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COMMENTARY

Sedges on the edge: new agronomic and research opportunities?

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Abstract

Background The paper by Tan and co-authors in this issue of *Plant and Soil* explores feedback mechanisms between functional traits and soil nutrient responses in tiger nut (*Cyperus esculentus* L.), with emphasis on their growth in marginal agricultural lands.

Scope Many of the world's top food species belong to the order Poales, specifically the family Poaceae. Cyperaceae, also Poales, are recognised for their ecological importance, yet currently provide only minor contributions to global food security.

Conclusions Wide ecological tolerance and naturally weedy tendencies may provide a unique niche for a significant increase in the production of tiger nuts as a global food resource. Further research on the ecology and agronomic potential of Cyperaceae is advocated.

Keywords Cyperaceae · Climate change · Marginal agriculture · Food security

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Introduction

A changing world must be ready to adapt to climate fluctuations and growing human populations. Fundamental to this is increasing agricultural production in a sustainable manner to ensure food security (Pozza and Field 2020). Climate change will necessitate significant new approaches to agriculture, including the balance of certain food types underlying human diets (McClements and Grossmann 2021; Canning 2022; Ivanovich et al. 2023; Saber and Mahrous 2023). Currently, most of our plant-based food comes from just three grasses, rice (*Oryza sativa* L.), wheat (*Triticum* species), and corn (*Zea mays* L.), despite large numbers of grass species being utilised throughout human history (Weide et al. 2018). Grasses are followed in importance by a variety of legume species, particularly chickpea (*Cicer arietinum* L.), dry bean (*Phaseolus vulgaris* L.), lentil (*Lens culinaris* L.), field pea (*Pisum sativum* L.), broad bean (*Vicia faber* L.), pigeonpea (*Cajanus cajan* L.), cowpea (*Vigna unguiculata* L.), lupins (*Lupinus* spp., peanuts (*Arachis hypogea* L.) and soybeans (*Glycine max* L.) (Ferreira et al. 2021; Dutta et al. 2022; Landis and Doyle 2023), a pattern of dietary consumption also observed in herbivores globally (Pansu et al. 2022).

The sedge family, Cyperaceae, is another member of the Order Poales, with a similar global distribution to the Poaceae, but it has just two species of economic significance as a food resource (Simpson 2008). The best-known food resource in the family is

tiger nut (*Cyperus esculentus* L.), with a documented history stretching back over 18,000 years (Sanderson 2005), likely much longer than many cereals utilised today. This long history of utilisation has clouded our understanding of its origins and patterns of diversification (De Castro et al. 2015). The only other globally significant food resource in the Cyperaceae is the Chinese water chestnut (*Eleocharis dulcis* L.; Quoc et al. 2021).

In other ways, Cyperaceae are of significant economic importance as they are of ecological significant at a global scale (with nearly 500 species in 45 genera listed by Simpson 2008), with particular importance in wetland systems around the world (Mishra et al. 2015). However, they also feature in dryland systems in Mediterranean-type ecosystems where their ability to release carboxylate to maximise P uptake is critical to their success (Shane et al. 2006a, b; Barrett 2013; Barrett et al. 2021; Elliott et al. 2021). Species of economic or ethnobotanical importance are mostly in the largest genera *Carex* and *Cyperus*, with smaller numbers of significant species in *Schoenoplectus*, *Eleocharis*, *Scleria* and *Fimbristylis* respectively (Simpson 2008), though a general lack of documentation for Cyperaceae means that current knowledge is probably a significant underestimate (see Barrett 2013). Most other species of economic importance are those considered to be weeds (Bryson and Carter 2008; Table 1). Historically, papyrus (*Cyperus papyrus* L.) enabled social transformation as the earliest source of paper, enabling widespread record-keeping and information transfer, and this species was also a food source (Bausch et al. 2022). Local climate change and disturbance saw the typical subspecies of papyrus come to the brink of extinction in Egypt (Serag 2000). To date, relatively few Cyperaceae are threatened, but given increasing pressure on wetlands and predicted climate change, this situation may change rapidly (Simpson et al. 2011).

Opportunities and risk for tiger nut cultivation

Increased cultivation of tiger nut presents novel opportunities as it is ecologically highly adaptable and able to be productive in in low-rainfall zones (Lapham 2006). Planting of tiger nut has been shown to increase soil microbial richness (Duan et al. 2022). In terms of a cash-crop, it fulfils many farmers' dreams in that it is a perennial species that 'grows like a weed'. Given its potential expansion as a production crop, its ecology has received additional attention in recent years. Particular attention has been paid to resource allocation to key organ development, including tubers, stolons, roots, stems, leaves, and inflorescences. Several cultivars, including a form sometimes recognised as *Cyperus esculentus* L. var. *sativus* Boeck., reproduce almost entirely by vegetative means, not allocating resources to inflorescence development (Follak et al. 2016; Pascual-Seva et al. 2015; Pascual-Seva and Pascual 2021). This results in increased resource allocation to tuber production, resulting in larger, sweeter tubers that are more attractive for human consumption (Zhang et al. 2022). Tiger nut has a relatively short development period for tubers once established (Lapham 2006) and its tubers provide a high nutritional value (Yamwemba et al. 2020). The tubers also have multiple opportunities for utilisation, including for oil or starch and they can be consumed fresh or dried (Yamwemba et al. 2020).

At a time when water resources are tipped to be one of the next greatest limitations on agricultural expansion (Cosgrove and Loucks 2015), the requirement for adequate rainfall or drip irrigation to achieve tuber production may be an important limitation (Pascual-Seva et al. 2016). Tiger nut also requires the input of fertiliser, especially phosphorus, to maximise yields (Tan et al. 2023), and the cost, environmental effects and future availability of these fertilisers should be carefully considered. However, carboxylate release by Cyperaceae make them ideally suited to cultivation in low-P systems as they are highly efficient at accessing limed P resources (Veselkin et al. 2014; Güsewell and Schroth 2017; Konoplenko et al. 2017). Nitrogen also has a critical influence on aboveground growth in tiger nut (Garg et al. 1967; Ransom et al. 2009), and also the production of shoot growth from stolons (Cao et al. 2022; Tan et al. 2022). Tan et al. (2023) provide a very useful addition to our knowledge of resource partitioning in the species and its response to particular fertiliser treatments, especially in arid regions.

In addition to its utilisation as a human food (both for tubers and oil), tiger nut is cultivated as a high-quality forage plant (Sánchez-Zapata et al. 2012). Given its multiple uses, the integration of both forage and oil production in semi-arid or marginal farming regions where grazing is prevalent may boost

Table 1 Selected Cyperaceae of economic significance (based on Bryson and Carter 2008; Simpson 2008; Simpson et al. 2011)

Species	Significance	Distribution
Actinoscirpus grossus (L.f) Goetgh. & D.A.Simpson	Weaving & basketry	Asia
Afrotrilepis pilosa (Boeck.) J.Raynal	Thatching	Africa
Bolboschoenus fluviatilis (Torr.) Soják	Waste-water treatment	Pantropical
Carex dimorpholepis Steudel	Poisonous to cattle	Asia
Cladium mariscus (L.) Pohl	Thatching	Pantropical
Cyperus alternifolius L.	Grazing, handcrafts	Tropical Africa
Cyperus articulatus L.	Weed, perfumery, medicinal	Pantropical
Cyperus brevifolius (Rottb.) Endl. ex Hassk.	Weed, medicinal	Pantropical
Cyperus conglomeratus Rottb.	Soil stabilisation	Asia
Cyperus corymbosus (L.) Rottb.	Weaving, basketry, handcrafts	Asia
Cyperus difformis L.	Major weed	Pantropical
Cyperus distans L.f.	Grazing	Pantropical
Cyperus esculentus L.	Food, major weed, soap making, oil	Pantropical
Cyperus haspan L.	Major weed	Pantropical
Cyperus involucratus Rottb.	Waste-water treatment	Pantropical
Cyperus iria L.	Major weed	Pantropical
Cyperus papyrus L.	Ecological, paper, food, fuel	Africa
Cyperus prolifer L.	Ornamental	Africa
Cyperus prolixus Kunth	Smoking	Peru
Cyperus rotundus L.	Major weed, medicinal, perfumery	Pantropical
Cyperus textilis Thunb.	Handcrafts	Africa
Eleocharis dulcis L.	Food	Pantropical
Fimbristylis dichotoma (L.) Vahl	Major weed	Pantropical
Fimbristylis miliacea (L.) Vahl	Major weed	Pantropical
Kobresia pygmaea (C..Clarke) C.B.Clarke	Grazing, building	Asia
Lepidosperma gladiatum Labill.	Soil stabilisation, weaving, medicinal, animal food	Australia
Lepironia articulata (Retz.) Domin	Basketry	Asia, Australia
Machaerina articulata (R.Br.) T.Koyama	Waste-water treatment	Australasia
Schoenoplectus californicus (C.A.Mey.) Soják	Waste-water treatment, boat building, weaving, food	Pantropical
Scleria depressa (C.B.Clarke) Nelmes	Thatching	Africa

productivity of both crop and grazing industries. How to best maximise these due land uses may be a valuable focus for future research. In this regard, balancing the proportion of nitrogen fertilizer utilized to maximise resource allocation to aboveground organs for forage, and belowground organs for food and oil would be very beneficial (Cao et al. 2022; Tan et al. 2023).

It is noted that *Cyperus esculentus* and the similar species *Cyperus rotundus* L. are considered to be 'some of the world's worst weeds' (Simpson et al. 2011). The same characteristics that instil resilience in a crop make these species very difficult to control or remove if their farming ceases at a given location (Bryson and Carter 2008; Henry et al. 2021). Tiger nut can even be a significant weed of rice fields, so its presence can lower productivity of critical grain crops (Kraehmer et al. 2016). Even in arid regions, species introduced for agronomic or aesthetic reasons can become highly problematic if not managed according to their ecology (Scott et al. 2018). Beyond weed control, relatively few studies have examined the ecology and cultivation of tiger nut in detail and there remains considerable potential for agronomic improvement (Yamwemba et al. 2020; Du et al. 2023).

Conclusions

Few genomic resources are available for Cyperaceae relative to Poaceae (Can et al. 2020), but a sound phylogenomic framework exists (Larridon et al. 2021), including for the complex genus *Cyperus* (Larridon et al. 2020), providing many avenues for future research. It is well-documented that wild relatives present many opportunities for understanding evolution and breeding potential for important crop species (e.g., in soybean; Landis and Doyle 2023) and further study of wild relatives of tiger nut are strongly encouraged.

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