Received: 25 March 2020 | Revised: 10 July 2020 | Accepted: 14 July 2020

DOI: 10.1002/ppp3.10155

Plants People Planet PPP Open Access

OPINION

Perception gaps that may explain the status of taro (*Colocasia esculenta*) as an "orphan crop"

Peter Joseph Matthews[1] | Michel Edmond Ghanem[2]

[1]Field Sciences Laboratory, National Museum of Ethnology, Osaka, Japan

[2]Plant Physiology and Crop Improvement Program, AgroBioSciences, VI Polytechnic University, Benguerir, Morocco

Correspondence
Michel E. Ghanem, Plant Physiology and Crop Improvement Program, AgroBioSciences, Mohammed VI Polytechnic University, Benguerir, Morocco.
Email: michel.ghanem@um6p.ma

Funding information
JSPS Kakenhi, Grant/Award Number: 17H01682 and 17H04614

Societal Impact Statement

Using Taro (*Colocasia esculenta*) as a case study, we examine how perception gaps contribute to negative feedback loops that create or maintain the orphan status of certain crops. For students and researchers seeking uncrowded areas for study, orphan crops and crop-wild-relatives offer large open spaces, figuratively and literally. Learning how to see what has not been seen may in turn help us to reduce our global dependence on very few crops, and the risks that follow from this. The combination of climate change and variability and increasing population has painted a dark picture of future food security for many regions in the world where resources are scarce. The key to future food and nutrition security may very well lie in unlocking the untapped potential of orphan and overlooked crops.

Summary

The present distribution of taro (*Colocasia esculenta*), as a cultivated food plant, extends from southern to northern Africa, western Asia to eastern Asia, throughout Southeast Asia and the Pacific Islands, and through the Americas, from the USA to Brazil. Despite its vast geographical range, high nutritional value, and considerable trade as a fresh and processed crop, there has been relatively little interest in taro and its wild relatives among research funding agencies, and little effective or large-scale assessment of production, trade and usage. Given the proven ability of this crop to grow under diverse climatic regimes, from the equatorial tropics to northern and southern temperate zones it may be useful to consider perception gaps that contribute to disregard of the crop. Here we suggest and discuss a range of perception gaps that together may explain the status of taro as an orphan crop. Perception gaps exist because of many factors: dogma, linguistic diversity, social biases, under-research, limited physical visibility of living wild populations, poor archaeological visibility, missing production numbers and inaccurate distribution maps. These contributing factors are shared, to lesser or greater extent, by many other orphan crops, but the disjunction between actual utilization (significant) and research effort (minimal) may be greater for taro than for most other "orphans".

KEYWORDS

Colocasia esculenta, gap, orphan crop, perception, taro

1 | INTRODUCTION: FEEDBACK LOOPS AND ORPHAN CROPS

Feedback occurs when information about the outcome of an activity is fed back into the activity (Capra, 1996; Sundkvist et al., 2005). In other words, a system component can itself be influenced indirectly by the changes it has induced, and this also applies to food system components (Sundkvist et al., 2005). Feedback loops can act as control mechanisms: in ecology, it is recognised that "negative loops counterbalance change and have a stabilizing effect, while positive feedback reinforces change and amplifies rather than reverses change" (Allaby, 1994).

Amplifying feedback favors major food crops on a global scale. These crops attract infrastructure, marketing, and research investment that increases their visibility and economic dominance, leading to further investment. This amplifying feedback loop has led to global dependence on a very small number of commodity crops. The State of the World's Biodiversity for Food and Agriculture mentions that out of 6,000 plant species that have been cultivated for food, fewer than 200 make major contributions to food production globally, regionally or nationally (FAO, 2019). Just five crops—wheat, corn (maize), rice, barley and soybean—have come to occupy approx. 60% of the world's agricultural lands (Leff et al., 2004), and the spread of these and other commodity crops has led to regional homogeneity across industrial cropping systems globally (Martin et al., 2019). The 2020 Global Nutrition Report (Global Nutrition Report, 2020), an annual independent assessment of the state of global nutrition, paints a similar picture. Among the key challenges highlighted by the report is the visible lack of dietary diversity. According to the report, agricultural policies have prioritized improving varieties of these crops to increase their productivity, neglecting other, more nutrient-dense crops, which are sometimes referred to as minor or orphan crops as a result.

Amplifying feedback can also reinforce negative effects, leading minor or less commercially valuable crops into a spiral of decline. This is apparent, for example in the expansion of coffee and other perennial cash crops into areas of shifting agriculture based on annual subsistence crops (Meyfroidt et al., 2013). As land for minor crops is lost and their cultural or economic importance declines, they tend to disappear. This tendency can be worsened by internal competition of minor crops for the limited arable land remaining for them. In Kenya for example, monocultural sugarcane farming has replaced indigenous vegetables, and among the vegetable species that remain, there has been further competition as the local ecology and food culture change (Masayi & Netondo, 2012). Complete disappearance of a minor crop is not inevitable however, as minor crop species and their varieties may persist in geographically, ecologically and economically isolated locations or in persistent social niches (such as backyard gardens in urban landscapes). Diverse agroecosystems still exist outside the large areas of intensive monoculture (Martin et al., 2019), and numerous international, national and local efforts are being made to preserve crop diversity. Balancing the scales, however, is difficult when a few large weights occupy one side, and the many small weights that remain lie scattered and out of sight. Such is the situation of orphan and minor crops. For crop diversity, a balancing feedback loop is not yet in sight.

Is taro an "orphan" crop? Falcon et al. (2017) describe "orphan or minor" crops as those that are: '…typically not traded internationally but which can play an important role in regional food security. For various reasons, many of these crops have received little attention from crop breeders or other research institutions wishing to improve their productivity.' Most orphan or minor crops have also received relatively little attention from archaeologists, ethnographers, and historians, a situation that naturally reflects their lower visibility in archaeobotanical records, and less obvious cultural or economic significance in the living world. While plants have many economic uses, most discussions of orphan crops focus on food plants, leaving an even greater number of crops so neglected that they are not even recognized as "orphans".

Global initiatives like the African Orphan Crops Consortium's (AOCC) list taro among the 101 traditional orphan or neglected crops that are considered important to local diets (AOCC, 2020). Similar statements can also be found on the Crop Trust webpage (Crop Trust, 2020). Scientific publications often refer to taro as an orphan (Akwee et al., 2015; Lebot, 2009; Lebot et al., 2018; Vaneker, 2013), or neglected and underutilized crop species (Chivenge et al., 2015; Mabhaudhi et al., 2017; Mabhaudhi et al., 2019), and no international research center has a mandate to support development of the crop (Lebot et al., 2018).

While emphasizing the ongoing importance of root and tuber crops, and presenting projections for their production in 2020, Scott et al. (2000) considered just four examples: cassava, potato, sweet potato, and yam. Data for taro were aggregated by these authors under "cassava", due to a lack of taro-specific data for global comparisons, and taro was therefore only mentioned in the footnotes for cassava. The lack of historical data for taro production and trade thus prevented projection for its future production and trade. Without such projections, growers and traders are unlikely to see economic potential in the crop. In our view, this example suggests that a feedback loop is reinforcing the low visibility of taro in discussions of global food supply, and confirms the status of taro as an orphan crop.

The present distribution of taro (*Colocasia esculenta*), as a cultivated food plant, extends from southern to northern Africa (Grimaldi, 2016; Grimaldi & van Andel, 2018; Grimaldi et al., 2018; Grimaldi, et al., 2018), western Asia to eastern Asia, throughout Southeast Asia and the Pacific Islands, and through the Americas, from the USA to Brazil (Matthews, 2006). Despite its vast geographical range, high nutritional value, and considerable trade as fresh and processed crop, there has been relatively little interest in taro and its wild relatives among research funding agencies (Manners & van Etten, 2018). In addition, there has been little effective or large-scale assessment of production, trade and usage. Among root crops, taro is unusual in also having highly-nutritious leaves (petioles and blades) (Ferreres et al., 2012; Isabelle et al., 2010; Standal, 1983) that are commonly consumed (young leaves of cassava and sweet potato can be eaten, but this does not appear to be general for either crop). As a result, taro as a whole offers a very rich complement of nutrients (carbohydrates, proteins, vitamins, antioxidants, and minerals; Huang, Titchenal, & Meilleur, 2000; Kaushal et al., 2015; Maga, 1992; Matthews, 2010; Nip, 1997; Onwueme, 1994; Opara, 2003; Standal, 1983).

Maintaining living collections of this vegetatively propagated root crop (either in field or under tissue culture) has always been expensive, and many institutional ex situ collections have been temporary, or have been reduced in size because of disease or lack of sustained funding (Ebert & Waqainabete, 2018). There are many historical, cultural, and practical reasons why taro continues to be under-supported as a subject of academic and practical research. Given the proven ability of this crop to grow under diverse climatic regimes, from the equatorial tropics to northern and southern temperate zones (Matthews, 2004) it may be useful to consider perception gaps that contribute to disregard of the crop.

Here we suggest and discuss a range of perception gaps that together may explain the status of taro as an orphan crop. These gaps arise from contributing factors that are shared, to lesser or greater extent, by many other orphan crops, but the disjunction between actual utilization (significant) and research effort (minimal) may be greater for taro than for most other "orphans". Despite its long history, positive attributes, and global distribution, taro has attracted very few large or sustained investments of research effort.

This article is based on a poster originally presented by the first author at the XIX International Botanical Congress, July 23–29, 2017, Shenzhen and partly reflects his own first-hand experience of mapping wild taro populations in many countries, in the general absence of prior literature on the existence of such populations. We present, for the first time, a global distribution map for taro based on documented sources. Are the perception gaps too many and too large, or are there inherent qualities in the plant, or in human responses to the plant, that prevent taro from gaining greater favor? The example of taro may provide a good starting point for considering how perceptions and perception gaps contribute to the underutilization of many crops. Learning how to see what has not been seen may in turn help us to reduce our global dependence on very few crops, and the risks that follow from this.

2 | WHY DO PERCEPTION GAPS EXIST?

A range of perception gaps for taro can be summarized as: (1) Dogma limiting the field of view; (2) linguistic diversity and naming leading to confusion or limited communication; (3) social biases or a reputation that are not favorable; (4) little scientific research; (5) limited physical visibility of living wild populations; (6) archaeological visibility of past production is poor; (7) production numbers are missing in agricultural databases; and (8) distribution maps are few and sketchy. This list is obviously not comprehensive, and in each case, further studies are needed to distinguish cause and effect, or to recognize the main contributions to a negative feedback loop.

2.1 | (1) Dogma: taro is more than a "tropical root" crop

"Tropical crops" often refer to plants that grow naturally in tropical climates, between the Tropic of Cancer and the Tropic of Capricorn (between latitude 23.5° north and south of the Equator). In English-language research literature on taro, the plant is often described as a "tropical root crop" (Johnston & Onwueme, 1998; Onwueme, 1994; Scott et al., 2000; and others). This description could be perceived as a form of 'dogma'—a commonly accepted, unquestioned truth. However, as taro is widely distributed in tropical to temperate regions of both hemispheres, it is much more than just a "tropical root crop" (Figures 1 and 6), and has multiple functions as a starchy food source and green vegetable (Figure 2) (Mitra, 2013; Opara, 2003), or as fodder for pigs (Buntha et al., 2008; Figure 3), or both (Evans, 2008; Matthews et al., 2012; Matthews & Naing, 2005; Zhu et al., 2000).

FIGURE 1 Cultivation of taro as a summer crop in Andong Province, South Korea, in the northern temperate zone (nearly 37 degrees North) (photo by P. J. Matthews)

FIGURE 2 Taro as a leafy or green vegetable. Upper left: wild leaves (*Colocasia esculenta*) gathered from river side, for evening meal (Philippines). Upper right: young leaves cooked with fish paste and coconut milk, known as *laing* (Philippines). Lower left: petioles peeled and cut into short sections, for cooking in vegetable curry (India). Lower right: stolons sold in town market, to be later peeled and cut into short sections before cooking (Vietnam) (photos by P. J. Matthews)

FIGURE 3 Taro leaves as fodder for pig in Vietnam. Left: leaves chopped before cooking. Right: a nutritious gruel prepared by cooking taro leaves together with rice bran (broken rice is also often used) (photos by P. J. Matthews)

The use of commensal wild taros as a green vegetable and fodder is widespread across South and Southeast Asia.

Although roots and tubers cover a much smaller area than cereals, they are another important human staple. The two major tuber crops are potatoes and cassava. Geographically, they are cultivated in contrasting climates (Leff et al., 2004). Potatoes are extensively grown in the colder temperate latitudes between 40°N and 75°N, with the highest potato cultivation intensity occurring at 55°N (Leff et al., 2004). On the other hand, cassava is grown in the equatorial and tropical regions (from 20°N to 30°S). Taro overlaps with these two major crops, spanning latitudes from 35°N to 35°S. In Japan, taro cultivation can reach 40°N. Compared to the two major root crops, taro occupies a more extensive latitudinal range (a total of approximatively 70°). Another underutilized crop, sweet potato (*Ipomoea batata* L.; Chivenge et al., 2015) also has very wide latitude (30°–40° latitudes in both hemispheres). Perhaps sweet potato and taro are both neglected because their production is dispersed, i.e. not so focused in one or the other climatic zone. Compared to sweet potato, which is strictly a dryland crop, taro spans wetland to dryland, so is dispersed in the hydrological dimension as well.

The apparent dogma of taro as a "tropical root crop" reflects a tendency of authors to cite well-known but not fully-informed publications when attempting to provide a general introduction to the crop in specialist papers. The dogma is generally taken for granted because it is true, as far as it goes, and the description has been repeated by different authors over many years.

2.2 | Linguistic diversity, vernacular naming and scientific literature

In different regions of the world, there are many different local, vernacular names for taro. Speakers in each local language can and do imagine that the crop is restricted to the area in which their language is spoken. Unless they are multilingual and aware of the wider literature or travel beyond their local area, they may never learn that the crop has a wider or global distribution. Similarly, even among highly literate researchers, the inability to read more than one research language may explain the slow transfer of knowledge concerning the distribution, diversity, production, uses and potentials of this crop. In East and Southeast Asia, significant bodies of research on taro have been published in Chinese, Japanese, Korean and other languages. In South America the research is often published in Spanish or Portuguese (see references cited in Vieira et al., 2019, and in Table S1). These research efforts are not well-known among readers who are restricted to English. With translation from other languages into English, taro might no longer appear to be an orphan crop. The usual agricultural classification as a "root crop" has also led to institutional disregard of taro as a "vegetable crop", though both are common uses for taro (see 1, 5), and the leaf nutritional qualities have been widely studied (Kaushal et al., 2015; Lambert, 1982).

In Austronesian languages, 'taro' and its cognates are used with precision as a name for *C. esculenta*, and similarly precise vernacular names exist for all the other edible aroids native to Asia and the Pacific (*Alocasia macrorrhizos*, etc.). In English popular and scientific writing, however, 'taro' is commonly applied to edible aroids as a group (Plucknett, 1983; Wang, 1983), despite the distinct agronomic, culinary and morphological traits of each genus and species. Other vernacular names for taro are also used with little consistency: dasheen, eddoe, and cocoyam (Plucknett, 1983). The latter is especially common in African and Caribbean research literature, and originates in Africa (Burkill, 1985). The aroid *Xanthosoma* is now widespread in Africa and is often called 'cocoyam' there, or 'new cocoyam' to distinguish it from taro (Bammite et al., 2018). *Colocasia esculenta* and cultivated *Xanthosoma* spp. have similar appearance, vegetative propagation, and culinary uses, so are often confused. Over centuries, changes in scientific naming for taro have also left a trail of different names that must be interpreted with care. In older research literature (i.e. literature from 50+ years ago), taro is often known as 'caladium' from an outmoded scientific name, *Caladium esculentum*, or as 'arum' or *Arum colocasia*. These names (Caladium and Arum) are sometimes repeated in recent publications such as Burrow and Emeneau (1984). Further difficulties for interpretation are found in ancient European and Mediterranean literature, in which the name 'colocasia' originally referred to the sacred lotus, *Nelumbo nucifera* (Grimaldi, et al., 2018). Cumulatively, linguistic perception of taro is complicated by the fact that many different, non-cognate names for taro have appeared in different language families, over very long periods of time. Apart from a pioneering survey by Blench (2012), there has been little effort to study the diversity of names for taro comprehensively, on a global scale.

2.3 | Social bias and reputation as a "poor-man's" crop, and poisonous weed

In some countries or regions, taro is perceived as a crop of poor or lower-status people, or ethnic minorities. In India, Englebrecht (1914) reported that in the United Provinces, the corm was an important food for the "lower classes" of the population. Although it was not often planted in large areas, it could be found everywhere in gardens, especially near the big cities. Wild taro growing around or near settlements is an abundant wild food resource in wet lowland regions of India and Bangladesh, and a Bengali proverb reflects the low status of the wild plant as food: "Talent recognizes talent; pigs recognize *kachu* (taro)" ("talent" in this phrase can also be interpreted as a jewel or gem; Abhijit Dasgupta and Sanjoy Roy, personal communication, 2019). As noted above, pigs do indeed recognize taro, to the benefit of farmers and consumers in many countries. In Egypt, the crop has long been regarded as a food of peasants, and is never served in restaurants (Matthews, 2006). Although taro is important for many people with low socio-economic status, this is not the full story. In Egypt for example, it is also a traditional New Year food of the minority Coptic community, served to celebrate the baptism of Christ, apparently because the cooking process requires so much water (Figure 4, left). In Cyprus, taro is traditionally known as "royal food", is served at wedding feasts, family feasts, and in restaurants, and is exported to satisfy demand by Cypriot immigrant communities in the United Kingdom (Matthews, 2006; Figure 4, right). In Japan, the crop is historically associated with poverty, as a "poor man's" substitute for rice, yet the *kaiseki* cuisine that developed around the tea ceremony includes recipes for taro, and taro is often found in side-dishes offered by restaurants in Japan, or in take-away lunch boxes (*bento*). The crop has especially high social status in Polynesian chiefdoms where social power depended (and still often depends) on the control of water for irrigated taro pond fields, and ownership of the fields and product (Spriggs, 2012).

Social bias also arises when taro is tried and rejected as a food by people unfamiliar with the appearance, taste and texture, or who experience poorly-prepared taro cooked by themselves or others. Taro corms and leaves contain calcium oxalate raphides (long needle-like crystals) to which an enzyme is attached (Bradbury & Nixon, 1998; Paull et al., 1999), and this combination (general in Araceae, the plant family of taro) can cause itching or severe irritation on hands, in the eyes, in the mouth, or in the throat during preparation and consumption. The acridity level varies in different varieties of taro, and can be reduced by peeling, cutting, grating, soaking, dehydration, chemical treatment, and fermentation, followed by cooking (Kaushal et al., 2015; Matthews, 2010). Due to the acrid nature of the plant, a

FIGURE 4 To prepare a soup in Egypt, slime is removed by rubbing cut corms with salt and washing with abundant water to remove slime produced at the cut corm surface (left). In Cyprus, slime is removed by rubbing the whole corm with a cloth, without any use of water, and then by cooking with a little lemon juice; shown here is the resulting stew prepared for a Saint's Day family feast (right) (photos by P. J. Matthews)

poor eating experience can make a lasting and unfavorable impression that in turn creates a poor reputation for the crop. This applies especially to Europeans who are mainly familiar with potato and the common green vegetables of temperate regions. For any distributor wishing to expand the market for taro in Europe, there is a real need for clear and informative labelling with recommendations for cooking (Matthews, 2004). Taro is correctly noted as a poisonous plant on many websites (e.g. Queensland Government, 2019) and is also commonly reported as an invasive "weed". In most cases where taro has been reported as a weed (e.g. Spain, Australia, and southern USA) (García-de-Lomas et al., 2012; Moran & Yang, 2012; Queensland Government, 2011), the plant was historically introduced as a food plant and cultivated or planted in naturally wet locations, from where it has spread. Although certain ethnic groups or minorities may recognize and harvest these newly-wild plants as food, their use values, or potential use values, have generally been overlooked. Vegetative self-propagation by taro is vigorous, and clones can easily spread from cultivation, naturalise in wet environments, and form commensal wild populations (Matthews, 2014; Matthews et al., 2017). The plant often invades ditches that are contaminated with waste from animals or humans, or chemical industrial wastes, rendering it unsafe and unappealing for consumption. When taro is described as weedy, invasive or poisonous, it is perhaps understandable not to emphasize its potential food value. Conversely, when the plant is reported as a food, the risk of poisoning may be downplayed, or not mentioned at all.

2.4 | Little scientific research

Most public and private investment in agricultural research is aimed at increasing production of high-value crops for high-paying markets or international trade. When taro is regarded as a "poor man's crop" or "marginal crop", this negative perception may discourage the research needed to take advantage of its many positive qualities for small-holder farming communities (Chivenge et al., 2015). We suggest that for public research organizations (like the Consultative Group for International Agricultural Research; CGIAR), the positive role of taro as a staple and subsistence crop among people of low socio-economic status should make the crop more important, not less. Taro is not over-researched in any region and still has a global research deficit. Manners and van Etten (2018) show that taro is under-researched relative to its contribution to healthy human nutrition yet shows promise under climate change. Regions of research deficit are tightly concentrated in tropical regions (Manners & van Etten, 2018). Manners and van Etten (2018) show that the research deficits of taro are concentrated in areas with projected increases of climate suitability of this crop. Tropical regions in general receive less research investment than the global average (Manners & van Etten, 2018). Pacific Island countries have invested much more in research and development of taro—especially the Pacific Community (SPC) and the University of South Pacific, Fiji (USP)—leading to relatively large-scale commercial production and export earnings derived largely from buyers among expatriate Pacific Islander communities, a result that parallels the Cyprus example mentioned earlier (Matthews, 2006). In many other countries, and especially Sub-Saharan Africa, very little attention has been given to this particular crop. The CGIAR Research Program on Roots, Tubers and Bananas (RTB), that intends to "work globally to harness the untapped potential of those crops in order to improve food security, nutrition, income and climate change resilience of smallholders, especially women and youth" devotes very little research and funding to taro and lists it under "other roots" (CGIAR-Roots Tubers & Bananas, 2020). According to the 2020 Global Nutrition Report (Global Nutrition Report, 2020), "donor funding for research and development has prioritised major staples at the cost of more nutritious crops and livestock." "The CGIAR, ... has traditionally allocated most of its commodity research budget to the major staples, increasing this after the 2008 food price crisis. The balance of funding has to be shared between fifteen crops, livestock, fish and trees." The report concludes that "Research and development investments should prioritise neglected staples such as sorghum, millets and tropical tubers.

2.5 | Visibility of living wild populations

The geographical and genetic origins of cultivated taro are not yet known. To find the origins, we must first gather information on the distribution and diversity of wild populations of *C. esculenta* and other *Colocasia* species (the crop wild relatives, Figure 5) (Matthews, 2014; Matthews et al., 2017). In recent years, many new wild species of *Colocasia* have been reported in mountainous regions of mainland and island Southeast Asia, and southern China. The number of known *Colocasia* species is currently at least nine and perhaps many more (Matthews & Nguyen, 2018; Rao, Hunter, Eyzaguirre, & Matthews, 2010). Easy access to the mountain habitats of wild *Colocasia* species has only become possible in recent decades as a result of the expansion of road systems across Asia. The physical visibility of wild relatives of cultivated taro has increased, but expansion of access has also contributed to destruction of the forest habitats of wild relatives. Modern road construction has enabled large-scale deforestation throughout the uplands of Asia. In Thailand, for example, it has been estimated that forest cover between 1961 and 1986 declined from 53% to 25% or less (Williams, 2003). Local endemic species or ecotypes of *Colocasia* may be disappearing before they are seen (extinction of an unrecorded species creates a permanent perception gap). Perception gaps are smaller, in taxonomic terms, for wide-ranging wild relatives because such taxa are more likely to be found. However, there have been no comprehensive geographical surveys for any of the wild *Colocasia* species reported by taxonomists, so in geographical terms there are still large perception gaps. Distinct, locally-adapted populations of wide-ranging *Colocasia* species (local ecotypes) might also become extinct before they are found or described.

2.6 | Archaeological visibility

Due to the widespread distribution of taro in traditional and non-commercial farming systems, some attention has been given to the crop by anthropologists and ethnographers. However, it is inherently difficult to reconstruct or perceive the long-term history of this or any crop from contemporary records alone. Unlike crops that produce hard seeds as the main product, or that produce fruit with hard stones, taro has not left an obvious archaeological or palaeobotanical record in any country. It is only in recent years that microfossil evidence for taro has been found, in a small number of sites. Starch and calcium oxalate raphides were tentatively attributed to taro by Loy et al. (1992), at the late Pleistocene site of Kilu Cave in the Solomon Islands. Haberle (1995) first described the distinctive traits of taro pollen, and was later able to identify taro pollen from late-Pleistocene lake sediments in Northeast Queensland (Haberle, 2005). Starch, raphides and possible seeds of taro (c. 1.5 mm long, with longitudinal grooves) have all been found at the Kuk wetland site in the highlands of Papua New Guinea (Fullagar, Field, Denham, & Lentfer, 2006; Lentfer & Deham, 2017).

These reports include direct evidence for the use of taro, but only circumstantial evidence for cultivation as it is possible that wild populations native to the region were able to spread into drains used to make swamps more suitable for growing other crops (e.g.

FIGURE 5 Crop wild relatives that are closely related to cultivated taro in evolutionary terms are wild populations of *Colocasia esculenta*, here shown in Queensland, Australia (left), and *Colocasia formosana*, here shown in northern Luzon, Philippines (right) (photos by P. J. Matthews). Wild populations of *C. esculenta* extend from mainland SE Asia to Australia and Melanesia, while *C. formosana* is only known in Taiwan and the northern Philippines

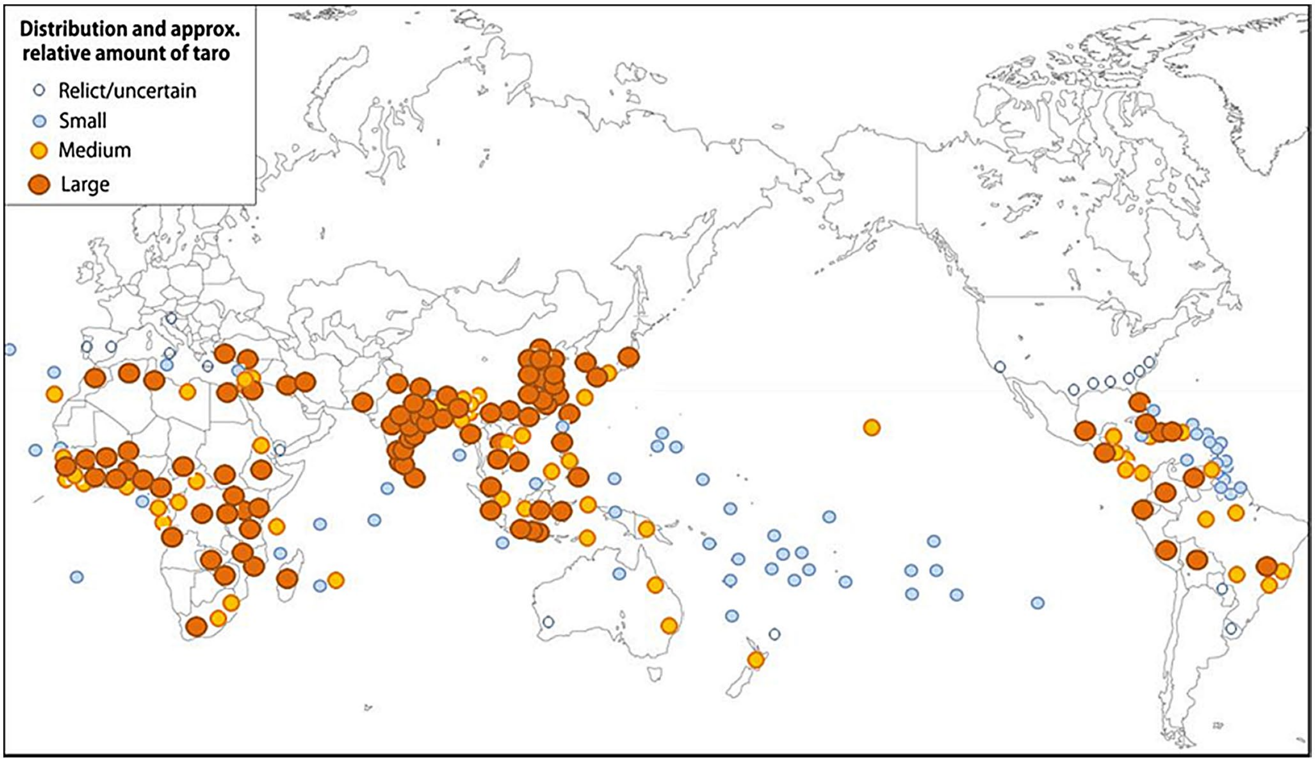

FIGURE 6 World distribution of taro with map points weighted to indicate approximate relative amounts, according to human population size, as explained in the text and Table S1

banana and yam). Although wild taro populations flower abundantly (Matthews, 2014; Matthews et al., 2012; Matthews & Naing, 2005), and produce distinctive pollen (Haberle, 1995, 2005), the plant is presumably not well represented in pollen records because pollen dispersal depends on specialist insects (Sultana et al., 2006), not wind. Most pollen is likely to rot together with the fallen spadix and spathe of the inflorescence. Recently, a pollen record for taro has been established in early cultivation sites in subtropical and temperate Polynesia (Prebble et al., 2019), a region first reached by humans around 1,000 years ago. The pollen records indicate that, outside the likely natural range of taro, the plant was carried and replanted as part of the initial colonization of Remote Oceania. This has long been assumed to be the case, based on the spread of linguistic terms related to taro, but physical evidence of the plant was lacking. The Pacific findings suggest that when sufficient attention is given, with the use of microscopy, we can expect to find archaeological evidence for taro in other regions where the plant has long been grown. In order for taro to gain greater historical recognition in Southeast, South and East Asia, archaeobotanical approaches need to be adopted more widely (cf. Denham et al., 2009).

In Japan, it has long been postulated that taro was already cultivated during the Jomon period (early to late Holocene; Hudson, 1999), but this is not yet evident in actual plant remains. In China, despite a long written record for taro, dating back to more than 2,000 years ago (Huang, 2012), there is also little archaeological evidence for the crop, though residues of taro starch have been reported on tools dated from 12,000 to 7,000 years ago at the Zengpiyan cave site in southern China (Lu, 2006, 2009). Further confirmation of these identifications may be needed, with special attention to other aroids that might have been used in southern China. In the eastern Mediterranean, historical records and an analysis of changes in the usage of vernacular names indicate that the crop may have first arrived not much earlier than 1,000 years ago (Grimaldi, et al., 2018). Desiccated plant macro-remains have often been preserved and found in the desert sites of Egypt and West Asia, but taro corms have only been reported once, at Quseir al-Qadim, where they were found together with the remains of other medicinal plants dated to the period AD 1050–1170 (van der Veen, 2011).

A growing awareness of the methods required to detect taro in archaeological sites, and in natural palaeobotanical deposits, may gradually lead to more targeted efforts to establish archaeological records for this crop. Meanwhile, much historical research remains to be done on the modern movements, production, diversity and utilisation of taro, throughout its global range. Many of the references that support our world map (Figure 6) are summaries of earlier sources for specific areas, countries, and regions. A good starting point for modern historical research on this crop will be local-language publications that provide primary (first-hand) reports on the production, distribution and uses of taro in each area indicated in our map. Ideally, integration of chronologically overlapping archaeological, botanical, ethnographic and historical records will help us to reconstruct the long-term history of taro, and how it became a global yet largely overlooked crop.

2.7 | Missing numbers in agricultural databases

For trade organizations and governments, it is very difficult to collect statistics on production and consumption of taro as a root crop because it is largely marketed through local distribution channels, and almost no statistics have been collected on its uses as a green vegetable (see 1 above). The Food and Agriculture Organization (FAO) is a United Nations (UN) supported organization responsible for publishing global statistics on food crop production, but depends on national-level reports of taro that are mostly unreliable, incomplete, or entirely lacking. This problem is not restricted to taro. Horton (1988) noted that "government agencies tend to underestimate root crop production and consumption because root crops are often grown in isolated areas on small, irregular plots, frequently as intercrops, relay crops, secondary crops, or backyard garden crops", and are thus easily overlooked. Taro occupies all of these overlooked production categories. In Table S1, we note all countries for which production of taro (as a root crop) was reported by FAOSTAT (FAO Statistics Division) (FAOSTAT, 2019), for the most recent year of 2017. Most FAOSTAT production estimates are not based on official figures provided by countries, but on imputation from a range of sources and data types (FAOSTAT, 2019). Despite the imputations, estimates remain lacking for most countries where taro is known to exist as a crop, including many countries with large populations in Africa, South America, and Asia (Table S1). This gap has been long-standing, and was noted by Lebot (2009) with reference to the FAOSTAT estimates for 2006.

How can we overcome the lack of direct empirical data? Here we suggest that the per capita production for geographic areas not represented in FAO data (Table 1) can be extrapolated from the average per capita production for areas that are represented, for our example year

TABLE 1 Countries in East, Southeast, and South Asia with numbers (blue highlight) or missing numbers (—) for taro production, together with rounded population numbers, and calculations of production per capita per year

	Country	Tonnes	Population	kg/capita/year
With numbers	China (PRC)	1,800,000	1,370,350,000	1.31
	Japan	175,000	126,999,800	1.38
	Philippines	112,262	100,096,500	1.12
	Thailand	95,000	67,223,000	1.41
	Taiwan	45,000	23,433,800	1.92
	Subtotals	2,227,262	1,688,103,112	Average 1.32
Missing numbers	India[a]	—	1,267,400,000	—
	Indonesia	—	252,810,000	—
	Pakistan	—	185,130,000	—
	Bangladesh	—	158,510,000	—
	Vietnam	—	92,550,000	—
	Iran	—	76,500,000	—
	Myanmar	—	53,720,000	—
	South Korea	—	49,510,000	—
	Malaysia	—	30,190,000	—
	Nepal	—	28,120,740	—
	North Korea[a]		24,700,000	
	Sri Lanka	—	21,450,000	—
	Cambodia	—	15,410,000	—
	Six nations with <10,000,000[b]	—	14,700,000	—
	Subtotals	—	2,270,700,00	—
		Approxi. Total taro-producing population in Asia	3,932,714,744	

Note: Annual production of taro was reported by FAOSTAT (2019) for the year 2013. Population figures for 2013 were reported by UN Population Division (2019) and Population Reference Bureau (2019).

[a]No reports of taro were found for North Korea (Table S1, Figure 6), but the country lies entirely within the northern taro cultivation zone of East Asia, with China and Japan both having significant production over the same latitudinal range. There are no reports of taro in Mongolia (part of East Asia) but this country lies outside the known range of cultivated taro.

[b]Taro-growing nations with <10 million people each: Bhutan, Brunei, Laos, Maldives, Singapore, Timor-Leste.

(2013). To calculate extrapolated production numbers, the average per capita estimate can be used as a multiplier for populations in countries where it is known that taro is produced and consumed. A priori, the extrapolation is likely to be more reliable for countries with similar food habits to those of East Asia and Southeast Asia (the countries with production numbers, in Table 1), where taro is generally eaten as an occasional side-dish, not as a daily main dish. This approach is of course not accurate, but can be used to encourage more accurate data collection, and greater awareness of the present and potential contributions of taro to local, regional, and world food security.

Using the data presented in Table 1, the average per capita production estimated for five Asian nations is 1.32 kg/capita/year. This figure is consistent with the general usage of taro corms as a seasonal, occasional component of side-dishes and soups, in Asian cuisines (authors' observation). No reduction has been made to account for skin peelings and other materials discarded when taro corms are prepared for cooking. Taro is always peeled before eating (and sometimes before being sold), so the calculated figures for each country are comparable. Although people in different areas of Asia have quite different food cultures, it is likely that most consume taro in similarly low amounts per capita. Combining population numbers for year 2013 with the average per capita estimate would lead to a huge increase in the global estimate of production.

Production for more than two billion people who are known to consume taro—as a traditional food crop in their countries—is unaccounted for in FAO global statistics (Table 1). For India alone, the perception gap represents a failure to see approx. 32% of likely production in the taro producing regions of Asia (East, South, and Southeast Asia combined). In total, counting all the countries with missing taro production data (Table 1), the perception gap represents approx. 57% of taro production in Asia, which in turn represents over half the total world population of 7.2 billion (in 2013).

For taro as a leafy or green vegetable, the perception gap is closer to 100% of a global consuming population that may also number in the billions. This statement is based on the authors' personal observations of the vegetable uses of taro from Oceania to East Asia and Northeast India, and from widely scattered reports of the consumption of taro blades, petioles and stolons (see 1 above). No formal attempt has ever been made to measure the global production of taro as a green vegetable. The blades, petioles and stolons have very different culinary qualities and uses, are usually harvested and sold separately (Figure 1), and ideally would be measured as distinct products.

2.8 | Few and sketchy maps: Where is taro cultivated?

The global distribution of taro has been shown in very few published maps. Early examples (Evans, 2008; Matthews, 1991, 2006; Spriggs, 2012) are sketchy, incomplete, and lack cited sources. Where is taro cultivated and where are the main growing regions? To help tackle this question, we searched a wide range of published literature (Table S1) to develop a world distribution map of taro as a modern cultivated crop (within the last century) or as a known introduced plant (if the present cultivated status of the plant is uncertain, this is indicated; Figure 6).

In Figure 6, map distribution points at the national or sub-national level have been weighted according to population size (<1 million, 1–10 million, and >10 million) in each nation or sub-national area concerned. The map provides a rough visual impression of the relative amount of taro produced in different regions of the world, assuming that most consumption of taro by the population of a given area is based on production in the same area (this may be true in most but not all areas), and that per capita consumption is similar everywhere (see 6 above). The weighting method is described in Table S1. In Australia, Europe, New Zealand and North America, the crop is supplied to minority immigrant communities mainly through trade, not local production. Extrapolating production in these areas by the method suggested above would lead to over-estimation, and the visual weightings in Figure 6 may be too much for such areas. The map under-emphasizes production in areas where taro is a daily staple (i.e. many Pacific islands). In principle, the relative weighting of map points in Figure 6 can be improved by more detailed analysis of taro production, trade, and consumption in each area.

The widespread production and use of taro in India is well described by Engelbrecht (1914), and his observations are still largely accurate:

> "The wild growing plant is very common in the humid tropical parts of India, but its corms are not edible. By contrast, the cultivated form is an important root crop, and the young leaves are also eaten as a green vegetable. It is grown in quite significant quantities, though usually only as a garden product, not as a true field crop. Special varieties are adapted to diverse conditions, so that their cultivation extends from the marshy lowlands of Lower Bengal to the humid mountains of Assam and Madras, the dry hills and highlands of the Deccan and Rajputana plateaux, and even to temperate regions of the Himalayas." (Engelbrecht, 1914, transl. P. J. Matthews)

Srinivas et al. (2011) also noted the widespread cultivation of taro in India, and identified numerous major production centers in the five states surveyed by them. Although many authors in India have written about taro in one or more states (Table S1), there does not seem to have been any comprehensive review of existing literature. Combining studies of production, distribution (e.g. Figure 7) and consumption might generate independent estimates of production that converge on a reasonable overall estimate for production in the country.

3 | FUTURE DIRECTIONS

Amplifying feedback has helped lead to humanity's present global dependence on a very small number of commodity crops, and to the

FIGURE 7 Taro is commonly sold by street vendors in New Delhi, India. Insert shows fresh, recently harvested side-corms (Photo: P. J. Matthews, September 2019)

erosion of genetic diversity within commodity crops (Mooney, 1980). This has created a situation of high risk because disease, unfavorable weather events, and climate change can more easily cause unexpected and large-scale food shortages when specific major crops are affected on a large scale over relatively short periods of months, years, or decades.

A large gap in the FAO records of global taro production is shown here by the absence of estimates for India and many other countries where taro is grown and eaten by large populations. If formal production estimates exist in these countries, they have not been reported by the FAO. Previous theories about the origins of cultivated taro, historical records, and recent research on genetic diversity in taro, indicate that India is not only an important producer of taro, but may also have had a central role in domestication of the crop (Chair et al., 2016; Matthews, 2014), thus pointing to practical and academic reasons for giving serious attention to the wild relatives of taro in India and other regions of Asia (see 4 above). For plant breeders, understanding the natural ecological adaptations of wild *Colocasia* species, and wild populations of *C. esculenta*, may provide important clues for new directions in the development of this crop.

Taro is an outstanding example of a crop that has been neglected as a subject of research: there is probably no other globally distributed starch crop for which there is no internationally funded institution with a global mandate for study—despite evidence that taro was probably one of the first crops to have a global distribution (only surpassed in extent by bottle gourd). Many gaps in awareness, interest and knowledge can contribute to the neglect, underutilization or decline of orphan crops such as taro. In Table S2 we compare scientific, biological, cultural, and taxonomic attributes of crops considered as orphan and representing the broad categories of root and tuber crops, legumes and cereals. The table shows that among the neglected root crops, taro has attracted much less research than the mandated common root crops of the CGIAR centers (IITA and CIAT-Bioversity). The present review of perception gaps is not complete but may represent the main gaps as far as taro is concerned. Among edible aroids, taro is the best-studied crop. Others are much more neglected but have certain advantages as crops, according to their specific ecological preferences and domestication history. Examples include: *Xanthosoma* spp., dryland starch and leaf crops originating in central America and now common in tropical regions of the world (Bown, 2000), and *Alocasia macrrorhizos*, a dryland crop that originated in Southeast Asia (Bown, 2000; Hay, 1999; Thompson, 1982). The latter produces giant, aboveground starchy stems that can serve as a standing food reserve for many years.

Perception gaps exist for innumerable plants with high potential value as local, regional or global sources for food, medicine, fiber, and other uses. The perception gaps described here are shared not only by other "orphan" crops and their wild relatives, but also by the wild relatives of many relatively well-studied and well-funded commodity crops (Anderson & de Vicente, 2010; Hunter et al., 2017; Hunter & Heywood, 2011). Recognizing perception gaps is a necessary starting point for investing research funds effectively. Since the beginnings of modern science, historical and agricultural research have always favored crops that are obviously important in commercial terms (see Ambrosoli, 1997, on this process in Europe, with special reference to forage crops, nitrogen-fixing crops, and cereals). While orphan crops and crop wild relatives have relatively little economic importance individually, their collective historical, economic, and potential future roles are significant.

How do perception gaps contribute to feedback loops that create and reinforce the orphan status of certain crops? How can orphan crops contribute to social and economic development? What can we learn about natural and cultural history from orphan crop species and their wild relatives? For students and researchers seeking uncrowded areas for study, orphan crops and their wild relatives offer wide open spaces, figuratively and literally. Every perception gap invites further investigation.

ACKNOWLEDGMENTS

Thanks to E. Tabuchi (National Museum of Ethnology, Japan) and A. Fiu (The Pacific Community, SPC, Fiji) for technical assistance in the preparation of this paper. A poster version was first presented at the XIX International Botanical Congress, Shenzen, 23–29 July, 2016, with support from the National Museum of Ethnology, Japan. This research was supported by JSPS Kakenhi No. 17H04614 (Matthews, 2017-2020) and JSPS Kakenhi No. 17H01682 (with K. Watanabe, Tsukuba University, Japan). For insights on taro as a "poor man's food", special thanks to Dr. Abhijit Dasgupta (Dept of Sociology, University of Delhi), and Dr. Sanjoy Roy (Dept of Sociology, North Bengal University). We are also grateful for constructive criticism by our anonymous reviewers.

ORCID

Peter Joseph Matthews https://orcid.org/0000-0003-2563-0976
Michel Edmond Ghanem https://orcid.org/0000-0003-0626-7622

REFERENCES

African Orphan Crops Consortium. (2020). Retrieved from http://africanorphancrops.org/meet-the-crops/

Akwee, P. E., Netondo, G., Kataka, J. A., & Palapala, V. A. (2015). A critical review of the role of taro *Colocasia esculenta* L. (Schott) to food security: A comparative analysis of Kenya and Pacific Island taro germplasm. *Scientia Agricola*, *9*(2), 101–108.

Allaby, M. (1994). *The concise Oxford dictionary of ecology*. Oxford, UK: Oxford University Press.

Ambrosoli, M. (1997). *The wild and the sown: Botany and agriculture in Western Europe, 1350–1850*. Cambridge: Cambridge University Press.

Anderson, M. S., & de Vicente, M. C. (2010). *Gene flow between crops and their wild relatives*. Baltimore, MA: The Johns Hopkins University Press.

Bammite, D., Matthews, P. J., Dagnon, D. Y., Agbogan, A., Odah, K., Dansi, A., & Tozo, K. (2018). Constraints to production and preferred traits for taro (*Colocasia esculenta*) and new cocoyam (*Xanthosoma mafaffa)* in Togo, West Africa. *African Journal of Food, Agriculture, Nutrition and Development*, *18*(2), 13388–13405. https://doi.org/10.18697/ajfand.82.17360

Blench, R. M. (2012). Vernacular names for Taro in the Indo-Pacific Region: Implications for centres of diversification and spread. In M. Spriggs, D. Addison, & P. J. Matthews (Eds.), *Irrigated Taro (*Colocasia esculenta*) in the Indo-Pacific: Biological, social and historical perspectives* (pp. 21–43). Osaka, Japan: National Museum of Ethnology.

Bown, D. (2000). *Aroids. Plants of the arum family*, 2nd edn. Portland, OR: Timber Press. 392 pp.

Bradbury, J. H., & Nixon, R. W. (1998). The acridity of raphides from the edible aroids. *Journal of the Science of Food and Agriculture*, *76*, 608-616.

Buntha, P., Borin, K., Preston, T. R., & Ogle, B. (2008). Digestibility and nitrogen balance studies in pigs fed diets with ensiled taro (*Colocasia esculenta*) leaves as replacement for fish meal. *Livestock Research for Rural Development 20*. Retrieved from http://www.cipav.org.co/lrrd/lrrd20/supplement/bunt2.htm

Burkill, H. M. (1985). *The useful plants of west tropical Africa, families A-D*. Kew, Australia: Royal Botanic Gardens.

Burrow, T., & Emeneau, M. B. (1984). *A Dravidian etymological dictionary*, 2nd edn. Oxford, UK: Clarendon Press.

Capra, F. (1996). *The web of life: A new scientific understanding of living systems*. New York, NY: Anchor Books, Doubleday.

CGIAR-Roots Tubers and Bananas. (2020) Retrieved from https://www.rtb.cgiar.org/crops/other-root-and-tuber-crops/

Chaïr, H., Traore, R. E., Duval, M. F., Rivallan, R., Mukherjee, A., Aboagye, L. M., … Lebot, V. (2016). Genetic diversification and dispersal of taro (*Colocasia esculenta* (L.) Schott). *PLoS One*, *11*(6), e0157712. https://doi.org/10.1371/journal.pone.0157712

Chivenge, P., Mabhaudhi, T., Modi, A. T., & Mafongoya, P. (2015). The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, *12*, 5685–5711.

Crop Trust. (2020) Retrieved from https://www.croptrust.org/crop/aroids/

Denham, T., Atchison, J., Austin, J., Bestel, S., Bowdery, D., Crowther, A., … Matthews, P. J. (2009). Archaeobotany in Australia and New Guinea: Practice, potential and prospects. *Australian Archaeology*, *68*, 1–10.

Ebert, A., & Waqainabete, L. M. (2018). Conserving and sharing taro genetic resources for the benefit of global taro cultivation: A core contribution of the Centre for Pacific crops and trees. *Biopreservation and Biobanking*, *16*(5), 361–367.

Engelbrecht, T. H. (1914). *Die Feldfrüchte Indiens in ihrer geographischen Verbreitung, 2 vols*. Hamburg, Germany: L. Friederichsen and Co.

Evans, D. (Ed.) (2008). *Taro Mauka to Makai: A Taro production and business guide for Hawai'i Growers*. Honolulu, HI: University of Hawai'i at Mānoa, College of Tropical and Human Resources.

Falcon, W. P., Naylor, R. L., & Fowler, C. (2017). Orphan Crops Project. Stanford University. Retrieved from http://fsi.stanford.edu/research/orphan_crops

FAO. 2019. The state of the World's biodiversity for food and agriculture. In J. Bélanger & D. Pilling (Eds.) *FAO commission on genetic resources for food and agriculture assessments*. Rome. 572 pp. Retrieved from http://www.fao.org/3/CA3129EN/CA3129EN.pdf

FAOSTAT. (2019) [Country production estimates for "taro (cocoyam)" in 2013]. Retrieved from http://www.fao.org/faostat/en/#home

Ferreres, F., Gonçalves, R. F., Gil-Izquierdo, A., Valentão, P., Silva, A. M. S., Silva, J. B., … Andrade, P. B. (2012). Further knowledge on the phenolic profile of *Colocasia esculenta* (L.) Shott. *Journal of Agriculture and Food Chemistry*, *60*(28), 7005–7015.

Fullagar, R., Field, J., Denham, T., & Lentfer, C. (2006). Early and mid Holocene tool-use and processing of taro (*Colocasia esculenta*), yam (*Dioscorea* sp.) and other plants at Kuk Swamp in the highlands of Papua New Guinea. *Journal of Archaeological Science*, *33*, 595–614.

García-de-Lomas, J., Dana, E. D., & Ceballos, G. (2012). First report of an invading population of *Colocasia esculenta* (L.) Schott in the Iberian Peninsula. *BioInvasions Records*, *1*(2), 139–143. https://doi.org/10.3391/bir.2012.1.2.10

Global Nutrition Report. (2020). *2020 Global nutrition report: Action on equity to end malnutrition*. Bristol, UK: Development Initiatives. Retrieved from https://globalnutritionreport.org/reports/2020-global-nutrition-report/

Golson, J., Denham, T., Hughes, P., Swadling, P., & Muke, J. Eds. (2017). *Ten thousand years of cultivation at Kuk Swamp in the highlands of Papua New Guinea. Terra Australis 46*. Canberra: ANU Press, The Australian National University.

Grimaldi, I. M. (2016). Taro across the oceans, journeys of one of our oldest crops. In U. Thanheiser (Ed.), *News from the past, progress in African archaeobotany* (pp. 67–81). Proceedings of the 7th International Workshop on African Archaeobotany in Vienna2–5 July 2012. Groningen, The Netherlands: Barkhuis.

Grimaldi, I. M., Leke, W., Borokini, I., Wanjama, D., & Van Andel, T. R. (2018). From landraces to modern cultivars: Field observations on taro *Colocasia esculenta* (L.) Schott in sub-Saharan Africa. *Genetic Resources and Crop Evolution*, *65*(7), 1809–1828.

Grimaldi, I. M., Muthukumaran, S., Tozzi, G., Nastasi, A., Boivin, N., Matthews, P. J., & van Andel, T. (2018). Literary evidence for taro in the ancient Mediterranean: A chronology of names and uses in a multilingual world. *PLoS One*, *13*(6), e0198333. https://doi.org/10.1371/journal.pone.0198333

Grimaldi, I. M., & van Andel, T. R. (2018). Food and medicine by what name? Ethnobotanical and linguistic diversity of Taro in Africa. *Economic Botany*, *72*(2), 217–228. https://doi.org/10.1007/s12231-018-9413-7

Haberle, S. G. (1995). Identification of cultivated *Pandanus* and *Colocasia* in pollen records and the implications for the study if early agriculture in New Guinea. *Vegetation History and Archaeobotany*, *4*, 195–210.

Haberle, S. G. (2005). A 23,000-yr pollen record from Lake Euramoo, wet tropics of NE Queensland, Australia. *Quaternary Research*, *64*(3), 343–356. https://doi.org/10.1016/j.yqres.2005.08.013

Hay, A. (1999). The Genus Alocasia (Araceae-Colocasiae) in the Philippines. *Gardens' Bulletin Singapore*, *51*, 1–41.

Horton, D. (1988). *Underground Crops: Long term trends in production of roots and tubers*. Morrilton, AR: Winrock International.

Huang, A. S., Titchenal, C. A., & Meilleur (2000). Nutrient composition of Hawaiian taro corms and breadfruit. *Journal of Food Compositions and Analysis*, *13*, 859–864.

Huang, S. (2012) Yu Ching (The book of Taro). In: M. Spriggs, D. Addison, & P. J. Matthews (eds) *Irrigated taro (*Colocasia esculenta*) in the Indo-Pacific: Biological, social and historical perspectives* (pp. 45–51). Osaka, Japan: National Museum of Ethnology.

Hudson, M. J. (1999). *Ruins of identity: Ethnogenesis in the Japanese Islands*, Honolulu: University of Hawai'i Press.

Hunter, D., L. Guarino, C. Spillane, & P. C. McKeown (Eds.) (2017). *Routledge handbook of agricultural biodiversity*. Oxon, UK and New York, NY: Routledge.

Hunter, D., & V. Heywood (Eds.) (2011). *Crop wild relatives: A manual of in situ conservation*. London, UK and Washington, DC: Earthscan.

Isabelle, M., Lee, B. L., Lim, M. T., Koh, W.-P., Huang, D., & Ong, C. N. (2010). Antioxidant activity and profiles of common vegetables in Singapore. *Food Chemistry*, *120*, 993–1003. https://doi.org/10.1016/j.foodchem.2009.11.038

Johnston, M., & Onwueme, I. (1998). Effect of shade on photosynthetic pigments in the tropical root crops: Yam, taro, tannia, cassava and sweet potato. *Experimental Agriculture*, *34*(3), 301–312. https://doi.org/10.1017/S0014479798343033

Kaushal, P., Kumar, V., & Sharma, H. K. (2015). Utilization of taro (*Colocasia esculenta*): A review. *Journal of Food Science and Technology*, *52*, 27–40. https://doi.org/10.1007/s13197-013-0933-y

Lambert, M. (1982). *Taro cultivation in the South Pacific*. Noumea, New Caledonia: South Pacific Commission.

Lebot, V. (2009). *Tropical Root and Tuber Crops. Cassava, Sweet Potato, Yams and Aroids*. Cambridge, UK: CABI.

Lebot, V., Saborío, F., Traore, E. R., Onyeka, T. J., Van Rensburg, W., Andrianavalona, V., … Losefa, T. (2018). Adapting clonally propagated crops to climate changes: A global approach for taro (*Colocasia esculenta* (L.) Schott). *Genetic Resources and Crop Evolution*, *65*, 591–606.

Leff, B., Ramankutty, N., & Foley, J. A. (2004) Geographic distribution of major crops across the world. *Global Biogeochemical Cycles*, *18*(1), 1–27. https://doi.org/10.1029/2003GB002108

Lentfer, C., & Deham, T. (2017). The archaeobotany of Kuk. In J. Golson, T. Denham, P. Hughes, P. Swadling, & J. Muke (Eds.), *Ten thousand years of cultivation at Kuk swamp in the highlands of Papua New Guinea* (pp. 163–187). Canberra, Australia: ANU Press, The Australian National University.

Loy, T. H., Spriggs, M., & Wickler, S. (1992). Direct evidence for human use of plants 28,000 years ago: Starch residues on stone artefacts from the northern Solomon Islands. *Antiquity*, *66*, 898–912.

Lu, T.-L.-D. (2006). The Exploitation of Taro in South China. Ethnobotany: At the Junction of the Continents and the Disciplines. Proceedings of the IVth International Congress of Ethnobotany, ICEB, 21–26 August, Istanbul, Turkey. Z. F. Ertug. Istanbul, Yayinlari. pp. 413–417.

Lu, T.-L.-D. (2009). Prehistoric coexistence: The expansion of farming society from the Yangzi River Valley to Western South China. In K. Ikeya, H. Ogawa, & P. Mitchell (Eds.), *Interactions between hunter-gatherers and farmers: From prehistory to present* (pp. 47–52). Osaka, Japan: National Museum of Ethnology.

Mabhaudhi, T., Chimonyo, V. G. P., Chibarabada, T. P., & Modi, A. T. (2017). Developing a roadmap for improving neglected and underutilized crops: A case study of South Africa. *Frontiers in Plant Science*, *8*, 2143. https://doi.org/10.3389/fpls.2017.02143

Mabhaudhi, T., Chimonyo, V. G. P., Hlahla, S., Massawe, F., Mayes, S., Nhamo, L., & Modi, A. T. (2019). Prospects of orphan crops in climate change. *Planta*, *250*(3), 695–708. https://doi.org/10.1007/s00425-019-03129-y

Maga, J. A. (1992). Taro: Composition and food uses. *Food Reviews International*, *8*(3), 443–473. https://doi.org/10.1080/87559129209540948

Manners, Y., & van Etten, J. (2018). Are agricultural researchers working on the right crops to enable food and nutrition security under future climates? *Global Environmental Change*, *53*, 192–194.

Martin, A. R., Cadotte, M. W., Isaac, M. E., Milla, R., Vile, D., & Violle, C. (2019). Regional and global shifts in crop diversity through the Anthropocene. *PLoS One*, *14*(2), e0209788. https://doi.org/10.1371/journal.pone.0209788

Masayi, N., & Netondo, G. W. (2012). Effects of sugarcane farming on diversity of vegetable crops in Mumias Division, Western Kenya. *International Journal of Biodiversity and Conservation*, *4*, 515–524.

Matthews, P. J. (1991). A possible tropical wildtype taro: Colocasia esculenta var. aquatilis. *Indo-Pacific Prehistory Association Bulletin*, *11*, 69–81.

Matthews, P. J. (2004). Genetic diversity in taro, and the preservation of culinary knowledge. *Ethnobotany Research and Applications*, *2*, 55–71. https://doi.org/10.17348/era.2.0.55-71

Matthews, P. J. (2006). Written Records of Taro in the Eastern Mediterranean. In Z. F. Ertug (Ed.), *Ethnobotany: At the junction of the continents and the disciplines*. Proceedings of the IVth International Congress of Ethnobotany, ICEB, 21–26 August, Istanbul, Turkey) (pp. 419–426). Istanbul: Yayinlari.

Matthews, P. J. (2010). An introduction to the history of taro as a food. In V. R. Rao, P. J. Matthews, P. B. Eyzaguirre, & D. Hunter (Eds.), *The global diversity of Taro: Ethnobotany and conservation* (pp. 6–30). Rome: Bioversity International.

Matthews, P. J. (2014). *On the trail of taro: An exploration of natural and cultural history*. Osaka, Japan: National Museum of Ethnology.

Matthews, P. J., Agoo, E. M. G., Tandang, D. N., & Madulid, D. A. (2012). Ethnobotany and Ecology of Wild Taro (*Colocasia esculenta*) in the Philippines: Implications for domestication and dispersal. In M. Spriggs, D. Addison, & P. J. Matthews (Eds.), *Irrigated taro (*Colocasia esculenta*) in the Indo-Pacific: Biological, social and historical perspectives* (pp. 307–340). Osaka, Japan: National Museum of Ethnology.

Matthews, P. J., Lockhart, P. J., & Ahmed, I. (2017). Phylogeography, ethnobotany, and linguistics: Issues arising from research on the natural and cultural history of taro *Colocasia esculenta* (L) Schott. *Man in India*, *97*, 353–380.

Matthews, P. J., & Naing, K. W. (2005). Notes on the provenance and providence of wildtype taros (*Colocasia esculenta*) in Myanmar. *Bulletin of the National Museum of Ethnology*, *29*, 587–615.

Matthews, P. J., & Nguyen, D. V. (2018). Taro: Origins and development. In C. Smith (Ed.), *Encyclopedia of Global Archaeology*. Cham, Switzerland: Springer. Live-Online: e1–4.

Meyfroidt, P., Vu, T. P., & Hoang, V. A. (2013). Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam. *Global Environmental Change*, *23*, 1187–1198. https://doi.org/10.1016/j.gloenvcha.2013.04.005

Mitra, S. (2013). Morphological and nutritional diversity of Indian swamp taro (*Colocasia esculenta* var. *stolonifera* L. Schott). *Tropical Agriculture*, *90*, 11–18.

Mooney, P. R. (1980). *Seeds of the earth: A public or private resource?* London, UK: International Coalition for Development Action.

Moran, P. J., & Yang, C. (2012). Distribution of wild taro (*Colocasia esculenta*) in subtropical Texas, growth of young colonies, and tolerance to simulated herbivory. *Subtropical Plant Science*, *64*, 18–28.

Nip, W. K. (1997). Taro. In D. S. Smith, J. N. Cash, W. K. Nip, & Y. H. Hui Taro. (Eds.), *Processing vegetable and technology* (pp. 355–387). Pennsylvania, PA: Technomic.

Onwueme, I. C. (1994). Tropical root and tuber crops—Production, perspectives and future prospects. FAO plant production & protection paper 126FAO, Rome, p. 228.

Opara, L. U. (2003). Edible aroids: Post-harvest operation [Electronic document]. Massey University (AGST/FAO editing), Palmerston. http://www.fao.org/3/a-av001e.pdf

Paull, R. E., Tang, C.-S., Gross, K., & Uruu, G. (1999). The nature of the taro acridity factor. *Postharvest Biology and Technology*, *16*(1), 71–78.

Plucknett, D. L. (1983). Taxonomy of the genus *Colocasia*. In J.-K. Wang (Ed.), *Taro* (pp. 14–19). Honolulu: University of Hawaii Press.

Population Reference Bureau. (2019). 2013 world population data sheet. http://www.prb.org/2013-world-population-data-sheet.

Prebble, M., Anderson, A. J., Augustinus, P., Emmitt, J., Fallon, S. J., Furey, L. L., … Porch, N. (2019). Early tropical crop production in marginal subtropical and temperate Polynesia. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(18), 8824–8833.

Queensland Government. (2011). Weeds of Australia. The University of Queensland. Special edition of Environmental Weeds of Australia for Biosecurity Queensland. http://keyserver.lucidcentral.org/weeds/data/03030800-0b07-490a-8d04-0605030c0f01/media/Html/Index.htm

Queensland Government. (2019). Children's Health Queensland Hospital and Health Service: Poisonous Plants – Taro (Colocasia). http://www.childrens.health.qld.gov.au/poisonous-plant-taro-colocasia

Rao, V. R., Hunter, D., Eyzaguirre, P. B., & Matthews, P. J. (2010). Ethnobotany and global diversity of Taro. In: V. R. Rao, P. J. Matthews, P. B. Eyzaguirre, & D. Hunter (Eds.), *The global diversity of Taro: Ethnobotany and conservation* (pp. 1–5). Rome, Italy: Bioversity International.

Scott, G. J., Rosegrant, M. W., & Ringler, C. (2000). Global projections for root and tuber crops to the year 2020. *Food Policy*, *25*, 561–597.

Spriggs, M. (2012) From Mendana to Riesenfeld: Early Accounts of and Speculation on Taro Irrigation in the Asia-Pacific Area. In: M. Spriggs, D. Addison, & P. J. Matthews (Eds), *Irrigated Taro (*Colocasia esculenta*) in the Indo-Pacific: Biological, social and historical perspectives* (pp. 1–19). Osaka, Japan: National Museum of Ethnology [Reproduces world map of Rivers 1926].

Srinivas, T., Nedunchezhiyan, M., & Misra, R. S. (2011) Marketing of taro in India. In: *NSCFT proceedings* (pp. 609–612). Kerala, India: CTCRI.

Standal, B. R. (1983). Nutritive Value. In J.-K. Wang (Ed.), *Taro: A review of* Colocasia esculenta *and its potentials* (pp. 141–147). Honolulu, HI: University of Hawaii Press.

Sultana, F., Hu, Y.-G., Toda, M. J., Takenaka, K., & Yafuso, M. (2006). Phylogeny and classification of Colocasiomyia (Diptera, Drosophilidae), and its evolution of pollination mutualism with aroid plants. *Systematic Entomology*, *31*, 684–702.

Sundkvist, A., Milestad, R., & Jansson, A. (2005). On the importance of tightening feedback loops for sustainable development of food systems. *Food Policy*, *30*, 224–239. https://doi.org/10.1016/j.foodpol.2005.02.003

Thompson, S. (1982). *Cyrtosperma chamissonis* (Araceae): Ecology, distribution, and economic importance in the South Pacific. *Journal D'agriculture Traditionnelle Et De Botanique Appliquée*, *29*(2), 185–203. https://doi.org/10.3406/jatba.1982.3868

UN Population Division. (2019) World population prospects 2019: Total Population—Both sexes (1950–2020). United Nations, https://population.un.org/wpp

van Andel, T. R., van der Velden, A., & Reijers, M. (2016). The 'Botanical Gardens of the Dispossessed' revisited: Richness and significance of Old World crops grown by Suriname maroons. *Genetic Resources and Crop Evolution*, *63*(4), 695–710. https://doi.org/10.1007/s10722-015-0277-8

van der Veen, M. (2011). Consumption, trade and innovation. Exploring the botanical remains from the roman and Islamic ports at Quseir al-Qadim, Egypt. Frankfurt, Africa Magna.

Vaneker, K. (2013). Aroid production and postharvest practices. In P. Thompson, & D. Kaplan (Eds.), *Encyclopedia of food and agricultural ethics*. Dordrecht, The Netherlands: Springer.

Vieira, G. H. S., Peterle, G., Loss, J. B., Peterle, G., Mulinario Poloni, C. M., Colombo, J. N., & Lo Monaco, P. A. (2019). Strategies for Taro (*Colocasia esculenta*) Irrigation. *Journal of Experimental Agriculture International*, *24*(1), 1–9.

Wang, J.-K. (1983). Introduction. In J.-K. Wang (Ed.), *Taro: A review of* Colocasia esculenta *and its potentials* (pp. 3–13). Honolulu, HI: University of Hawaii Press.

Williams, M. (2003). *Deforesting the earth: From prehistory to global crisis*. Chicago, IL and London, UK: University of Chicago Press.

Zhu, D., Eyzaguirre, P. V., Zhou, M., Sears, L., & Liu, G. (Eds.) (2000). Ethnobotany and genetic diversity of Asian taro: focus on China. Proceedings of the Symposium on Ethnobotanical and Genetic Study of Taro in China: Approaches for the Conservation and Use of Taro Genetic Resources.10–12 November 1998, Laiyang Agricultural College, Laiyang, Shandong, China.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Matthews PJ, Ghanem ME. Perception gaps that may explain the status of taro (*Colocasia esculenta*) as an "orphan crop". *Plants, People, Planet*. 2021;3:99–112. https://doi.org/10.1002/ppp3.10155