The Journal of Agricultural Science

cambridge.org/ags

A review of the *de novo* domestication and cultivation of edible Australian native plants as food crops

Crops and Soils Review

Cite this article: George NA, Coorey R, Dixon K, Bennett SJ (2023). A review of the *de novo* domestication and cultivation of edible Australian native plants as food crops. *The Journal of Agricultural Science* **161**, 778–793. https://doi.org/10.1017/S0021859624000078

Received: 2 May 2023
Revised: 30 November 2023
Accepted: 21 December 2023
First published online: 22 February 2024

Keywords:
agronomic research; bush tucker; crop domestication; germplasm collection; native foods

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Abstract

Australia has a diverse and unique native flora with thousands of edible plant taxa, many of which are wild relatives of important food crops. These have the potential to diversify and improve the sustainability of Australian farming systems. However, the current level of domestication and cultivation of Australian plants as food crops is extremely limited by global standards. This review examines the current status and potential for future *de novo* domestication and large-scale cultivation of Australian plants as food crops. This is done in the context of international new crop development and factors that impact the success or failure of such efforts. Our review finds considerable potential for native Australian plants to be developed as food crops, but the industry faces several significant challenges. The current industry focuses on niche food markets that are susceptible to oversupply. It also suffers from inconsistent quantity and quality of product, which is attributed to a reliance on wild harvesting and the cultivation of unimproved germplasm. More active cultivation is necessary for industry growth, but attempts have historically failed due to poorly adapted germplasm and a lack of agronomic information. The *de novo* domestication and large-scale cultivation of Australian plants as food crops will require an investment in publicly supported multidisciplinary research and development programmes. Research programmes must prioritize the exploration of plants throughout Australia and the collection and evaluation of germplasm. Programmes must also seek to engage relevant stakeholders, pursue participatory research models and provide appropriate engagement and benefit-sharing opportunities with Indigenous Australian communities.

Introduction

Australia has a diverse and unique native flora, spanning major biome types from tropical to arid to alpine, with thousands of edible plant taxa, many of which are wild relatives of important global food crops. Over the last 40 years, individuals have argued for the domestication and cultivation of edible Australian plants as crops (e.g. Yen, 1993; Considine, 1996; Bell *et al*., 2011; Abdelghany *et al*., 2021; Drake *et al*., 2021), yet, the commercial cultivation of Australian plants for food remains limited. The Macadamia nut (*Macadamia integrifolia* Maiden & Betche, *M. tetraphylla* L.A.S. Johnson, and their hybrids), native to coastal areas of the states of Queensland and New South Wales and domesticated in Hawaii from the 1920s, remains the only widely grown food crop endemic to the Australian continent (Shigeura and Ooka, 1984; Johnson and Burchett, 1996).

The lack of domesticated native Australian food crops is surprising, given that multiple food crops have been derived from the native flora of every other inhabited continent (Stalker *et al*., 2021). However, the absence of native Australian domesticates should not imply a lack of suitability of Australian plants to become food crops. In this review, we argue that there is considerable potential for the *de novo* domestication and cultivation of Australian plants as food crops and that investing in such domestication and cultivation could assist in diversifying Australian farming systems, providing environmental and economic sustainability benefits (Lin, 2011; Kahane *et al*., 2013; Isbell *et al*., 2017; Burchfield *et al*., 2019). We review the prior research and development of Australian native food plants in light of international new crop development efforts and the factors that impact the success or failure of these efforts. Constraints to developing native Australian crops and associated farming industries are identified, along with a framework for overcoming these constraints.

The need for greater crop diversity in Australian farming systems

Australia has around 60 million hectares of actively cultivated farmland (ABARES, 2022a). Around one-third of this area, predominantly in the continent's southwest, south and east,

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comprises monocultures of rainfed, annual grain crops (ABARES 2022a, 2022b). Three crops, wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and canola (*Brassica napus* L.), represent approximately 90% of the planted area (ABARES, 2022a, 2022b), and contribute significantly to globally traded staple foods and international food security (ABARES, 2022a, 2022b; FAOSTAT, 2022). These intensive, high-input, low-diversity monocultures of annual crops are not considered sustainable, given their negative environmental impacts and lack of resilience to disturbances such as climate change (FAO, 2017; Pretty *et al.*, 2018). Lack of diversity in agricultural systems is not limited to Australia: globally, farming systems are underpinned by an increasingly limited number of major annual crop taxa, and global diets are becoming less diverse, which negatively impacts the resilience of global food systems (Khoury *et al.*, 2014; Martin *et al.*, 2019; Bentham *et al.*, 2020).

Factors such as interannual weather variability, water insecurity, soil degradation and loss, ecosystem disturbance, pests and diseases pressure and changing global markets for agricultural commodities threaten the long-term viability of Australian agricultural systems, and such disturbances are likely to worsen in the future (Keating and Carberry, 2010; Cresswell *et al.*, 2021). Climate change poses a particularly serious challenge. Productivity in Australian grain farming has already been negatively impacted by the aridification of previously mesic production environments (Sudmeyer *et al.*, 2016; Hochman *et al.*, 2017). It is predicted that Australian agricultural industries and the agricultural sector worldwide will need to make significant changes to agronomic management and species selection to adapt to future climatic conditions (Howden *et al.*, 2010).

Increasing agrobiodiversity is a well-recognized strategy to improve the resilience and sustainability of agricultural systems (Jacobsen *et al.*, 2015; Isbell *et al.*, 2017; Li *et al.*, 2023). Agrobiodiversity can be increased through the production of minor crops, the introduction of exotic crops or the *de novo* domestication of new taxa (Massawe *et al.*, 2016; Toensmeier, 2016; Mustafa *et al.*, 2019; N'Danikou and Tchokponhoue, 2019). *De novo* domestication means the domestication and cultivation of species with little or no prior history of domestication or cultivation. New species provide opportunities for diversification of farming systems and enable transformational changes required for long-term sustainability (Rickards and Howden, 2012; Petersen and Snapp, 2015; Pretty *et al.*, 2018). For example, the use of high-diversity agricultural systems which favour perennial species, termed *perennial polycultures*, is proposed as one strategy for increased agricultural sustainability (Brummer *et al.*, 2011; Iverson *et al.*, 2014; Toensmeier, 2016; Crews *et al.*, 2018), but is difficult to achieve in Australia given existing crop species options (Hatton and Nulsen, 1999; Hobbs and O'Connor, 1999; Pate and Bell, 1999; Bell *et al.*, 2010; Loomis, 2022). Native Australian food crops could potentially provide economically viable perennial species that are well-adapted to local production environments, making perennial polycultures more feasible (Shelef *et al.*, 2017).

Many of Australia's most economically important agricultural industries were developed only recently (Nelson and Hawthorne, 2000; Salisbury *et al.*, 2016). Nearly three-quarters of the total value of crop production in Australia from the 1950s to 1990s is derived from new crops and emerging agricultural industries (Fletcher, 2002; Salvin *et al.*, 2004; Foster, 2014). Along with diversification benefits, native Australian food crops could, therefore, also lead to new, economically valuable agricultural industries. Globally, many governments and organizations recognize the value of new crops and invest in developing new crop species to enable similar economic opportunities (Janick *et al.*, 1996; Williams, 2005; Foster, 2014).

Can Australian flora be a source of new food crops?

Australia's native flora comprises approximately 20 000 recognized taxa of vascular land plants, around 85% of which are endemic (DEWR, 2007; Chapman, 2009; Broadhurst and Coates, 2017). Many individual taxa are known to be edible, with all plant food groups represented – cereals, pulses, nuts, roots and tubers, fruits and vegetables (Isaacs, 1987; Low, 1991; Latz, 1995; Bindon, 1996). Lists of edible native Australian plants have been compiled, derived predominately from records of plants traditionally eaten by Indigenous Australians (e.g. Isaacs, 1987; Low, 1991; Latz, 1995; Bindon, 1996; Hansen and Horsfall, 2019). Hansen and Horsfall (2019) and Latz (1995) provide comprehensive and regionally specific lists. The former documents approximately 400 edible taxa in southwest Western Australia, and the latter documents 110 taxa in the central desert region. Southwestern Australia has approximately 8000 native vascular plant taxa (FloraBase, 2021), and the central desert 1500 (FloraNT, 2021; AVH, 2023), suggesting 5–7% of local plant species are edible. This is comparable to or slightly lower than global estimates, suggesting that 10–20% of local flora in temperate regions globally could be edible (Rapoport and Drausal, 2013).

Lists of edible species are likely incomplete due to the loss of traditional Indigenous knowledge following European colonization, a lack of comprehensive documentation, cultural preferences in plant use and differing definitions of 'edible' (Rapoport and Drausal, 2013). To illustrate this, southwestern Australia has 39 genera in the legume sub-family Faboideae, representing 500 currently named taxa, with many endemic (FloraBase, 2021). Central Australia has 41 genera representing 138 currently named taxa in Faboideae (FloraNT, 2021). Hansen and Horsfall (2019) and Latz (1995) do not report the seed of these taxa as having been traditionally eaten, and there are no widely published reports of the seed of any Faboideae being eaten elsewhere in Australia. This is despite some taxa being crop wild relatives, such as *Glycine* Willd. and *Vigna* Savi. The seed composition of Australian Faboideae is not well studied, but anti-nutritional and potentially toxic compounds commonly occur in legumes (Tiwari *et al.*, 2011; Kumar *et al.*, 2022), and may have limited the traditional use of Australian taxa as food. Such compounds have been reduced or eliminated via appropriate food preparation techniques and breeding in domesticated legumes and could potentially be eliminated in Australian native legumes (Bell *et al.*, 2011; Bohra *et al.*, 2022; Zhang *et al.*, 2022). Many Australian Faboideae could, therefore, be considered 'potentially edible' and worth investigating for *de novo* domestication (Bell *et al.*, 2011). Including even a small number of the Faboideae expands the edible proportion of Australian flora to the high end of global estimates (Rapoport and Drausal, 2013). This simple estimate illustrates how Australia could have 4000 or more plant species suitable for exploration as potential food crops.

What is the potential of edible Australian flora for producing new crops?

Various traits influence crop domestication potential, the specific traits favouring domestication vary between species and crop type

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

(DeHaan *et al.*, 2016; Fuller *et al.*, 2023), and some plant taxa are more straightforward to domesticate than others (DeHaan *et al.*, 2016; Stalker *et al.*, 2021). Given the diversity of edible plant taxa native to the continent, it seems probable that some Australian species will have a combination of traits favouring *de novo* domestication. The development and global success of the Macadamia nut industry illustrates that some Australian species have traits that make them suitable for domestication. Furthermore, related plant taxa have often been independently domesticated in geographically separate regions, most probably because these taxa share common traits favouring their domestication (Wang *et al.*, 2014; Renny-Byfield *et al.*, 2016; Wu *et al.*, 2018). At least 130 Australian taxa are crop wild relatives (Rapoport and Drausal, 2013; Norton *et al.*, 2017), including species from *Oryza* L. (rice) (Henry, 2019; Abdelghany *et al.*, 2021), *Sorghum* (L.) Moench (Ananda *et al.*, 2020), *Vigna* Savi (beans) (Lawn 2015) and *Glycine* Willd. (soybean) (Hwang *et al.*, 2019). As well as providing a genetic resource for associated breeding programmes of domestic crops (Henry, 2023), such taxa are likely to share some traits that favoured their relatives' domestication, increasing their potential for *de novo* domestication. This suggests that edible Australian flora has good potential for producing new crops.

An overview of the current Australian native food industry

Historical use of Australian plants as food by humans

Australia's edible native flora has been extensively utilized by people since their arrival on the continent some 65 000 years ago, although a debate about whether plant cultivation was practised on the Australian continent before European colonization is ongoing (Pascoe, 2014; Keen 2021; Sutton and Walshe, 2021; Denham and Donohue, 2023). Plant domestication and cultivation, where plants have diverged morphologically and genetically from wild ancestors due to human selection and the reliance of human communities on these plants for most of their food intake, does not appear to have occurred in the Australian continent before the arrival of Europeans (Sutton and Walshe, 2021). Plant domestication is a continuum, however, without a well-defined start and endpoint (Winterhalder and Kennett, 2006; Meyer *et al.*, 2012; Zeder, 2015; Stetter *et al.*, 2017; Stalker *et al.*, 2021; Fuller *et al.*, 2023). Some 'early' plant cultivation and domestication are not readily distinguished from other forms of plant exploitation, particularly in the archaeological record (Zeder, 2015; Denham and Donohue, 2023).

There is evidence for the intensive management and manipulation of Australian flora by people via practices such as the use of fire and the translocation of food plants (Hallam, 1989; Bowman, 1998; Clarke, 2011; Ens *et al.*, 2017; Silcock, 2018; Lullfitz *et al.*, 2020a, 2020b; Keen, 2021; Fahey *et al.*, 2022), and 'non-agricultural' cultures are also known to have engaged in 'niche constructive' behaviours that maintained or increased the productivity of their environments (Smith, 2011; Anderson, 2013; Lightfoot *et al.*, 2013; Thompson *et al.*, 2021a, 2021b). Such activities can result in lasting changes in the geographic distribution and genetic composition of plant taxa (Levis *et al.*, 2017; Coughlan and Nelson, 2018; Levis *et al.*, 2018; Pavlik *et al.*, 2021). This appears to have resulted in detectable changes in the genetics of some Australian taxa (Rangan *et al.*, 2015; Lullfitz *et al.*, 2020a, 2020b) and may have also resulted in phenotypic changes. For example, it has been proposed that the large grain size in some native Australian *Oryza* may reflect human selection (Henry, 2019). This may impact efforts to domestic Australian species as crops in the future.

Features of the current industry

The possibility of cultivating edible Australian plants as crops has been acknowledged for over a century (Maiden, 1889). However, the Australian 'native foods industry' did not commence until approximately the 1980s (Cherikoff and Brand, 1983; Brand-Miller and Cherikoff, 1985; Cherikoff and Brand, 1988). Commercial native food production now takes place in all Australian states and territories (Clarke, 2012; Sultanbawa and Sultanbawa, 2016), but the current industry is small in terms of total production and economic value. Excluding Macadamia, total output was estimated to average only 8 tonnes in 2010 (Clarke, 2013), with a farm-gate value of $21 million in 2019 (Laurie, 2020), in comparison to the total gross value of Australian agriculture of $55 billion in 2015–16 (ABARES 2022a, 2022b).

Most of the production and economic value of the industry is represented by only 11 taxa (Table 1) (Clarke, 2013; Laurie, 2020). These came to dominate the industry through multiple 'organic' routes over four decades and are mainly used as 'niche' food additives or flavourants (i.e. herbs and spices) or are fruits that are processed into value-added products. Feedstock material used by the food industry is obtained from wild and cultivated sources (Clarke, 2013; Laurie, 2020). Most of the taxa are native to eastern and northern Australia's tropical, subtropical and oceanic climate zones (Fig. 1A), except for *Solanum centrale* (Fig. 1B), which grows in arid zones of Australia. Since the native ranges of the taxa do not overlap with the Australian grain production regions, these species offer little potential to diversify existing grain industries with locally adapted crops. Those taxa that do grow in the grain belt include *Santalum acuminatum* (Quandong) (Fig. 1C) and multiple species of *Acacia* (Table 1). Quandong is an obligate root hemiparasite that requires a host tree and produces a fleshy fruit with an edible nut (Ahmed and Johnson, 2000; Lee, 2013). These traits give it limited potential for broadscale planting in grain-producing regions. Conversely, the various species of *Acacia* produce a grain legume (or *pulse*) and offer the prospect of large-scale planting for bulk food production (Ahmed and Johnson, 2000; Bartle *et al.*, 2002; Lee, 2013). Aside from the taxa in Table 1, around 40 other Australian plant taxa are sold for food (Table 2) (CNFS, 2022; Tucker Bush, 2022). These represent a greater diversity of food types than the taxa in Table 1 and are native to a broader range of environments. However, the majority are native to eastern Australia and are used only as niche food additives.

Literature dating back to the late 1990s has examined the utilization of Australian native plants as food crops and the development of the native food industry. Authors have consistently concluded there is a good market potential for Australian food plants, especially those considered novel and with exceptional nutritional profiles (Cherikoff, 2000; Konczak *et al.*, 2009; Clarke, 2012; Sultanbawa and Sultanbawa, 2016; Birch *et al.*, 2023). They also conclude that Australian plants offer valuable opportunities for diversifying the continent's agricultural systems with well-adapted new crops that can enhance environmental and economic sustainability (Considine, 1996; Ahmed and Johnson, 2000; Bell *et al.*, 2011; Abdelghany *et al.*, 2021; Drake *et al.*, 2021; Canning, 2022). However, the various authors have

Table 1. Plant taxa and their relatives that are the current focus of the Australian native food industry (Clarke, 2013; Laurie, 2020)

Species	Common name	Family	Food type	Approximate native range	Climate
Acacia spp. Commonly *A. victoriae*; *A. adsurgens*; *A. aneura*; *A. colei*; *A. coriacea*; *A. cowleana*; *A. kempeana*; *A. murrayana*; *A. tenuissim*; *A. pycnantha*; *A. retinodes*; *A. sophorae*	Wattle	Fabaceae	Seed	Continent wide genus	
Acronychia acidula and *A. oblongifolia*	Lemon Aspen, Pigeon Berry, Southern Lemon Aspen, White Aspen	Rutaceae	Herb/ spice	Coastal Qld, NSW and Vic	Cfb, Cfa, Cwa
Backhousia anisata (syn Syzygium anisatum) and *Backhousia citriodora*	Anise myrtle, Aniseed myrtle, Ringwood, Lemon myrtle, Lemon Ironwood, Lemon scented myrtle, Sweet Verbena tree	Myrtaceae	Herb/ spice	Mainly coastal Qld	Cfa, Cwa, Aw
Citrus glauca (syn Eremocitrus glauca), *C. australasica (syn Microcitrus australasica)*	Finger Lime, Desert lime	Rutaceae	Fruit	Coastal Qld and NSW, Inland areas of Qld, NSW and SA.	Cfa, Bsh, Bsk, Bwh
Davidsonia jerseyana, *D. johnsonii*, *D. pruriens*	Davidson Plum, Queensland Itchtree, Ooray Smooth Davidsonia	Cunoniaceae	Fruit	Coastal Qld and NSW	Am, Af, Cfa, Cwa
Kunzea pomifera	Muntries, Emu apple	Myrtaceae	Fruit	South-eastern SA and western Vic	Csb, Csa, Bsk
Santalum acuminatum and *S. spicatum*	Quandong, Sweet Quandong, Wild Peach, Desert Peach, Native Peach, Guwandhuna, Gutchu, Wanjanu, Mangata, Goorti, Wadjal	Santalaceae	Fruit/ nut	Southern Australia	All except tropical
Solanum centrale	Bush tomato, Desert raisin	Solanaceae	Fruit	Inland areas mainly WA, NT and SA	Bwh, Bsh
Syzygium luehmannii, *S. australe* and *S. oleosum*	Riberry, Small-leaved Lilly Pilly, Clove Lilli Pilli	Myrtaceae	Fruit	Coastal Qld and NSW	Am, Af, Cfa, Cwa
Tasmannia lanceolata	Tasmanian pepper, Mountain pepper, Native pepper, Pepperberry, Pepperleaf	Winteraceae	Herb/ spice	Tas, Vic and southeast NSW	Cfb
Terminalia ferdinandiana	Kakadu Plum, Billy Goat Plum, Green Plum, Salty Plum, Wild Plum, Murunga, Marnybi, Manmohpan, Kullari Plum, Gubinge	Combretaceae	Fruit	Northern NT and northwest WA	Aw, Bsh

The approximate native range obtained from the Australasian Virtual Herbarium (AVH 2023).
WA, Western Australia; NT, Northern Territory; SA, South Australia; Qld, Queensland; NSW, New South Wales; Vic, Victoria; Tas, Tasmania; Af, Tropical rainforest; Am, Tropical monsoon; Aw, Tropic Savanna with dry winter; Bsh/Bsk, semi-arid hot; Bwh, arid hot; Cfa, humid sub-tropical; Cfb, oceanic; Csa, Mediterranean hot summer; Csb, Mediterranean warm summer; Cwa, dry-winter humid subtropical.

also identified significant challenges. The current emphasis on niche food markets makes them susceptible to oversupply (Clarke, 2012; Clarke, 2013), necessitating the development of new crops capable of supplying larger markets. The industry also grapples with inconsistent quantity and quality of supply, attributed mainly to a reliance on wild harvesting and the cultivation of unimproved germplasm, so there is a need for more active cultivation and the use of improved cultivars to address this problem (Stynes, 1997; Salvin *et al.*, 2004; Lee, 2013; Abdelghany *et al.*, 2021). Although some active cultivation efforts are underway, they face obstacles such as a lack of information on cultivation methods, challenges posed by pests and diseases and an overreliance on manual labour (Ahmed and Johnson, 2000; Clarke, 2012, 2013; Lee, 2013; Sultanbawa and Sultanbawa, 2016). To advance the industry, ongoing research is required, with a critical need for cultivar development, general agronomy and market development (Gorst, 2002; Salvin *et al.*, 2004; Lee and Six, 2010; Clarke, 2012, 2013; Sultanbawa and Sultanbawa, 2016).

Research on individual taxa

To quantify the extent of research on individual taxa published in the 20 years between 2001 and 2021 (the time since the last scholarly review of the industry by Ahmed and Johnson, 2000), the Thomson Reuters Web of Science database was searched for publications in scholarly journals relating to the taxa in Table 1 and Table 2. We identified 234 research articles mentioning at least one of the taxa from Table 1 (Fig. 2). *Acacia* was excluded, given the large number of individual taxa in the genus, taxa found outside Australia and the non-food use of the species globally. No relevant published work was found for the taxa in Table 2. For comparison, the total research output for the taxa with the *most* published research is comparable to the

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

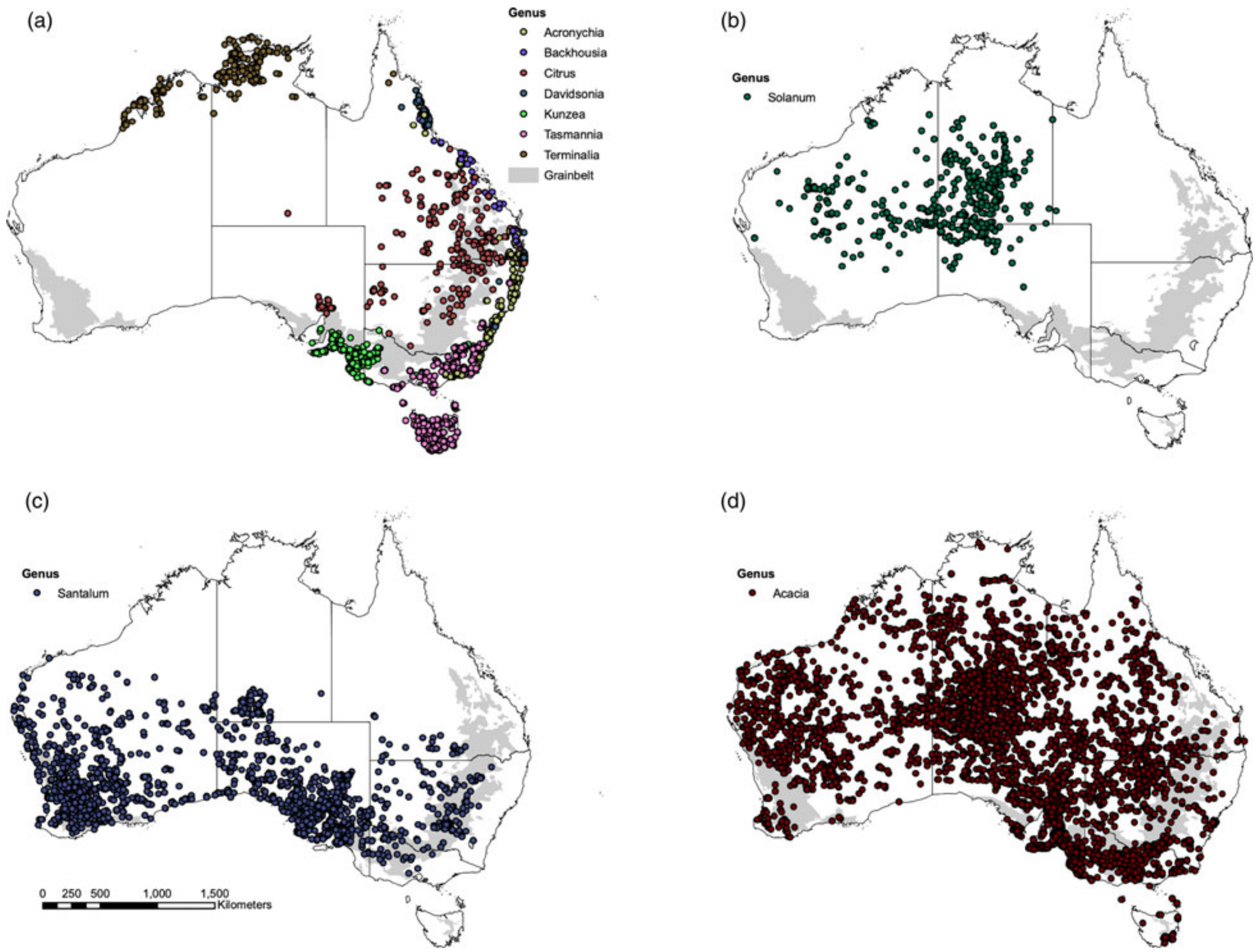

Figure 1. The maps in panels A–D show the distribution of taxa listed in Table 1. The maps are based on collection information from the Australian Virtual Herbarium (AVH 2023). The Australian grain production zone is shown in grey. The distribution of (a) *Acronychia acidula* and *A. oblongifolia*, *Backhousia anisata* (syn *Syzygium anisatum*) and *B. citriodora*, *Citrus glauca* (syn *Eremocitrus glauca*), *C. australasica* (syn *Microcitrus australasica*), *Davidsonia jerseyana*, *D. johnsonii*, *D. pruriens*, *Kunzea pomifera*, *Tasmannia lanceolata* and *Terminalia ferdinandiana*. (b) *Solanum central*; (c) *Santalum acuminatum* and *S. spicatum*, (d) *Acacia victoriae*; *A. adsurgens*; *A. aneura*; *A. colei*; *A. coriacea*; *A. cowleana*; *A. kempeana*; *A. murrayana*; *A. tenuissim*; *A. pycnantha*; *A. retinodes*; *A. sophorae.*

Australian research output for minor crops like kiwifruit, with 41 papers (*Actinidia),* or Blueberry (*Vaccinium*), with 106 papers over the same period (ABARES, 2022a, 2022b). Publications covered by the Web of Science Core Collection are assigned to at least one subject area category. We found that the journal articles relating to the taxa mainly related to food sciences, chemistry or nutrition (Fig. 2). Papers addressing other areas relevant to the development of the industry, such as agronomy and genetics, represented only a quarter of all publications. Ahmed and Johnson (2000) observed that most published research at the time of their review was focused on the compositional analysis of native food plants, and other critical areas were lacking. Our literature search shows this trend has continued, and whilst compositional analysis is essential for industry development, lack of research in other areas has likely contributed to the slow pace of industry development.

Agrifutures Australia, previously called the Rural Industries Research & Development Corporation (RIRDC), is a statutory authority established by the Australian Federal Government to support new and emerging industries. Since 2000, Agrifutures Australia has produced 43 reports dealing wholly or partly with different aspects of the Australian native foods industry (Agrifutures, 2022), but only one has been published since 2017 (Table 1). While agronomy and germplasm improvement are addressed more frequently than in the published literature, food science or compositional analyses remain the most common area of research (Fig. 3). Like the scientific literature, it is a relatively small number of publications for any individual taxon (Fig. 4).

Some individual edible taxa have had more concerted research aimed at their domestication as crops. Germplasm screening and selection, genetics and reproductive biology studies and some agronomy have been undertaken for *Kunzea pomifera* (Page, 2004; Page *et al*., 2006a, 2000b; Do *et al*., 2014, 2018a, 2018b). Native *Acacia* have been the focus of development as a grain crop in Australia and elsewhere (Lister *et al*., 1996; Maslin *et al*., 1998; Bartle *et al*., 2002; Hele, 2002; Rinaudo *et al*., 2002; Midgley and Turnbull, 2003; Rinaudo and Cunningham, 2008). Native Australian legumes, aside from *Acacia*, have also been explored as pulses, with the examination of grain yield and seed composition (Rivett *et al*., 1983; Bell *et al*., 2011; Ryan *et al*., 2011; Bell *et al*., 2012). Several commercial *Citrus* varieties have been developed by hybridizing Australian native *Citrus* spp. with domestic *Citrus* spp. (Sykes, 1997; Hele, 2001; Agrifutures, 2017). Native *Oryza* spp. has been considered as source of germplasm for improving domestic rice, but germplasm collection and

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

Table 2. The edible plant taxa sold by the Tuckerbush and Creative Native Food Service companies at the time of writing in 2023

Species	Common name	Family	Type	Approximate range
Adansonia gregorii	Boab Roots	Malvaceae	Root/tuber	Northwest WA
Alpinia caerulea	Australia Ginger	Zingiberaceae	Herb/spice	Coastal Qld and NSW
Antidesma bunius and *A. erostre*	Bignay/Wild Grape	Phyllanthaceae	Fruit	Coastal Qld
Apium annuum and *prostratum*	Native celery parsley	Apiaceae	Vegetable	Coastal southern and eastern Australia
Araucaria bidwillii	Bunya	Araucariaceae	Nut	Coastal Qld and NSW
Arthropodium strictum	Chocolate lily	Asparagaceae	Roots/ tubers	Mainly SA, Vic, NSW, Qld
Athertonia diversifolia	Atherton Almonds	Proteaceae	Nut	Coastal Qld and NSW
Atractocarpus fitzalanii	Native Gardenia	Rubiaceae	Fruit	Coastal Qld
Atriplex nummularia	Saltbush	Amaranthaceae	Vegetable	Inland areas of all mainland states
Austromyrtus dulcis	Midyim Berries	Myrtaceae	Fruit	Coastal Qld and NSW
Barbarea australis	Native wintercress	Brassicaceae	Vegetable	Tas
Brachychiton populneus	Jurrajin seed	Malvaceae	Seed	Qld. NSW, Vic
Chamelaucium uncinatum	Geraldton Wax	Myrtaceae	Herb/spice	Southwestern WA
Cymbopogon ambiguus	Native lemongrass	Poaceae	Herb/spice	All mainland states
Dianella revoluta	Dianella	Asphodelaceae	Fruit	Southern and eastern Aust.
Dimocarpus australianus	Rainforest lychee	Sapindaceae	Fruit	North Coastal Qld
Dioscorea hastifolia	Warrine	Dioscoreaceae	Roots/ tubers	Southwestern WA
Diospyros australis	Black Plum	Ebenaceae	Fruit	Coastal Qld and NSW
Diploglottis australis and *D. campbellii*	Large and small leaf Tamarind	Sapindaceae	Fruit	Coastal Qld and NSW
Disphyma crassifolium	Karkalla Beach bananas	Aizoaceae	Herb/spice	Southern Aust.
Elaeocarpus angustifolius	Blue quandone	Elaeocarpaceae	Fruit	Coastal Qld
Enchylaena tomentosa	Ruby saltbush	Amaranthaceae	Fruit	All mainland states
Eremophila alternifolia	Scented Emu Bush	Scrophulariaceae	Herb/spice	Predominantley southern inland areas of WA, SA
Eupomatia laurina	Bolwarra	Eupomatiaceae	Herb/spice	Coastal Qld and NSW
Ficus coronata	Sandpaper fig	Moraceae	Fruit	Coastal Qld and NSW
Haemodorum spicatum	Mean	Haemodoraceae	Roots/ tubers	Southwestern WA
Hibiscus heterophylla	Native rosella	Malvaceae	Fruit/flower	Coastal Qld and NSW, northern WA, NT
Melastoma affine	Blue Tounge	Melastomataceae	Fruit	Coastal Qld and NSW, northern WA, NT
Mentha satureioides and *M. australis*	Bush mint	Lamiaceae	Herb/spice	NSW, Vis, southern SA and Qld
Microseris lanceolata and *M. scapigera*	Yam diasy	Asteraceae	Roots/ tubers	Southwestern Aust.
Myoporum insulare and *M. montanum*	Boobialla/Waterbush	Scrophulariaceae	Fruit	Coastal southern Australia
Olearia axillaris	Coastal Rosemary/Coastal daisy	Asteraceae	Herb/spice	Coastal southern and western Australia
Pipturus argenteus	Native mulberry	Urticaceae	Fruit	Coastal Qld
Platysace deflexa	Youlk	Apiaceae	Roots/ tubers	Southwestern WA
Plectranthus graveolens (Coleus graveolens)	Basil bush	Lamiaceae	Herb/spice	Coastal Qld and NSW
Pleiogynium timorense	Burdekin plum	Anacardiaceae	Fruit	Coastal Qld
Podocarpus elatus	Illawara plum	Podocarpaceae		Coastal Qld and NSW

(*Continued*)

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Table 2. (*Continued.*)

Species	Common name	Family	Type	Approximate range
Pouteria australis	Black apple	Sapotaceae	Fruit	Coastal southern Qld and NSW
Prostanthera rotundifolia and *P. incisa*	Native mints, Native Thyme	Lamiaceae		NSW, Vic, Tas
Rubus probus	Atherton raspberry	Rosaceae	Fruit	Coastal Qld
Scaevola spinescens	Maroon bush	Goodeniaceae	Fruit	Inland areas of all mainland state
Sterculia quadrifida	Peanut tree	Malvaceae	Seed	Coastal Qld, NT and northern WA
Tetragonia tetragonioides	Warrigal greens	Aizoaceae	Vegetable	Southern Aust.

WA, Western Australia, NT, Northern Territory, SA, South Australia, Qld, Queensland, NSW, New South Wales, Vic, Victoria, Tas, Tasmania.

characterization and the systematic identification of research priorities have also taken place with the aim of *de novo* domestication (Henry *et al*., 2010; Henry, 2012; Henry, 2019; Abdelghany *et al*., 2021). Germplasm screening (Davies *et al*., 2005), genetic analysis (Shapter *et al*., 2013; Mitchell *et al*., 2015) and commercialization of elite lines have been undertaken for *Microlaena stipodes*, a widespread native grass that produces an edible grain similar to rice (Chivers *et al*., 2015; Shapter and Chivers, 2015). Several other grass species are also being actively investigated as potential grain crops (Khoddami *et al*., 2020; Drake *et al*., 2021). Despite this research and development effort, a large-scale commercial agricultural industry has yet to develop for these taxa.

Indigenous engagement and benefit sharing

Australian plants can hold cultural and spiritual significance to people in the Indigenous Australian community (Clarke, 2011), but their engagement and benefit-sharing with the native foods industry has historically been limited (Considine, 1996; Stynes, 1997; Ahmed and Johnson, 2000; Clarke, 2013; Lingard and Martin, 2016; Sultanbawa and Sultanbawa, 2016; Drake *et al*., 2021). '*The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization*' aims to implement the access and benefits-sharing obligations of the International Convention on Biological Diversity (Lee, 2013; Leha *et al*., 2019; Sherman and Henry, 2020; Fyfe *et al*., 2021). Australia ratified the Convention on Biological Diversity, and while it is not presently a participant in the Nagoya Protocol, current domestic measures purport to align with the principles outlined in the protocol (DCCEEW, 2021). However, others have found that traditional knowledge and intellectual property regarding edible native plants currently lack comprehensive legal protection in Australia or may not be adequately protected by existing laws (Leha *et al*., 2019). Food is globally recognized as an intangible cultural heritage, eligible for special recognition and protection (Di Giovine and Brulotte, 2016; Galanakis, 2019). So even without clear intellectual property ownership or legal frameworks for protecting traditional biological knowledge, moral and ethical obligations remain for those seeking to develop native Australian food crops (Leha *et al*., 2019; Jarvis *et al*., 2021; Maclean *et al*., 2022). Indigenous Australian support for developing native food industries is generally considered conditional on ensuring such industries recognize and respect culturally or spiritually significant plants, along with their traditional uses (NLE, 2022). Any research and development targeting Australian native food plants must, therefore, acknowledge the ongoing cultural connections of Indigenous Australian peoples with native flora and take steps to ensure Indigenous Australian communities have opportunities to engage, lead and benefit from the industry.

We believe current ambiguities around Indigenous Australian engagement and benefit sharing will likely hinder research and development activities, and this must be addressed if the industry is to develop. Firstly, even if legislation regarding intellectual property ownership and benefit-sharing is enacted, ownership of traditional knowledge and biological resources and appropriate avenues for benefit-sharing are often unclear. This is the case when information regarding taxa is well-documented, in the public domain, and has been so for a prolonged period. There is ambiguity in the Nagoya Protocol regarding historical germplasm collections and information (Sherman and Henry, 2020). Moreover, some edible plant taxa have wide native ranges spanning many Indigenous Australian communities, and under these circumstances, intellectual property ownership and appropriate benefit-sharing avenues are also unclear. Surveys of Indigenous Australian stakeholders have found that most respondents support the development of a native food industry (NLE, 2022). However, stakeholders still have divergent opinions about whether the commercial development of native food plants as crops should occur and what form the industry should take (Ahmed and Johnson, 2000; Clarke, 2013; Drake *et al*., 2021). This makes it challenging to identify, engage and coordinate among owners of traditional biological knowledge and find consensus regarding the appropriate way to domesticate and cultivate some species.

The complexity of creating legal and ethical frameworks that both protect and allow the use of traditional ethnobotanical knowledge is a globally recognized problem, as is a lack of engagement and benefit sharing with traditional owners when commercializing traditional foods (Zimmerer and De Haan, 2017; Antonelli, 2023). A discussion of a possible framework for the ethical development of native Australian crops that can address the challenges described above is outside the scope of this review, but the challenges will act as a major obstacle to research and development activities, and nationally consistent legislation and best practice guidelines to address them are urgently needed.

What are the ways forward for native Australian food crops?

Six key areas stand out that would support the use of Australian native plants as food: (i) active cultivation; (ii) germplasm

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

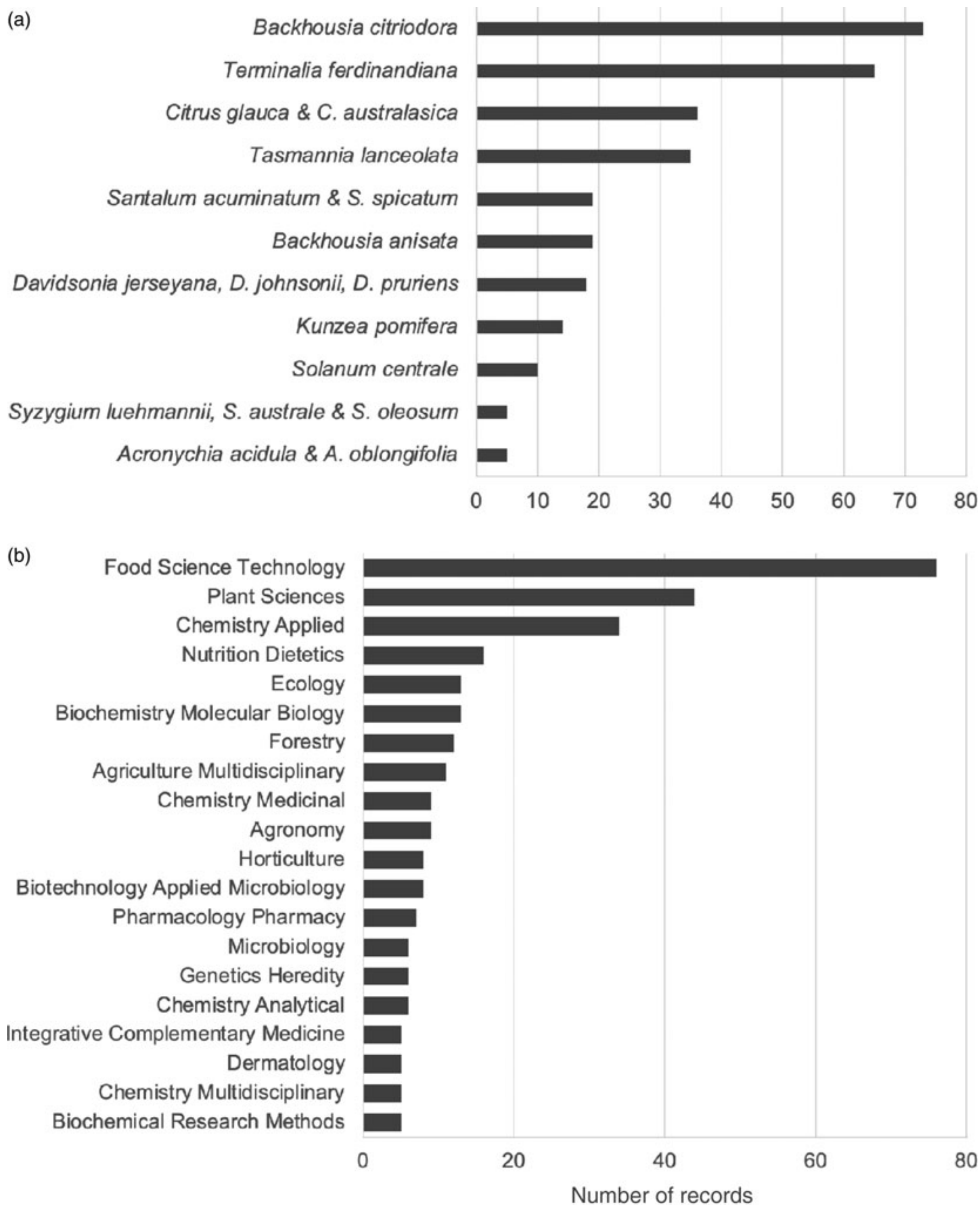

Figure 2. The number of scholarly journal articles in the Web of Science database that mention: (a) at least one of the plant taxa prioritized by the Australian native food industry (Table 1), published between 2001 and 2021. (b) The number of scholarly publications of Australian native species relating to individual Web of Science subject categories.

collection, characterization and improvement; (iii) basic research; (iv) sustained public funding of critical R&D; (v) greater diversity of food types and cultivation regions; (vi) engagement with Indigenous stakeholders and participatory approaches to research and (vii) consideration of the implications of domestication for conservation, and Indigenous traditional knowledge and use. These are discussed in detail below.

Active cultivation

Wild harvesting remains the primary source of material in the native food industry for many taxa. Wild harvests can provide economic returns to communities engaged in the collection and are attractive to those advocating for 'ecological' approaches to agribusiness industries (Ahmed and Johnson, 2000; Clarke, 2013; Lee, 2013). However, wild harvesting is also associated with challenges such as inconsistent and unpredictable yields and product quality, limited supply, limited scope for expansion, high demand for labour and possible negative impacts on natural ecosystems (Miers, 2004; RIRDC, 2008; Clarke, 2013; Sultanbawa and Sultanbawa, 2016; Laurie, 2020). Additionally, wild harvesting is not risk-free for workers. For example, wild harvesting of native *Oryza* risks attack by saltwater crocodiles (Abdelghany *et al.*, 2021). Consequently, although wild

Figure 3. The number of reports published by Agrifutures Australia that address subject matter relating to Australian native food plants.

harvesting may be viable for specific regions and species, potentially augmented by 'active management' or 'enrichment planting' of otherwise wild plant communities (Lee and Courtenay, 2016), industry growth will require active cultivation.

Germplasm collection, characterization and improvement

The wild phenotype of most, if not all, plant taxa is sub-optimal for commercial utilization (Wilson, 2007; Brummer *et al.*, 2011; DeHaan *et al.*, 2016), and suboptimal germplasm is a significant obstacle to viable cultivation of edible Australian plants (Stynes, 1997; Salvin *et al.*, 2004; Lee, 2013; Abdelghany *et al.*, 2021). Germplasm screening and improvement will therefore be essential for the active cultivation of edible Australian plants to meet the needs of growers and consumers.

Even if wild taxa are identified that pose few challenges to *de novo* domestication, research and development will still be needed to address problematic traits (DeHaan *et al.*, 2016; Toensmeier, 2016). Information regarding commercially important traits is unavailable for most Australian edible taxa, making it impossible to assess their potential as crops or to set research and development priorities. Furthermore, any available information often relates to germplasm of unknown provenance or collections with minimal genetic variation (e.g. see discussions in Sultanbawa and Sultanbawa (2016)). Many edible Australian taxa have broad distributions spanning a considerable range of

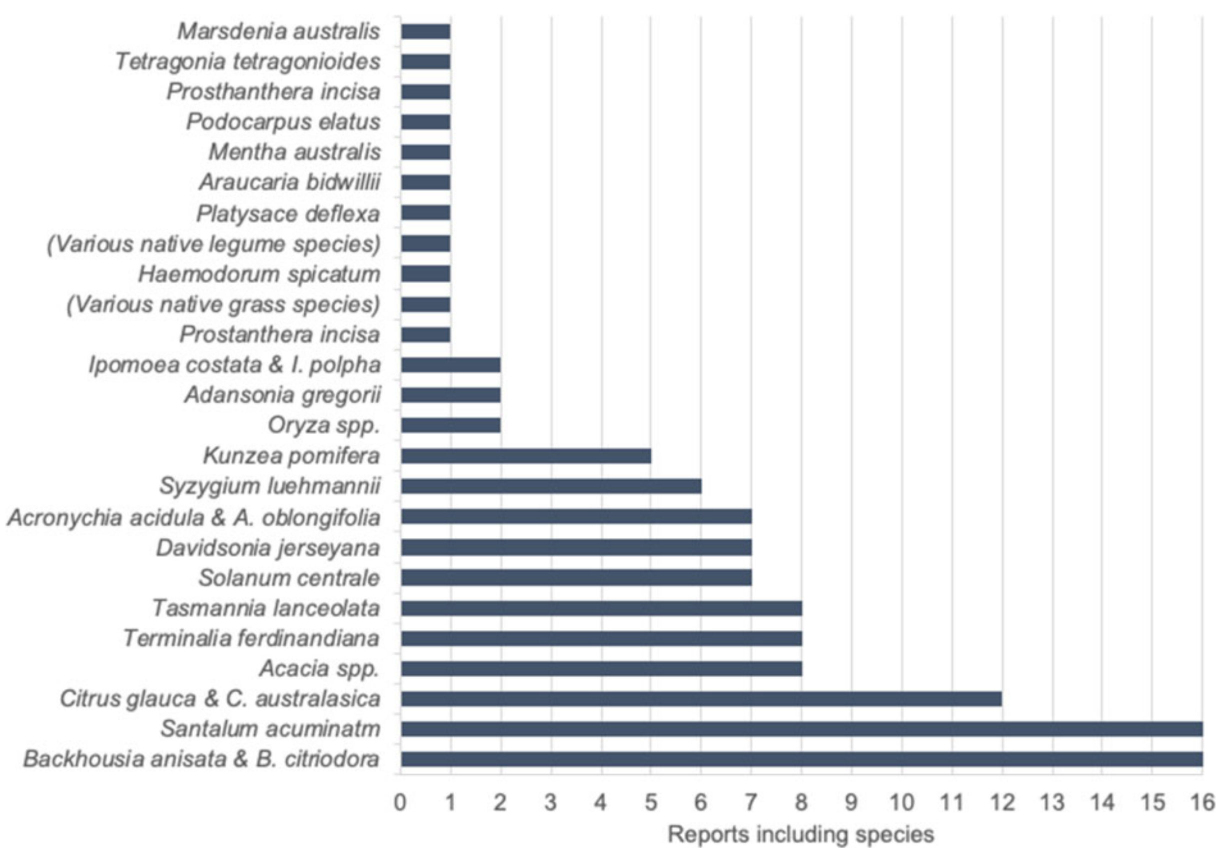

Figure 4. The number of reports published by Agrifutures Australia that address the native food taxa.

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

climatic and edaphic conditions and display high genetic and morphological diversity, including variation in economically important traits (Davies *et al*., 2005; Ariati *et al*., 2007; Mitchell *et al*., 2015; Shapter and Chivers, 2015; Broadhurst *et al*., 2017; Snowball *et al*., 2021). Drawing conclusions regarding a species' suitability for domestication from samples of minimal genetic diversity is, therefore, of limited value or even potentially misleading. For example, Ryan *et al*. (2011) identified the representation of genetic diversity in germplasm collections and its evaluation under controlled conditions as a critical gap in assessments of Australian native pulses.

Assembling genetically diverse germplasm collections and then evaluating and selecting improved cultivars is an effective strategy for cultivar development, and remains an essential method for plant breeding globally (Murphy, 2007; Acquaah, 2015; Rebetzke *et al*., 2019), particularly for minor crops that lack resources for research and development (Jacobsen *et al*., 2015). However, crop domestication initially involved, on average, the modification of only three major traits, which were controlled primarily by single genes (Meyer *et al*., 2012; Østerberg *et al*., 2017; Stetter *et al*., 2017). So, the use of molecular breeding techniques that target limited numbers of single gene traits to 'mimic' domestication events could increase the speed and efficiency of new crop development from Australian flora (Smýkal *et al*., 2018; Gasparini *et al*., 2021; Luo *et al*., 2022; Bartlett *et al*., 2023; Henry, 2023). Such approaches come with risks, though, including that a focus on single genes may over-simplify domestication or neglect the importance of agronomy and genotype-by-environment interactions in the crop phenotype (Passioura, 2020; Van Tassel *et al*., 2020; Bartlett *et al*., 2023), and should therefore be used in conjunction with more traditional approaches. Centralized breeding may also not address the specific localized needs of growers (Fadda *et al*., 2020), or provide opportunities to engage with Indigenous communities (Bartlett *et al*., 2023). Thus, we believe a range of strategies, including 'traditional' approaches in the early stages of crop development, genetic screening to ensure sufficient diversity and strategic investment in molecular breeding, are appropriate.

Germplasm collection and characterization must consider the historical use of taxa by people, which may have influenced the genetic diversity and geographic distribution of edible taxa. Taxa with high levels of anthropogenic translocation may show a lack of population genetic structure or a structure corresponding to human activity (Lullfitz *et al*., 2020a, 2020b). Therefore, phylogeographic patterns resulting from human translocation of food plants should be considered in germplasm collection documentation and activities. Plant populations from areas with intensive utilization could be targeted for germplasm collection because these populations may exhibit a higher frequency of individuals with useful genotypes. Further work is needed to investigate the anthropogenic influence on Australian plant genetics and phylogeographic patterns to inform germplasm collection, characterization and crop development activities.

Habitat loss due to clearing native vegetation for agriculture and subsequent land degradation has heavily impacted many ecosystems in Australia (Cresswell *et al*., 2021). As a result, the remaining native vegetation is often highly fragmented (Hobbs and Yates, 2003; Hopper and Gioia, 2004; Coates *et al*., 2014; Broadhurst and Coates, 2017), and faces ongoing pressure from pests, disease and climate change (Cresswell *et al*., 2021). Preservation of genetic diversity is essential for agricultural sustainability globally, as well as conservation efforts. Care must also be taken as the greater use of native plants as crops brings risks such as gene flow between domesticated and wild populations, posing potential threats to wild populations (Haygood *et al*., 2003), particularly if wild populations are small and highly fragmented.

The need for basic research

Poorly adapted germplasm, a lack of agronomic information and insufficient investment to address these issues are also commonly identified as significant obstacles to the growth and expansion of the Australian native food industry (Salvin *et al*., 2004; Clarke, 2012; Clarke, 2013). Developing productive and economically viable farming systems in Australia and globally has relied on basic agricultural research (Hunt *et al*., 2019; Zaidi *et al*., 2019; Hunt *et al*., 2021). There is a need globally for more significant investment in basic research to increase agrobiodiversity and food security (Jacobsen *et al*., 2015; Toensmeier, 2016), not just in Australia. Many wild plant taxa have been explored as potential crops (Janick, 1996; Janick, 1999; Janick and Whipkey, 2002; Janick and Whipkey, 2007), but few are now commercially viable and widely grown (DeHaan *et al*., 2016). A common issue is that basic research needed to understand and address problematic plant traits that inhibit economically viable production is missing, as is research to underpin commercially viable agronomy (Jolliff, 1990; Blade and Slinkard, 2002; Wilson, 2007; Abbo *et al*., 2014; DeHaan *et al*., 2016). Basic applied research will, therefore, be essential for developing the Australian native food industry.

The need for sustained public funding of R&D

Developing new crops and associated agricultural industries, particularly from undomesticated taxa, requires a sustained, long-term, and multidisciplinary research effort (Wollenweber *et al*., 2005; Runck *et al*., 2014; DeHaan *et al*., 2016). Successful new crop industries in Australia and elsewhere have relied on sustained public research investment in multi-decade and multi-disciplinary research programmes (Williams, 2005; Collins and Norton, 2019; Pratley and Kirkegaard, 2019). This is illustrated by the introduction and development of canola (*Brassica napus*) (Colton and Potter, 1999; Salisbury *et al*., 2016) and edible lines of lupins (*Lupinus angustifolius*) (Nelson and Hawthorne, 2000). The successful development of native Australian crops will require similar research and development efforts. Public funding for such research work in Australia is relatively limited, unsustained or often non-existent and has also not attracted investment from private enterprises. This stands as a significant hurdle to the further development of the industry.

A possible funding and industry development model already exists in Australia in the form of the Research and Development Corporations (RDC). Supported partly by levies on producers, RDCs have brought demonstrable benefits to several agricultural industries (CRRDC, 2016). Agrifutures Australia is the RDC responsible for supporting research and industry development for edible Australian plants as part of a broader mandate to support new agricultural industries. However, it does not currently provide sustained funding of the sort needed for *de novo* domestication of food crops. Dedicating a specific RDC to native crop domestication could meet global calls for governments to support more diverse and locally adapted food systems built partly on non-conventional crops (Antonelli, 2023). By administering research through national and regional RDC panels comprised of stakeholders,

https://doi.org/10.1017/S0021859624000078 Published online by Cambridge University Press

including members of the Indigenous Australian community, such a model could also provide a mechanism to address engagement and benefit-sharing challenges. When intellectual property ownership is complex, disputed or distributed, such a body could collect levies and administer a consolidated fund.

Greater diversity of food types and regions

The Australian native food industry is biased towards niche markets. Expanding the number of taxa under consideration to encompass more food types, such as grains or pulses, that can supply large-scale staple food markets and to include taxa adapted to a more diverse range of agroecosystems, particularly the grain production zones, will increase opportunities for large-scale native food production to diversify existing extensive agricultural industries. This necessitates research and development towards a more diverse range of edible species.

Participatory research approaches

Participatory germplasm improvement and agronomic research are increasingly common in Australia and globally (Walters *et al*., 2018; Snapp *et al*., 2019; Colley *et al*., 2021; Lacoste *et al*., 2022). Participatory research includes stakeholders in evaluating and selecting germplasm, developing research targets and conducting agronomic research to address industry constraints (Shelton *et al*., 2016; Walters *et al*., 2018; Snapp *et al*., 2019; Lacoste *et al*., 2022). Participatory breeding has been used successfully to improve the productivity and quality of crops in several regions, notably in some minor crops (Ceccarelli, 2015; Shelton *et al*., 2016; Ceccarelli and Grando, 2020; Fadda *et al*., 2020). On-farm agronomic research can better understand and address complex genotype, management and environmental interactions (Rotili *et al*., 2020), identify industry needs, and encourage more rapid adoption of new crops and farming practices (Hunt *et al*., 2019). Participatory research can yield efficiencies in a stretched research funding environment, complement traditional research programmes and create additional avenues for engagement and empowerment of Australian Aboriginal communities.

Conclusions

There is considerable potential for the *de novo* domestication and cultivation of native Australian plants as food crops. Such crops could provide valuable new agricultural industries that increase the long-term sustainability of Australian agricultural systems and contribute to global food security. The primary impediment is inadequate funding and policy needed to underpin appropriate research and development, particularly basic cultivar development and agronomic research needed for active cultivation. Historically, successful new crop programmes show that developing native Australian food crops will require a sustained investment in publicly supported multidisciplinary research and development. This could happen through established Australian agricultural funding frameworks like the RDCs. Research and development activities must commence with collecting and evaluating a range of edible taxa, from throughout the continent, targeting species with the potential for large-scale staple food markets and adapted to a diverse range of agroecosystems. Finally, development programmes must also engage all relevant stakeholders and provide appropriate engagement and benefit-sharing opportunities with Indigenous communities.

Acknowledgements. We sincerely thank Dr Angela Pattison, The University of Sydney, and Professor Sally Thompson, The University of Western Australia, for providing comments on drafts of this review.

Author contributions. N. A. G. and K. D. conceived the review topic and N. A. G. researched and wrote the manuscript. S. J. B., R. C. and K. D. revised the manuscript and provided additional intellectual content.

Funding statement. This research did not receive any specific funding.

Competing interests. None.

Ethical standards. Not applicable.

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