Ex-situ conservation and domestication research; a nexus of hope for sustainable utilization of neglected and underutilized plant species in Malawi

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ABSTRACT

Efforts to unearth the potentials inherent in traditionally important yet neglected underutilized plant species (NUPs) in Malawi have had varying scopes, successes, and shortfalls. Studies on NUPs have mainly focused on indigenous fruit trees with socioeconomic potential. Most published literature on NUPs in Malawi has been on domestication of wild fruits, an agenda spearheaded by ICRAF since the early 1990s. The focus on other plant groups such as indigenous vegetables, roots and tubers has been limited. Wild plants domestication is a key initiative for promotion of their utilization. However, with the existing threats to plant biodiversity, domestication needs to be mirrored with conservation. This review, which utilized literature obtained from various search engines, sought to catalogue research done to facilitate domestication for documented underutilized plants in Malawi. It has been noted that there is uneven and uncoordinated research focus. Most species documented as underutilized have not been scientifically assessed as a way of promoting their utilization. Research done so far has not led to full domestication, i.e., where a domesticated species is able to compete with existing crops, produce adequate and good quality yield, be profitable and requiring reduced inputs. There still exist research gaps that need to be bridged including cultural acceptability and development of robust germplasm to ease cultivation. Mainstreaming NUPs in R&D in Malawi and Ex situ conservation is suggested as an urgent strategy to ensure NUPs preservation as resource-demanding domestication efforts grind-on.

Keywords: *Conservation, domestication, ex-situ, underutilized plant species (NUPs), Malawi.*

1.0. INTRODUCTRY BACKGROUND

Traditionally, Malawians have had a diverse array of plant species that have been gathered and used for consumption, medicine, and art among others. The different plants species have either been cultivated or collected from natural forests. In Malawi, there is over-reliance on maize as a staple food while other known consumable indigenous plants in form of tubers, fruits, leaves, and stems etc. remain underutilized. This has reduced the food resource base for both rural and urban communities (Mkandawire, 2006). Neglected and underutilized plant species (NUPs) are non-commodity plants whose potential has not been fully utilized irrespective of them being once locally popular yet currently neglected for varied reasons (Padulosi & Hoeschle-Zeledon, 2004).

1.1 Underutilized plant species. What are they?

Underulized species are called different names depending on the author. The names include abandoned, new, underutilized, neglected, lost, underused, local, minor, traditional, forgotten, alternative, niche, promising, underdeveloped (Padulosi & Hoeschle-Zeledon, 2004) and orphaned species (Armstead et al., 2009). Within this nomenclatural diversity, there are crosscutting issues that apply to all (Padulosi & Hoeschle-Zeledon, 2004) and identify six common features of NUPs namely; play key role in local consumption and production systems, highly adapted to agroecological niches and marginal areas, represented by ecotypes or landraces requiring improvement, their utilization draws on indigenous knowledge, underrepresented in ex situ gene banks, and have a seed supply system that is either fragile or non-existent. In summary, NUPs are not being conserved and utilized to the same degree as conventional or 'circular' species (Chishakwe, 2008). The Global Facilitation for Underutilized Species (GFU) defines NUPs as: "…. those with a potential, not fully exploited, to contribute to food security and poverty alleviation". In this paper NUPs are defined as "plant species with potential to contribute to food security and poverty alleviation yet not fully exploited and conserved for their purported potential"

1.2 The rise of NUPs research

Due to population increases, decline in agricultural productivity resulting from reduced land holdings and climatic variability (Gornall et al., 2010); interest in underutilized plants has arisen as a solution to address the concomitant food insecurities (Abukutsa Onyango, 2011), and broadly help address global challenges such as environmental degradation, poverty, malnutrition, and disease (Garrity, 2004). From when interest arose in NUPs in 1987 with the formation of International Centre for Underutilized Crops spearheaded by 189 international scientists (Williams & Haq, 2002), significant strides have been made to promote their production and utilization. Most underutilized crops are known to have nutritive value (Yang & Keding, 2009), health benefits (Adesina & Gbile, 1984; Heever & Venter, 2006), a superior adaptation to harsh climates (Abukutsa Onyango, 2011), and a potential for income generation due to cultural, agronomic, or economic reasons ((Schmidt et al., 2010). To fully benefit from NUPs, further necessary research is needed to alleviate existing barriers to their utilization. In this regard, while some NUPs have had adequate research attention, some species remain neglected. Even among the well-studied species, some grey areas persist that inhibit full domestication to enhance utilization. Overall, at the national level, NUPs research has been largely uncoordinated and somewhat random (especially regarding what species to research on). This review thus sought to highlight what underutilized taxa have been studied and to what extent. Specifically, the review aimed to assess how far, from domestication perspective, are the studied species and what research gaps remain. A research strategy is suggested to guide future research on conservation and domestication of underutilized plant species in Malawi.

2.0. THE WHY AND HOW DOMESTICATION OF NUPs?

The call to domestication emanates from the recognized potential of underutilized plant species and a growing recognition by the scientific community of the need for their utilization and conservation (Dulloo et al., 2010). The reasons for plant domestication so far have been to promote increased nutrition and diversified cash income for smallholder farmers (Padulosi & Hoeschle-Zeledon, 2004; Akinnifesi, et al., 2007). Other researchers have sought to create employment around promotion of NUPs (Akinnifesi et al., 2007; German et al., 2009). A few however have advocated for domestication to sustain a rural medicinal ecosystem (Guta et al., 2016; Sagona et al., 2020) and to rebuild dwindling forest resources and general environmental health (Maghembe et al., 1994; Padulosi & Hoeschle-Zeledon, 2004; Mwase et al., 2006). Elsewhere underutilized crop species are being developed for new industrial products especially oils and starches, as alternative crops for export, for use as heritage varieties as part of culture and to improve food production in difficult environments (Williams & Haq, 2002). NUPs have also become a means for climate change adaptation due to their resilience (Nyong et al., 2007; Altieri & Nicholls, 2013; Atlin et al., 2017;). Calls for the conservation of NUPs are not as loud irrespective of various threats they face.

2.1 Threats to underutilized species

Malawi has the highest deforestation rates in SADC regions with 40,000 ha of forest lost annually (Ngwira & Watanabe, 2019) due to agriculture expansion, and excessive biomass use (in form of fuelwood and charcoal). With 90% of the population directly dependent on agriculture (FAO, 2015), deforestation is likely to continue into the near future. At an ecosystem level, forest loss is directly linked to diversity loss (Decaëns et al., 2018). Forests biodiversity perform key roles in ecosystems functioning and to humanity. A great diversity of underutilized taxa is potentially lost due to deforestation and there is an urgent need to conserve this diversity. Underutilized taxa can be categorized as food, medicine, and other cultural value. Conservation via domestication of edible fruits has been tried in Malawi with mixed results.

2.2 Plant domestication as a means for conservation

The focus of NUPs domestication is warranted based on the enormous potential they hold. However, with the overall threat to plant biodiversity, it is critical that domestication efforts be coupled with conservation efforts, a paradigm where *ex situ* techniques are key. *Ex-situ* conservation, "the conservation of components of biological diversity outside their natural habitats" (CBD, 1992), has been promoted as a way of plant biodiversity protection (Raven, 2004), with a primary purpose of supporting restoration in situ populations (Volis & Blecher, 2010). The key challenges recognized regarding this approach include the need to capture existing genetic diversity, avoidance of loss of viability, avoidance of selection pressure and genetic drift (Raven, 2004). Domestication is an *ex-situ* conservation approach (Teletchea, 2017) that has been widely deployed in plant conservation efforts. This practice functions to reduce pressure on wild populations, allowing for recruitment and diversification (Simons & Leakey, 2004). Domestication as a process, comprises various research-intensive steps, usually requiring time and investment to achieve complete domestication. According to (DeHaan, et al., 2016), a fully domesticated species must successfully compete with existing crops, produce adequate and good quality yield, be profitable and requiring reduced inputs.

2.3 The domestication process.

The process of domestication is categorized in three, research demanding phases; screening research, crop improvement research and development of domesticated species (Figure 1). These phases are based first on domestication candidate's species pool.

In general, the domestication pathway comprises two phases; production of domestication candidate species and domestication process itself.

2.1.1. Domestication candidate pool production

The first phase is the compilation of a pool of candidate species for domestication. This phase is key and requires stakeholder consensus. The criteria for inclusion could be based on several criteria including importance to indigenous communities, population status in the wild, popularity of usage within a country, potential for value addition, among others. For successful domestication, underutilized domestication candidates pool ought to be synchronized across research institutions. This ensures reduced duplication and effort spread.

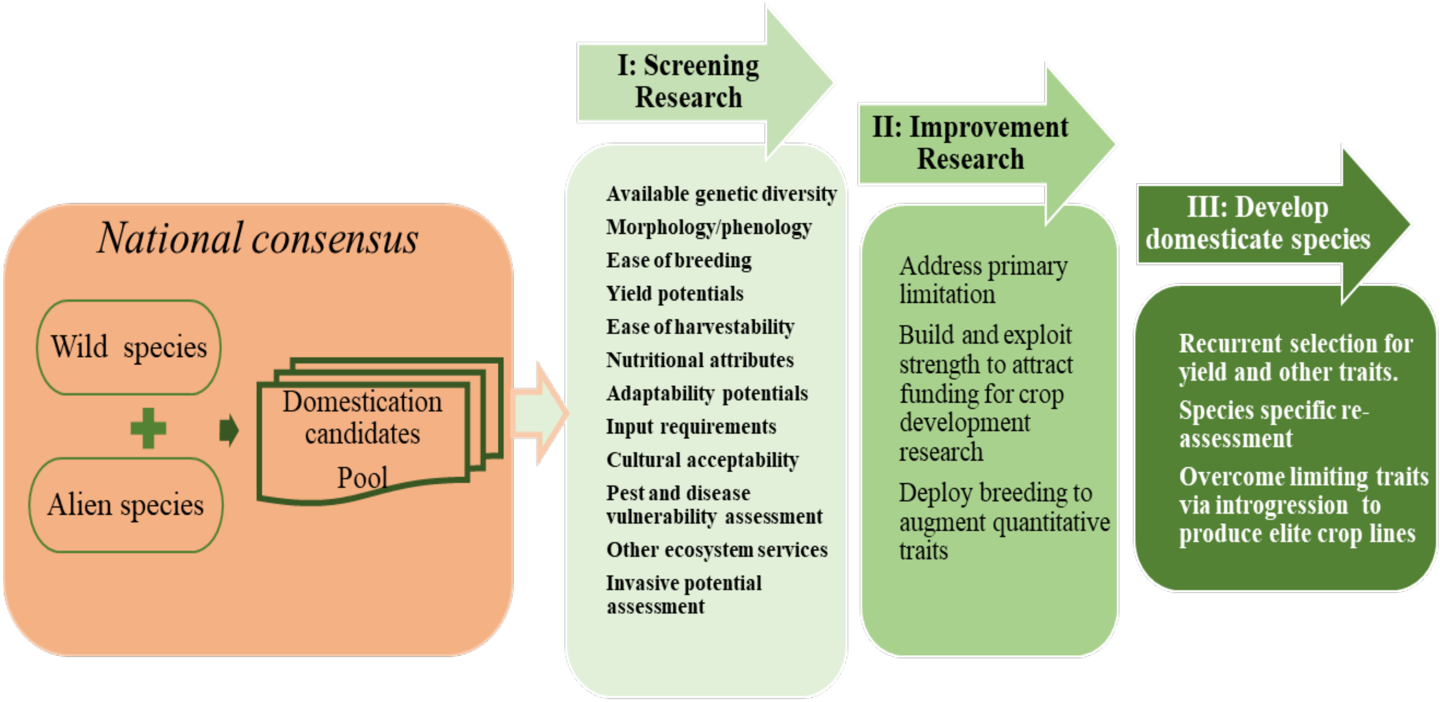

Figure 1: *A domestication strategy for plants, conceptualized after (DeHaan et al., 2016).*

2.1.2. The domestication phase

This phase occurs in three sequential steps of screening, improvement, and variety development (Figure 1). The first phase is the most key and has been called “high throughput” step. Most of research occurs in this phase. A species that qualifies proceeds to the last two phases. The screening phase aims to address key crop and societal barriers to domestication. The above steps may differ, in terms of resource demands, for seed crops, root and tubers, and tree fruits (Meyer & Purugganan, 2013). Section 3.0 reviews literature on underutilized plant species research to approximate the positioning of various taxa on the domestication pathway.

3.0. IS RESEARCH ON NUPs SUPPORTIVE OF DOMESTICATION?

Research in agriculture has been dominated by what are called key agricultural crops such as staples e.g., maize, rice potatoes, and wheat (Iizumi & Sakai, 2020). Research of NUPs has been underfunded and not a priority (Katoch, 2020). Nevertheless, research in NUPs is key irrespective of whether domestication is the end goal, since NUPs play some key role in livelihoods of indigenous communities. NUPs, due to their linkage to cultural heritage and place of origin, can play key roles in the future agro-ecology if cultures and their indigenous knowledge systems (IKS) are “harvested” before their loss along with the ‘wind of modernization’. IKS can augment scientific studies and facilitate crop/plant improvement and promotion of NUPs. In the Malawian case, several NUPs have been studied to varying degrees and in somewhat a haphazard manner. For some, studies have looked at value addition first without an understanding of ethnobotany of a species. All

NUPs studied in Malawi still require further studies mostly to do with understanding the general biology and conservation status. A synopsis of some studied NUPs in Malawi traceable from publications and possible research gaps that still exist, is thus provided (table 1).

Table 1: *Priority underutilized crops found in Malawi as documented by Williams & Haq, (2002)*

Cereals	**Fruits and nuts**	**Vegetables**	**Root and tubers**
Echinochloa spp	*Uapaca* spp., *Tamarindus indica, Sclerocarya birrea, Strychnos* spp, *Adansonia digitata, Vangueria* spp, *Zizyphus mauritiania*	*Ipomoea aquatica, Amaranthus* sp, *Corchorus* sp, *Solanum americanum Solanum nigrum, Solanum aethiopicum, Solanum macrocarpus, Hibiscus sabdariffa, Gymnandropsis synandra, Crotalaria* spp, *Brassica carinata, Vernonia spp.' Basella alba, Citrullus* local spp., *Cucumis* local spp., *Telfairia* spp., *Abelmoschus* spp. *Vernonia* spp.	*Dioscorea* spp., *Colocasia* spp., *Vigna vexillata, Xanthosoma* spp., *Sphenostylis stenocarpa Solenostemon rotundifolius Plectranthus esculentus, Tylosema fassoglense, Tylosema esculentum, Harpagophytum procumbens.*

Table 2: *Underutilized fruits, vegetables. cereals. roots and tubers in Malawi adapted from Kwapata & Edje, (1984); Kwapata & Maliro, (1997); Franzel et al., (2008); Mweta, (2009); Faucher & Revoredo-Giha, (2019); Chipungu, (2022;)*

Cereal	**Fruits and nuts**	**Vegetables**	**Root and tubers**
Sorghum bicolor and *Eleusine coracana*	*Uapaca kirkiana, Parinari curatellifolia, Strychnos cocculoides, Flacourtia indica, Azanza garckeana, Annona senegalensis, Vangueria infausta, Adansonia digitata, Syzygium guineense, Tamarindus indica, Vitex doniana Ximenia Americana, Physalis peruviana, Uapaca nitida, Vitex payos,*	*Corchorus trilocularis, Cucurbita maxima, Amaranthus lividus, Gynandropsis gynandra, Capsicum spp., Bidens pilosa, Adenia cissampeloides, Hibiscus physaloides, Campestris spp. Albizia antunesiana, and yet to be scientifically confirmed Kalundikankhwale, Lusokololonde, Mphulula, Luyuzi*	*Dioscorea* spp., *Colocasia* spp., *Vigna vexillata, Xanthosoma* spp., *Sphenostylis stenocarpa Solenostemon rotundifolius Plectranthus esculentus, Tylosema fassoglense, Tylosema esculentum,*

3.1 Neglected and underutilized vegetables (Table 1 &2)

3.1.1 Amaranthus spp., *(Bonongwe)*

Amaranthus spp. is a relatively well researched vegetable. Research focus has been on its general biology and chemical composition. (Mwase et al., 2014) and Nyasulu et al., (2021) characterized the existing agromorphological diversity of *Amaranthus spp*. Drought tolerance has been investigated for some Malawian accessions (Kwapata et al., 2002). In terms of nutrition, studies have been done on phytochemical and mineral composition (Kachiguma et al., 2015; Lesten & Masamba, 2020), antioxidant content and properties (Wakisa, 2012; Issa et al., 2021) and the impact on these using different cooking methods (Issa et al., 2020). The potential for using and processing *Amaranthus spp*., seed in Malawi has also been investigated (Kigel et al., 200; Kamoto et al., 2018;), but no further published follow up studies seem to have been done. *Amaranthus spp*., is almost domesticated in Malawi. It is one of the few indigenous vegetables that has a wider usage. Formalization of the seed market could further enhance its cultivation including localized seed production as opposed to dependence on imported seed which is costly to the farmers.

3.1.2 Cleome gynandra L.

C. gynandra is a vegetable that grows as a weed in most tropical countries, but is a semi cultivated tropical leafy vegetable in many parts of Sub-Saharan Africa (SSA), where leaves and shoots are gathered from the wild or are cultivated and consumed as food or medicine (Jinazali et al., 2017). In Malawi this vegetable grows almost countrywide. Irrespective of its widespread distribution and use, it remains one of the underutilized plants in Malawi. Very little research has been done compared to elsewhere in Africa (Mishra et al., 2011; Onyango et al., 2013). The only traceable work on *C. gynandra* in Malawi is where its nutritional content was investigated (Jinazali et al., 2017). There is thus a need for localized research on this underutilized plant to understand the Malawian population fully. This is needed considering variability of genetics, physiology, nutrient content and composition, and adaptation among others that change with space and time (Greenfield & Southgate, 2003; van der Walt et al., 2009; Afolabi et al., 2019).

The vegetables, *Abelmoschus* spp, *Basella alba*, *Brassica carinata*, *Corchorus* spp., *Crotalaria* spp., *Cucumis* local spp., *Cleome gynandra*, *Hibiscus sabdariffa*, *Ipomoea aquatica*, *Solanum aethiopicum*, *Solanum americanum*, *Solanum macrocarpus*, *Solanum nigrum*, *Telfairia* spp., and *Vernonia* spp., remain both under-researched and underutilized. As components of wider studies, value chain analysis has been done for *Brassica carinata, Solanum aethiopicum* (Chagomoka et al., 2014). *Hibiscus sabdariffa,* has been investigated for its wine making potential (Ngwira, 1996); *Cleome gynandra* and *Abelmoschus* spp for nutrient composition

(Jinazali et al., 2017; Mwadzingeni et al., 2021); *Corchorus* spp., for nutritional composition under different preparation methods; and preliminary studies on disease resistance in *Brassica carinata* (Nyalugwe et al., 2014).

3.2 Underutilized fruits and nuts (Table 1 &2)

Efforts to domesticate and commercialize indigenous fruit trees date back to 1989 as part of the regional effort and spearheaded by World Agroforestry Centre under its Agroforestry Tree Domestication Programme (Akinnifesi et al., 2007). Agroforestry programs involving indigenous trees had an element of promoting traditionally important yet underutilized plant species. This is apparent from an agroforestry term 'Cinderella trees' which refers to "traditionally important indigenous species that have been overlooked by science for agroforestry and forestry" (Leakey & Newton, 1994; Leakey et al., 2005). The focus of the agroforestry initiative in Malawi and the SSA aimed at addressing some global challenges as enshrined in the Millennium Development Goals (MGDs) (Garrity, 2004), particularly those addressing hunger, poverty, and malnutrition. Domestication of agroforestry trees thus targeted cultivation of indigenous fruit species with potential of economic viability by providing marketable products from farms that would generate cash for resource-poor rural and peri-urban households (Leakey & Simons, 1998; Leakey et al., 2005). In Malawi, research on NUPs was first done under the agroforestry program, prioritized species that included *Uapaca kirkiana, Adansonia digitata, Strychnos cocculoides, Mangifera indica, Zizyphus mauritiana, Vangueria infausta, Azanza garckeana* and *Tamarindus indica* among others (Leakey, 1999; Akinnifesi et al., 2004; Saka et al., 2007). It is opined that while the role of agroforestry is positive, some equally important NUPs could have been neglected, especially those that were not prioritized in the agroforestry program. Reviewed below are summaries of some research on fruits and nuts done towards domestication.

Vigna subterranea **L. (Verdc.) (Bambara nut-Nzama)**

Vigna subterranea is one of the underutilized nuts in Malawi despite its potential for large scale production and improvement of the food resource base for the country (Mkandawire, 2006). Underutilization of *V. subterranean* in Malawi has been attributed to the general localized lack of knowledge of the crop. This lack of knowledge is clear from a review of *V. subterranean* in Sub-Saharan Africa (Mkandawire, 2006) where there is no mention of it in Malawi. Recent research indicates that phenotypic and genetic diversity of the nuts in Malawi has been investigated (Yalaukani et al., 2022 *in press*). However, critical knowledge on Malawian *V. subterranean* still lacks which includes the general ecology of the species, growth and reproductive potential, macro/micro-climatic requirements, existing and potential uses, market potential and value addition options. Elsewhere *V. subterranean* is a well-studied and utilized taxa. Growth and development requirements are known (Collinson et al., 1996), the existing genetic diversity is documented (Amadou et al., 2011), climatic influences on yield have been studied (Collinson, 1997), crop and genetic improvement have been tested (Hillocks et al., 2012; Massawe et al., 2005; Wigglesworth, 1997), effects of different agronomic practices on yield are known (Collinson et al., 2000; Kouassi & Bi, 2010), utilization, market potential and value addition issues (Greenhalgh, 2000; Hillocks et al., 2012; Murevanhema & Jideani , 2013), are well established.

3.2.1 Uapaca kirkiana L (Masuku)

Uapaca kirkiana is one of the most widely studied of Malawian underutilized plant species. Indigenous knowledge related to use, general biology, and propagation of *Uapaca kirkiana* are well documented (Ntupanyama et al., 2008). Studied also are *U. kirkiana'*s early growth requirements, general biology, and reproductive ecology (Ngulube et al., 1995,1998; Mhango et al., 2000; Chirwa & Akinnifesi, 2007); existing genetic diversity (Mwase et al., 2010), physiochemical and organoleptic characters of its juice (Saka *et al.,*2007), product market and consumer preferences (Mmangisa, 2006), domestication efforts (Mhango, 2000; Akinnifesi et al., 2004; Leakey et al., 2012; Akinnifesi et al., 2007). Successful domestication of *U. kirkiana* remains one of the issues still under investigation. One such challenge is overcoming the length of the juvenile period for implementation in on-farm cultivation (Akinnifesi et al., 2009). Notable progress and success has been made in marcotting and grafting for *U. Kirkiana* (Akinnifesi et al., 2009). Such efforts are key in overcoming barriers to domestication such as long juvenile periods as observed in scenario common for indigenous fruits species.

While conservation and sustainable utilization of *U. kirkiana* have been investigated elsewhere (Hamisy, 2004), in Malawi such studies have not been the mainstay in research of underutilized plant species. *U. kirkiana* is a wild plant species, and until successfully domesticated, its continued existence shall hugely rely on protection of its natural habitat (*in situ* conservation). Research, with focus on conservation is largely lacking or anecdotal.

3.2.2 Adansonia digitate L. **(Baobab)**

Just as *U. kirkiana, A. digitata* is also one of the well-studied taxa of the underutilized plant species of Malawi. Its nutritional value and phytochemical compositions are well documented (Saka et al., 1994, 2007; Kamanula et al., 2018;). For some parts of Malawi, population structure and distribution of *A. digitata* are well known (Chirwa, 2006). The physiology, phenotypic variation in seeds and fruits of this species are adequately covered just as is the existing genetic variability (Munthali et al., 2013) and how such variability affects seed germination and seedling growth (Munthali et al., 2012). At a regional level however, almost all aspects of *A. digitata,* that can inform its utilization are well documented (Sidibe et al., 2002). In the case of Malawi more comparative research, to fully allow optimum utilization of the species, needs to be done particularly regarding understanding its *In-situ* population structure, resource base and conservation in the face of increasing demand for its pulp.

The baobab tree provides food, medicine, fiber, crafts, and income to local communities in Malawi and Africa, and its fruit pulp has recently begun to be commercialized in Europe and the USA. Malawi is one of the major exporters of baobab fruit pulp to the west (Sanchez, 2011). As stated, not all however is known about the local baobab populations in Malawi. Research into conservation of *A. digitata* need to be enhanced. The overall population outlook for *A. digitata* is not rosy. The baobab populations in southern Malawi are known to be ageing populations, with low recruitment from seeds, and a considerable percentage are diseased mature trees (Sanchez, 2011; Venter & Witkowski, 2013). All these population bottlenecks call for "assisted recruitment" to ensure that the populations are ecologically and socially sustainable. The species has been propagated successfully through grafting with a success graft take of over 80 % in some trials (Akinnifesi et al. 2009, Jenya et al. 2018) signifying the potential to scale up its adoption for domestication and conservation on farm.

3.2.3 Sclerocarya birrea, **(Marula)**

Sclerocarya birrea, has received a great deal of research comparatively. Some early research focused on natural variability of wild populations (Chirwa et al., 2007) and a broader understanding of its ecology (Chirwa & Akinnifesi, 2008). Assessments of growth, fruit production and yields (Nyoka et al., 2015; Msukwa et al., 2016;) and associated phenotypic plasticity (Mkwezalamba et al., 2015) are well documented. The reproductive biology of the species especially its mating systems has been documented (Msukwa et al., 2019). Phenological studies have focused on flowering onset, fruit set and period to maturity (Msukwa et al., 2019). Msukwa et al, (2021) focused on insect pest for various *Sclerocarya birrea* provenances. The nutritional aspects of *S. birrea* have covered phytochemical composition (Kamanula et al., 2022). Genetic diversity studies for the Malawi population seem to be lacking for this taxon.

3.2.4 Strychnos cocculoides (Monkey orange) Kabeza

Strychnos cocculoides (Monkey orange), from the family Loganiaceae grows naturally in most woodlands and lowlands of Malawi (Shoko et al., 2013). The fruit locally known as Kabeza (Tumbuka, Tonga), mateme (Chichewa) has been traditionally consumed by local communities since time in memorial. Domestication efforts for *S. cocculoides* date back to the early 90s (Maghembe et al., 1994). The biology and ecology of *S. cocculoides* are well documented (Chirwa & Akinnifesi, 2008). Fruit characteristics and seed germination have been investigated (Prins &

Maghembe, 1994; Mkonda et al., 2003). Much attention has also been paid to investigating chemical properties of juice extract from *S. cocculoides*. The studied chemicals include general phytochemicals, volatile compounds and organoleptics (Msonthi et al., 1985; Saka et al., 2007; Shoko et al., 2013). Juices from *S. cocculoides* have been tested for value addition and have been proved to have higher levels of vitamin C and iron (Saka et al., 2007). Organoleyptic evaluation of Strychnos cocculoides were studied by (Tumeo et al 2009) where some compositions (pulp:water, volume to volume) of the juice made were more preferred by the consumers than others. More needs to be done to upscale such milestone research.

3.2.5 Other Indigenous fruit species

Not much published research has been done on *Tamarindus indica, Vangueria* spp, and *Zizyphus mauritiania.* Fruit processing including wine making have been assessed (Ngwira, 1996; Mauambeta, 1999;) for *T indica*. Regarding the *Vangueria* spp, group, research has dealt with domestication potential (Maghembe et al., 1994) as highlighted in Chirwa & Nguluwe, 2000), its local community utilization (Chilimampunga, 2002) and seedling growth and survival under variable watering regimes (Mng'omba et al., 2011). Germination studies (Prins & Maghembe, 1994) on *Zizyphus mauritiania* has been assessed, on its nutritional value with emphasis on factors affecting nutritional content (Tembo et al., 2008). Overall, *Z mauritiana* shows potential for domestication (Akinnifesi et al., 2007).

3.1. Neglected and underutilized roots and tubers (Table 1 &2)

Root and tuber (R&T) crops have been recognized important roles in the nutrition and economy of the rural communities (Malilo, 2001). The focus of both production and research has been on what can be called as major root and tubers; cassava sweet potato and Irish potatoes. Most R&Ts Malawi is endowed with are largely neglected and underutilized and some are not fully domesticated. Some notable neglected and underutilized R&Ts include *Colocasia esculenta, Dioscorea sp. Nymphaea petersiana, Harpagophytum procumbens, Plectranthus esculentus, Solenostemon rotundifolius, Sphenostylis stenocarpa, Tylosema esculentum, Tylosema fassoglense, Vigna vexillata* and *Xanthosoma spp.*

3.3.1 Colocasia esculenta (L.) **(Cocoyam)**:

Colocasia esculenta is known to contribute significant proportions of carbohydrate diet in the tropical and sub-tropic regions, especially for infants due to high digestibility of its starch and relatively high mineral content (Ojinnaka & Akobundu, 2009). In Malawi it remains a relatively underutilized species. The use of cocoyam starch in industry remains underexploited (Mweta et al., 2015). *C. esculenta* thus remains an underexploited plant species in Malawi both at subsistence level and industrial application levels.

Research on *C. esculenta* in Malawi has so far elucidated the ethnobotanical and morphological characters of the species (Mwenye et al., 2010) and comparative nutrient contents (Mwenye et al., 2011). In addition, there is known genetic diversity among cocoyam growing in Malawi especially between those growing in the northern and southern regions of the country (Mwenye et al., 2015). How this genetic diversity relates to other relevant attributes of the plant remains to be investigated. In terms of value addition, cocoyam starch has a unique role to play in industrial application as it has been shown to differ from traditional starch sources (Mweta et al., 2008, 2010, 2015). In terms of research, not much has been studied regarding conservation of the populations or enhancement of domestication. This shortfall coupled with limited knowledge of the general ecology and climatic requirements could be hampering widespread cultivation and subsequent use of this important plant species. Otherwise, cocoyam expresses great productivity particularly in wetlands hence its contribution to diets can easily be scaled up. Lately (Chipungu, 2022) assessed opportunities and challenges in the production, utilization, and marketing of minor root tubers in Malawi.

3.3.2 Dioscorea spp.

This group comprise several species for example, (Mwafongo et al., 2010) found six species that are used mainly for food and medicine. Some *Dioscorea* specie*s* have shown domestication potential (Maliro, 2001). Morphological characterization for cultivated *Dioscorea* spp has been carried out (Msowoya-Mkwaila et al., 2013). An analysis of morphological and genetic differences (Luhanga et al., 2014; Msowoya, 2004) shows some variability between cultivated and wild relatives of *Dioscorea* spp. An assessment of physicochemical, functional, and structural properties of native *Dioscorea* species exhibit higher protein levels than other tubers (Mweta, 2009). Despite long history of homestead domestication of the species countrywide, large scale production has always proved elusive.

3.3.3 Nymphaea petersiana **(Nyika)**

This is a tuber of significance in the lower Shire particularly useful during lean periods of the year when households run out of usual food. It’s one of the underutilized plant species in Malawi. Research on the plant is largely nonexistent. The only publication on the species hails the potential the tuber has in addressing issues of micronutrient malnutrition, availability in times of famine, and versatility of meals that are made from the tubers (Chawanje et al., 2007). These attributes associated with *N. petersiana* make it the right candidate for localized solutions to issues of hunger, malnutrition, and disease. A comprehensive scientific understanding of the physiology, ecology, existing genetic diversity, domestication, utilization, and potential value addition for *N. petersiana* are issues of necessity.

3.3.4 Research status on other root and tubers.

Some work on phylogenetics taxonomy, distribution, and medicinal use has been done on *Plectranthus esculentus* (Paton & Mwanyambo, 2018) while *Xanthosoma sagittifolum* has been studied for its ethno-botanical and morphological characteristics (Mwenye et al., 2010) and mineral composition (Mwenye et al., 2011). In other countries however these taxa are greatly utilized. In Nigeria, *Xanthosoma sagittifolium* enjoys widespread use and plays a key role in household nutrition security (Onyeka, 2014; Boakye et al., 2018;) and genetic improvement programs are reported (Saborío et al., 2004)(. In South Africa, *Harpagophytum procumbens* has been extensively utilized and studied especially for its medicinal properties (Gxaba & Manganyi, 2022; Menghini et al., 2019). Its toxicology (Joshi et al., 2020) and quality control (Pretorius et al., 2022) have recently been documented. *Sphenostylis stenocarpa's* important nutritional contribution (Fabusiwa, 2021) advanced approaches to crop improvement (Oluwole et al., 2021), disease resistance (Afolabi et al., 2019), yield assessments (Ibirinde et al., 2019; Aremu et al., 2020) and its conservation status (Nnamani et al., 2017) have been reported. Regarding *Tylosema esculentum,* no extensive uses are reported and has been called an orphan crop (Cullis et al., 2018) however its potential (Cullis et al., 2022), starch composition (Hamunyela et al., 2020) have been explored. *Vigna vexillate is* considered a "lost crop". Current research is diverse including its genetic diversity (Dachapak et al., 2018) identification of domestication traits (Dachapak et al., 2018), morphological and nutritional assessments (Tripathi et al., 2018). Indicative progress along domestication and utilization strategy of 10 species under review is shown in figure 2.

4.0. BARRIERS TO FULL DOMESTICATION

The key barriers to plant domestication can be broadly categorized as species-based and society-based. Research to resolve species-based, and plant specific, limitations is key. Trait improvement research should aim at yield traits that conform with the "domestication syndrome" as discussed in (Denham et al., 2020). Some traits requiring quick resolution include; complex germination requirements, poor seedling vigor, invasive spreading, or extreme height and plasticity (DeHaan et al., 2016). For the candidate domestication taxa reviewed in this paper, research has focused on understanding what obtains in these species (Prins & Maghembe, 1994; Mkonda et al., 2003; Munthali et al., 2012;). It is imperative that much of domestication research should focus on enhancing the identification NUPs desirable traits that can facilitate domestication i.e., domestication syndrome (Denham, et al., 2020). Plant traits that suit consumer acceptance are known to facilitate domestication (Harouna et al., 2019). Of the society-based barriers, issues of yield amount, growth rates, taste, (Denham et al., 2020) do play a role in overall acceptability. One barrier, rather beyond a botanist, is dealing with acceptability of a given species. For vegetables reviewed in this paper, this seems to be one of the remaining hurdles to full domestication.

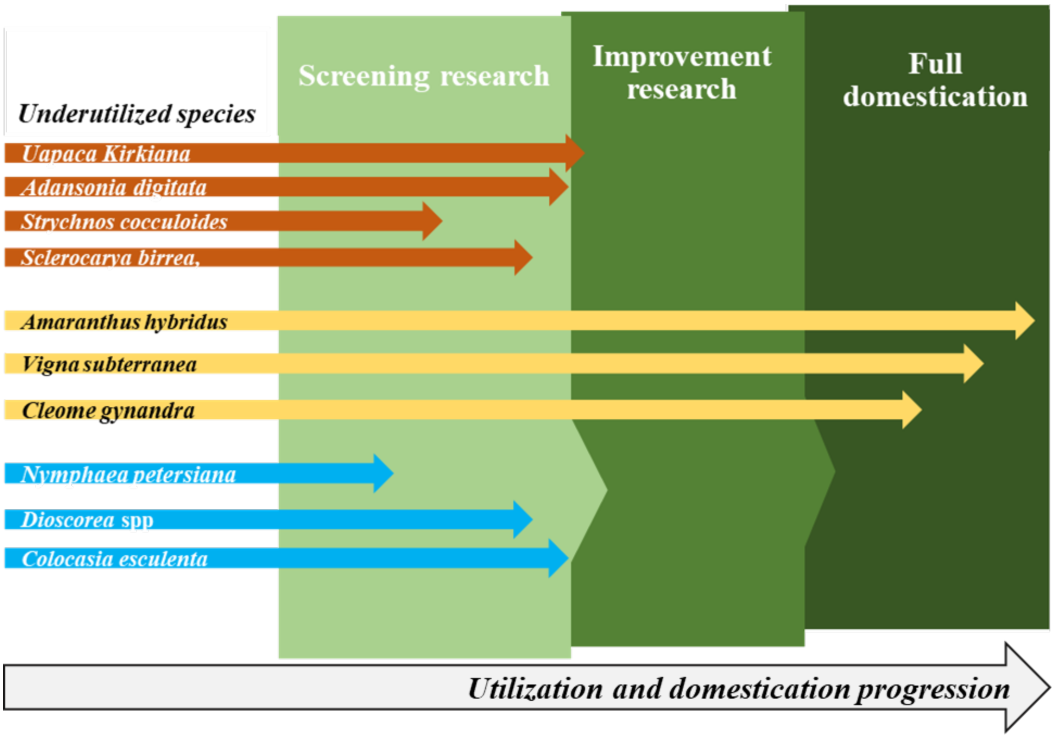

Figure 2: *Indicative progress along domestication (and utilization) strategy pathway 10 species reviewed in the paper.*

5.0. THE CASE FOR *EX-SITU* CONSERVATION

The process of domestication requires a pool for domestication efforts since it takes time and is research intensive (Figure 2). *Ex-situ* conservation can serve two purposes; first, it could be used to assess early aspect of the domestication process and secondly, it would serve as a reservoir for genetic diversity that would otherwise have been lost. Malawi is likely to continue to face the challenge steady decline in plant diversity. Deforestation will remain a challenge as poverty forces people to over-rely on forest resources. Agricultural expansion (beyond the existing acreage) is inevitable in the short term as not enough land exists for agricultural expansion (Giller et al., 2021). This scenario will likely force people to clear whatever remains of forest to agriculture. Projected population increases for Malawi spell the same dark view of existing remnant forest resources. Ex situ conservation will thus ensure preservation of currently existing diversity of **NUPs** as the process of domestication grinds-on.

Various strategies of *ex-situ* conservation are reviewed in (Abeli et al., 2020; Engels & Ebert, 2021; Hay, 2021). While Malawi can borrow from these, some promising ones include on-farm diversity maintenance and field gene banks. On-farm maintenance of some crops works to avoid genetic erosion, especially for underutilized plant (Dulloo et al., 2010) which are under-represented in most conventional gene banks. Field gene banks: areas where live plants are kept can be explored as alternatives. Though with challenges as in (Dulloo et al., 2010), field gene banks can be promoted at national, institutional and community levels. Plants not suitable for the above strategies can benefit from enhanced tissue culture techniques. Tissue culture for production of plants for restoration proved key in conservation of endangered plant species in Hawaii (Werden et al., 2020), alongside other strategies. Tissue culture thus could help overcome domestication bottlenecks that hinder germplasm availability.

6.0. CONCLUSION AND WAY FORWARD

In William and Haq, 2002 analysis, Malawi does not appear under countries with national programs on underutilized crops and countries with some research interest on expanding use of underutilized crops. There is need to set a national research agenda that clearly defines underutilized plant species for Malawi and spells out future research trajectory for all stakeholders involved. Specifically, there is need for: 1) Coordinated cataloguing of Malawi's underutilized plant species (crops and other key native taxa) and underutilized species prioritization. Such a prioritization could be based on relative distribution, local popularity, wide climatic tolerance, population status in the wild (threatened or not). 2) Coordination of research to prevent costly overlaps and biased attention to certain species.

While the number of underutilized plant species in Malawi is relatively large, notable progress is traceable on just a few species. These include *Uapaca kirkiana, Adansonia digitata, Colocasia esculenta, S. cocculoides* and *Amaranthus* spp. The promotion of wider adoption and use of underutilized plant species in Malawi has the potential to help alleviate several pressing challenges the country faces. The challenge of deforestation and "exponential" population increase entail that *ex-situ* conservation is a key additive to the current domestication efforts. NUPs species prioritization should cover all native plant groups i.e., cereals, fruits and nuts, vegetables and pulses and roots and tubers. While in the past (under the agroforestry led initiatives) prioritized fruits had to be of economic value with the 'end need' being poverty alleviation among others, an approach that recognizes both tangible value and conservation value is envisaged. Finally, a national coordinating unit/section dealing with NUPs conservation and domestication is proposed at national level. This entails mainstreaming underutilized plant species in the national research and development agenda. This, it is projected, could reduce research bias, and ensure that the prioritized species are evaluated up to the final stage of the domestication process.

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