions of up to 19% (Tao and Zhang, 2010). In a meta-analysis of projected crop yields in a range of climate change and adaptation scenarios, Challinor et al. (2014) concluded that the development of new cultivars was the most effective modification. Indeed, the development of new crop varieties is at the top of a list of technological adaptation options presented by Noble et al. (2014). Plant breeders are therefore in need of diverse and novel sources of genetic diversity to produce new crop varieties able to cope with the impacts of changing growing conditions (Deryng et al., 2011; Duveiller et al., 2007; FAO, 2008; Feuillet et al., 2008; Guarino and Lobell, 2011; Jones et al., 2003; Li et al., 2011; Luck et al., 2011; McCouch et al., 2013; Muñoz-Amatriaín et al., 2014). Due to the breadth of genetic diversity inherent in CWR populations, which are adapted to a wide range of environmental conditions, they are likely to become increasingly important as sources of genetic diversity to produce crop varieties able to cope in the altered environmental conditions induced by climate change (FAO, 2008, 2010, 2011; Ford-Lloyd et al., 2011; Guarino and Lobell, 2011; Kell et al., 2012a; Maxted et al., 2012; Vollbrecht and Sigmon, 2005; Zamir, 2001), especially in the light of enhanced gene discovery and breeding techniques, as well as improved knowledge of the use of exotic germplasm in breeding programs (Dwivedi et al., 2008; Feuillet et al., 2008; Hajjar and Hodgkin, 2007; Lobell et al., 2008; McCouch et al., 2013; Zamir, 2001). CWR are therefore a fundamental component of plant genetic resources for food and agriculture (PGRFA) and may contribute significantly to future food security.

1.2. Threats to crop wild relatives and current conservation status

CWR species occur in a wide range of habitats, including high altitude steppe, forests, riversides, coastal beaches and cliffs, crop and pasturelands, orchards, roadsides and urban areas. Some are relatively common and widespread but many have limited distributions and habitat niches. Like other wild species, CWR are subject to an increasing range of threats in their native habitats (FAO, 1996, 1998, 2010, 2011; Maxted et al., 2008, 2012, 2015), including deforestation, logging, plantation agriculture and forestry, agricultural industrialization, desertification, urbanization, mining and quarrying, invasive species and climate change (Bilz et al., 2011; Kell et al., 2012b; Maxted and Kell, 2009; Maxted et al., 2014). Many wild relatives of major crops are found in disturbed, pre-climax communities—the habitats most affected by increasing levels of anthropogenic change and destruction (Jain, 1975). Compared to other wild species found in more stable climax communities, CWR are therefore likely to be disproportionately and adversely impacted by environmental change (Maxted and Kell, 2009). In a study of the Red List status of CWR in Europe, the most frequently reported threat was unsustainable farming practices, such as severe overgrazing, conversion of land to monocultures and the heavy application of fertilizers, herbicides and pesticides (Kell et al., 2012b). In China the main threat to wild plant species (and thus also CWR) is habitat loss and degradation, with agro-forestry impacting 29% of affected threatened species, infrastructure development impacting 12%, and the remaining 59% being impacted by harvesting or other forms of habitat loss and degradation (Qin et al., 2013).

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