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State of knowledge and perspectives on wild loquat: *Uapaca kirkiana mell. Arg* (Euphorbiaceae) in Malawi (Southern Africa)

État des connaissances et perspectives sur la nèfle spontanée (*Uapaca kirkiana* mell. Arg (Euphorbiaceae)) au Malawi (Afrique australe)

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Abstract

Various parts of the plant *Uapaca kirkiana*, Euphorbiaceae family, are widely used in African countries for medicinal, food, economic, and social purposes. In traditional African medicine, the plant is used to treat fever and infections. On a socio-economic level, the plant is recognized as contributing to the improvement of household income. Due to its socio-economic and therapeutic importance, it has become a plant widely used by populations and highly sought by researchers aiming at validating scientifically and/or supporting its traditional use and its adoption in domestication. Although it is widely used in traditional medicine and has socio-economic importance,there is a lack of information on its phytochemical composition and biological activityand socio-economic importance. Using searching tools such as Google Scholar, PubMed and library literature, a total of 1,235 articles were identified. To avoid duplication, articles indexed in multiple databases were removed, leaving 109 articles. Only 91 articles met the requirements and study inclusion criteria. Therefore, this review provides a systematic overview of the socio-economic importance, species structure, biological activities, phytochemical constituents, and ethnomedical properties of the plant. The data show that *U. kirkiana* is a promising plant with socio-economic and pharmacological potential and can therefore be useful in contributing to the fight against climate change and food security.

Keywords: *Uapaca kirkiana*; Euphorbiaceae; Biology; ecology and taxonomy

1. Introduction

Uapaca kirkiana Mell. Arg or the loquat is a multi-purpose fruit tree widespread in southern Africa (Chawafambira et al. 2020), and used in various forms for human consumption. It has great economic, social, cultural, and therapeutic importance among thepoor rural and peri-urban areas. The fruit is commonly used for beverages, laxatives, and purgatives, and appears to be the most marketed plant part (Akinnifesi et al. 2004).

Farmers and other stakeholders have recognized the socio-economic value of *Uapaca kirkiana*.. *Uapaca kirkiana* has a high level of preference among farmers, consumers, and experts (Akinnifesi et al. 2004). One of the key values of the fruit is its valuable contribution to diet quality (Packham 1993) and overall food security. The multiple uses of this fruit tree justify research on this plant (Akinnifesi et al. 2004; Chawafambira et al. 2020; Jinga et al. 2020; Kadzere et al. 2006; Mwamba 1995; Ngulube et al. 1998).

Several studies have highlighted the importance of loquat in the traditional diets of rural communities (Chawafambira et al. 2020; Ngulube et al. 1997). However,studies on the socio-economic benefits that loquat provides to the local communities directly relying on this plant are few. Natural populations of the species are declining due to overexploitation, climate change impacts, habitat loss, and lack of conservation strategies (Chawafambira et al. 2020). These pressures reduce the capacity of forest ecosystems to protect and conserve biodiversity (Kokou et al. 2023). To reduce the risk of a drastic decline in fruit resources and genetic diversity, programs have been implemented to protect, domesticate, and valorize *U. kirkiana*. research on regeneration technics has also been conducted, including the effects of propagule types and fruiting period on fruit and seed size, seed germination, and seedling growth (Mng'omba and Sileshi 2015). In Malawi, landscape restoration strategies do not adequately consider economically valuable perennials such as *U. kirkiana*. However, domestication studies are underway, and collection and processing remain predominantly female activity. An inventory of the potential of alien and indigenous plants in Malawi has shown that *U. kirkiana* is one of the most valuable neglected and underutilized fruit-producing woody species and food plants (Omotayo and Aremu 2020).

Despite the quite important number of publications on *U. kirkiana*, the analysis of the results do not facilitate a cross-reading of the knowledge on this plant. There is still a lack of knowledge about several important matters regarding *U. Kirikiana* which could support implementation of coherent strategies for the sustainable management of its stands facing anthropogenic pressures and climate change. This study aims to systematically provide information on the taxonomy, biology, ecology, ethnobotany, pharmacology, and phytochemistry of *U. kirkiana*, to the available literature. More specifically, it aims to take stock of knowledge on research already carried out on *U. kirkiana*, to guide future research.

2. Methodology

2.1. Data collection

The assessment of the state of knowledge on *U. kirkiana* was based on the analysis of scientific articles, dissertations, reports, and thesis published between 1978 and 2023. This research was conducted in the English language. Documentation were performed in Harzing's Google Scholar, PubMed, Research Gate, Publish, or Perish databases (Ahlidja et al. 2024; Samarou et al. 2022). This database allowed publications from the Crossref, Google Scholar, and Pubmed engines to be grouped. To search for publications on *U. kirkiana* , the following keywords were used together or separately: *U. kirkiana*, taxonomy, uses, socio-economic, ecology, biological activities, and pharmacological activities. The bibliographic resources also include the Bielefeld academic search engine, Science Direct. A review of some physical documents in the Mzuzu University Libraries complemented this literature search.

2.2. Data processing

A total of 1,235 articles were identified. To avoid duplicatres, articles indexed in multiple databases were removed, leaving 109 articles. Only 91 articles met the study inclusion criteria. The process of identifying and filtering articles for this systematic review was carried out manually (Figure 1).

Analysis of the data from the literature included a PCA by cross-referencing the list of publications and linking the theme to the year of publication. The PCA function in R software was used.

The selected publications were classified according to the following 10 research themes: (i) history and description of *U. kirkiana*; (ii) biological and pharmacological activities; (iii) method of management and conservation; (iv) Ethnobotany; (v) distribution and structure of the population; (vi) multiplication and germination; (vii) use and valorization; (viii) domestication; (ix) forestry and (x) climate change. The data collected was analyzed in a spreadsheet to discriminate the addressed subjects , by year of publication, geographical origin and field of study (category) of the each publication.

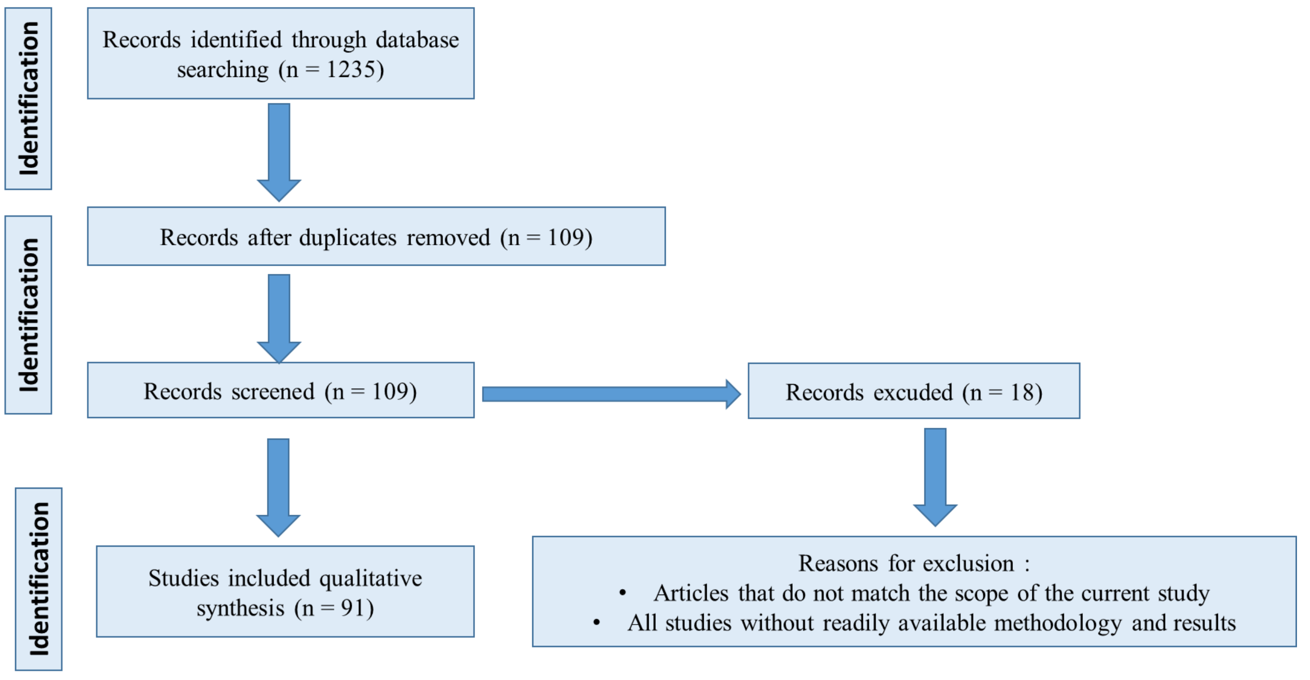

Figure 1: Flowchart showing the systematic literature search used in selecting research articles for the review

2.3. Geographical location of Malawi

Malawi is a landlocked country located in the eastern region of Africa, without direct access to the sea and covers an area of 118 480 km2. It is bordered by Zambia to the West, Mozambique to the South and East, and Tanzania to the North-East. Located between 9° and 17° south latitudes and between 32° and 36° East longitudes. The country covers 900 km length with approximately 160 km width. Malawi is subdivided into three (3) administrative and economic regions which are: Northern Region with 6 Districts (26,931 km²), Central Region with 9 Districts (35,641 km²) and the Southern Region with 13 Districts (31,753 km²). Ecologically, the country is subdivided into 4 agro-ecological zones on the basis of relief, climate and floristic specificities.

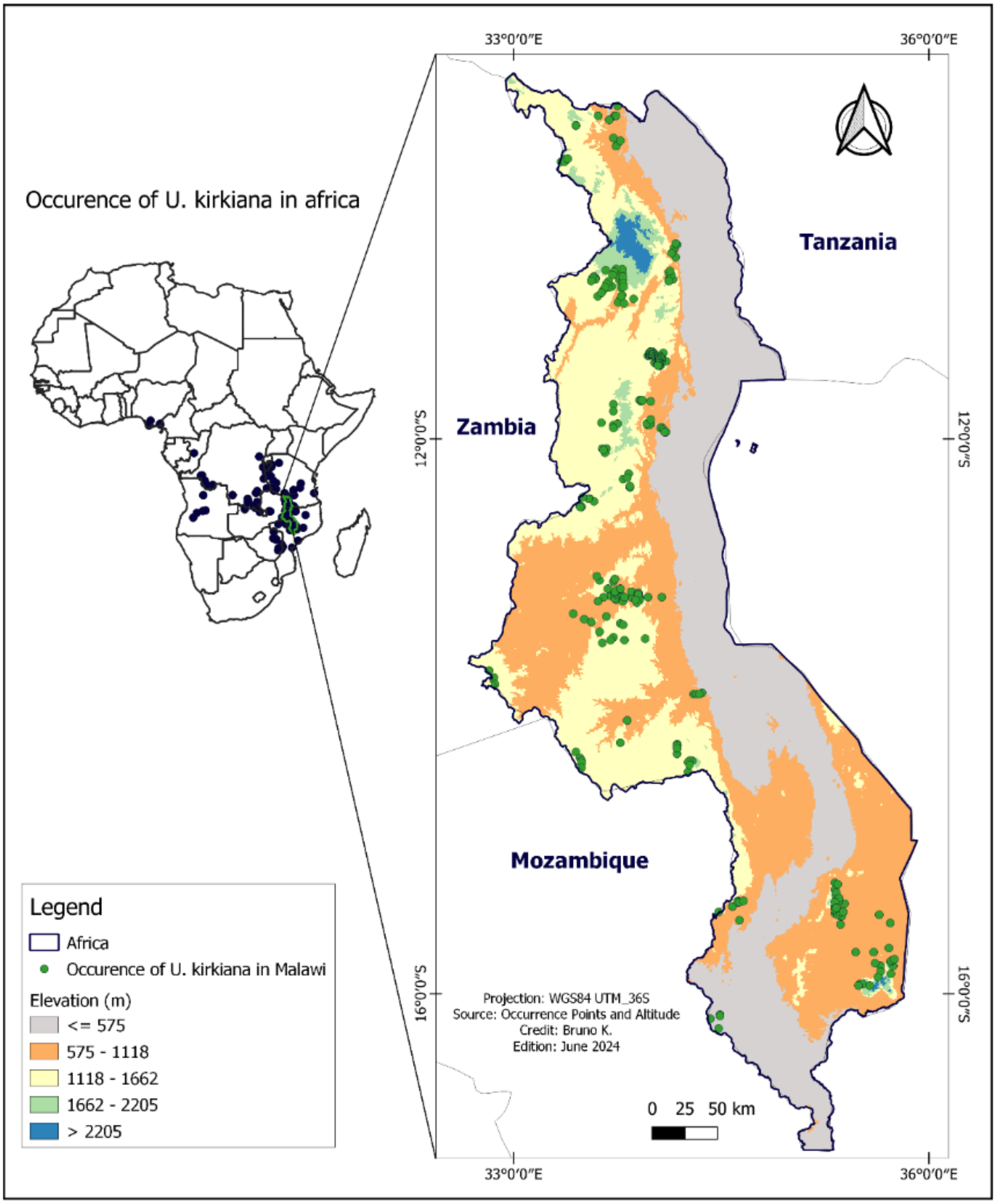

Figure 2: Map of the study area showing the geographical distribution of U. kirkiana in Africa and Malawi

3. Result and discussions

3.1. Research themes covered on *U. kirkiana*

the most frequently topics addressed on U. kirkiana concern Biological and pharmacological activities, multiplication and germination, sylviculture, and the history and description , accounting for 21%, 20%, 18%, and 14% respectively (Figure 3). The least developed subjects are domestication, the impact of climate change, use and development, distribution and population structure, management and conservation, and socio-economic importance. To assessthe dependence and links between the variables, we carried out the analysis of the chi square test which revealed a p-value = 0.0297, less than 0.05. Which indicates that there is a dependence between the two variables. This shows that the publication themes depends on publication categories (figure 4).

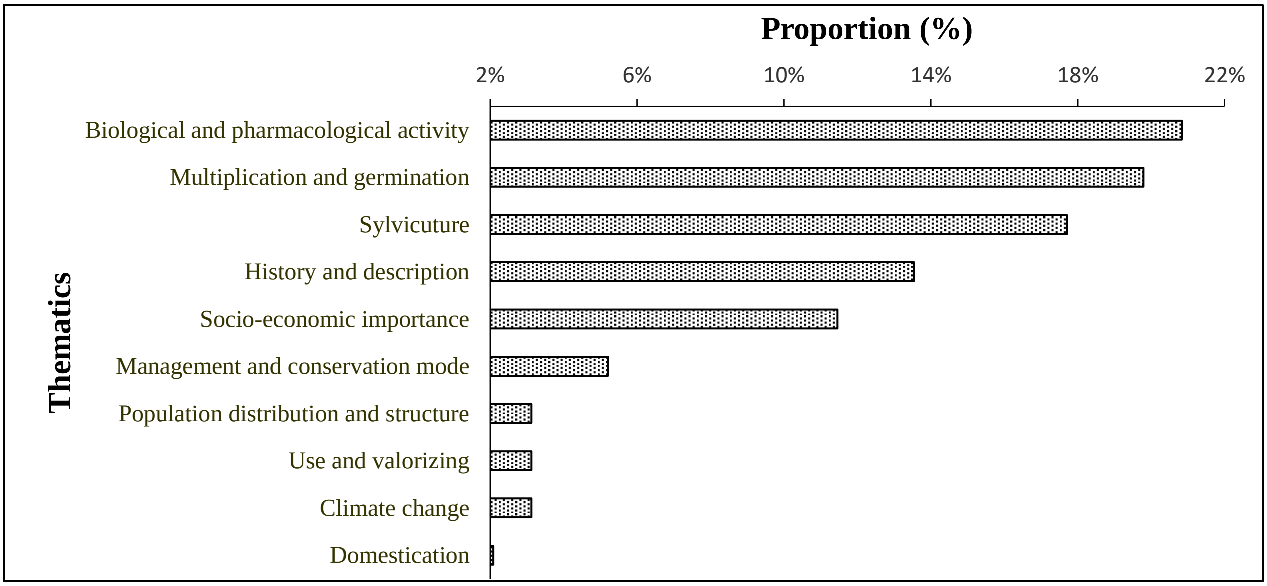

Figure 3. Breakdown of publications by research theme

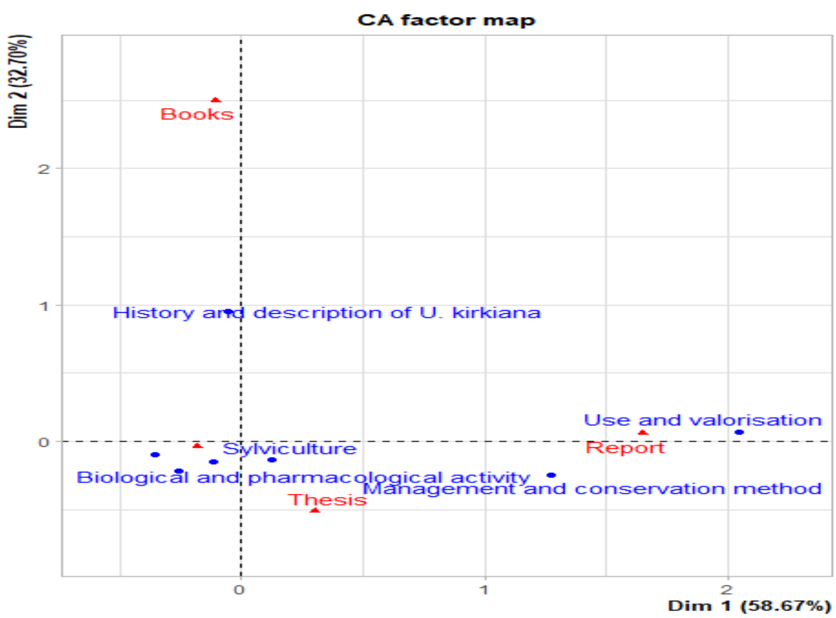

Figure 4. Factorial correspondence analysis (FCA)

Most of the scientific publications available were conducted in southern Africa specially Malawi, Zambia, and South Africa (Figure 5 and 6). Research on this species has also been carried out in Tanzania, Zimbabwe, and the DRC. In Malawi, research on the pharmacological and medicinal properties of the plant, multiplication and germination, and forestry have been recorded (Akinnifesi et al. 2008).

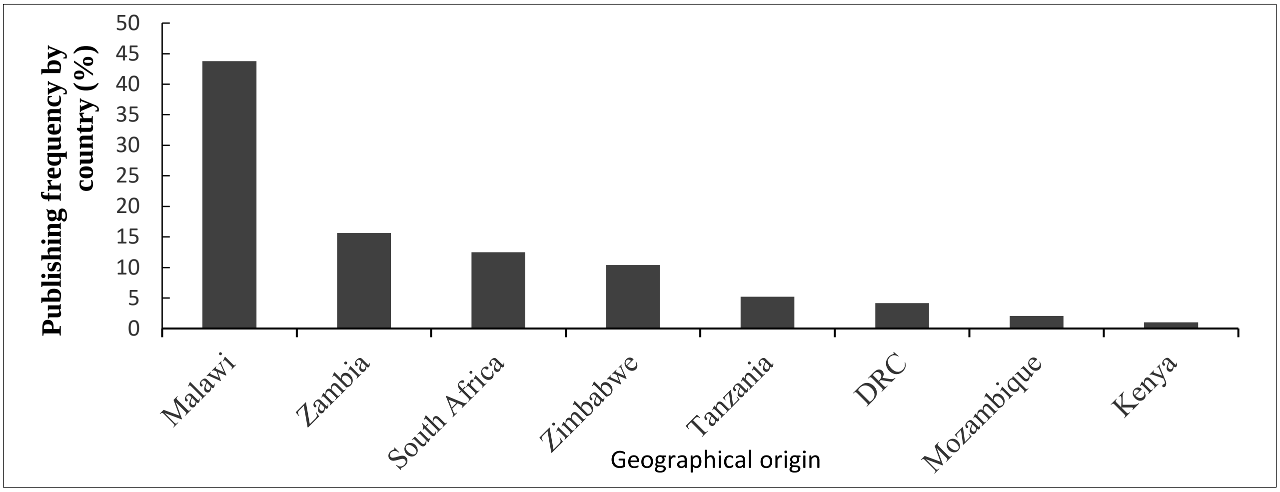

Figure 5: Geographical origin of publications on *U. kirkiana*

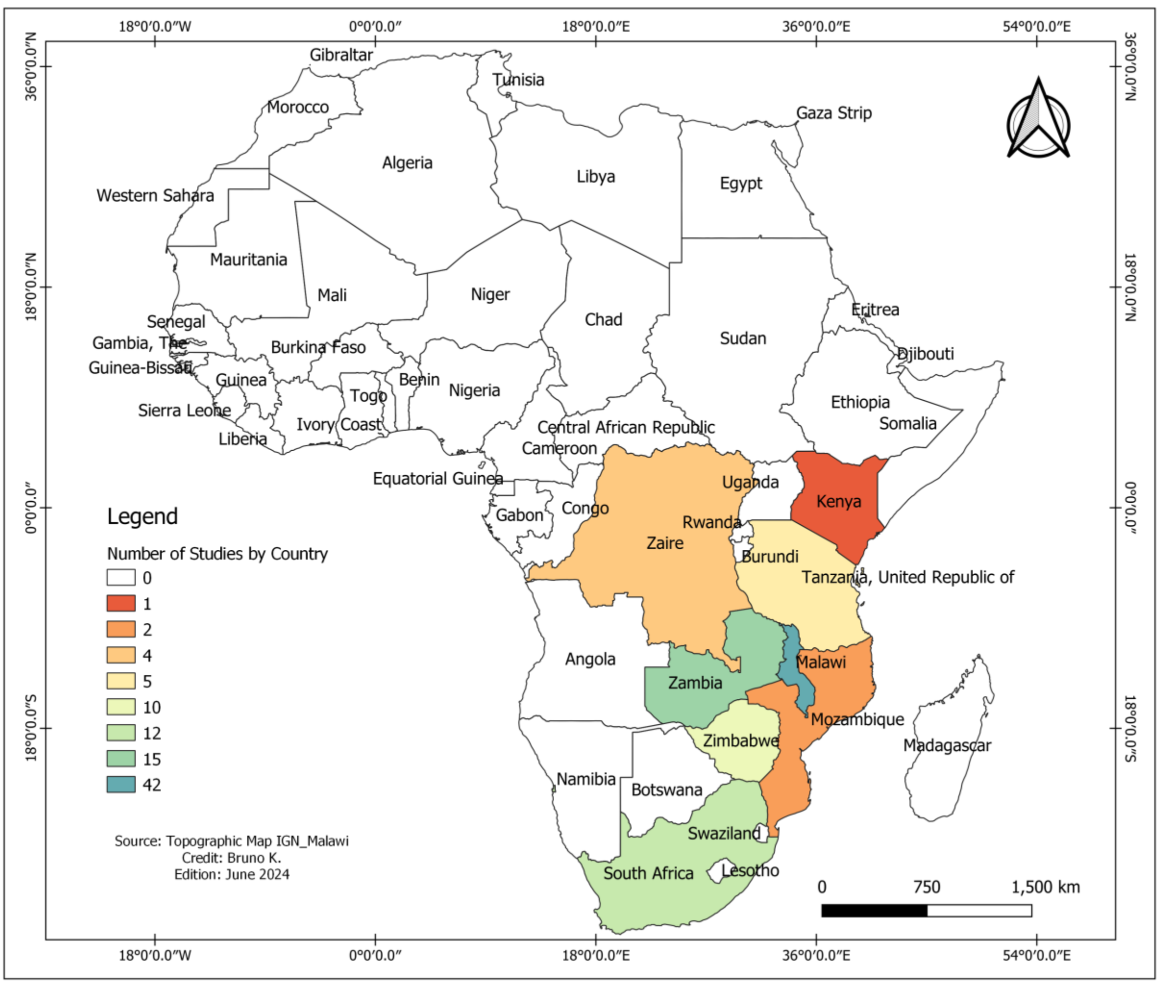

Figure 6: Category of countries according to the number of publications

Within the framework of the state of knowledge on *U. Kirkiana*, we distinguish four (4) main categories of publications: journal articles, dissertations, books, and study reports. The bibliographical review identified more articles (85) than dissertations (5), books (2), and (8) reports, which make up the documents centralized, read, and classified (Figure 7).

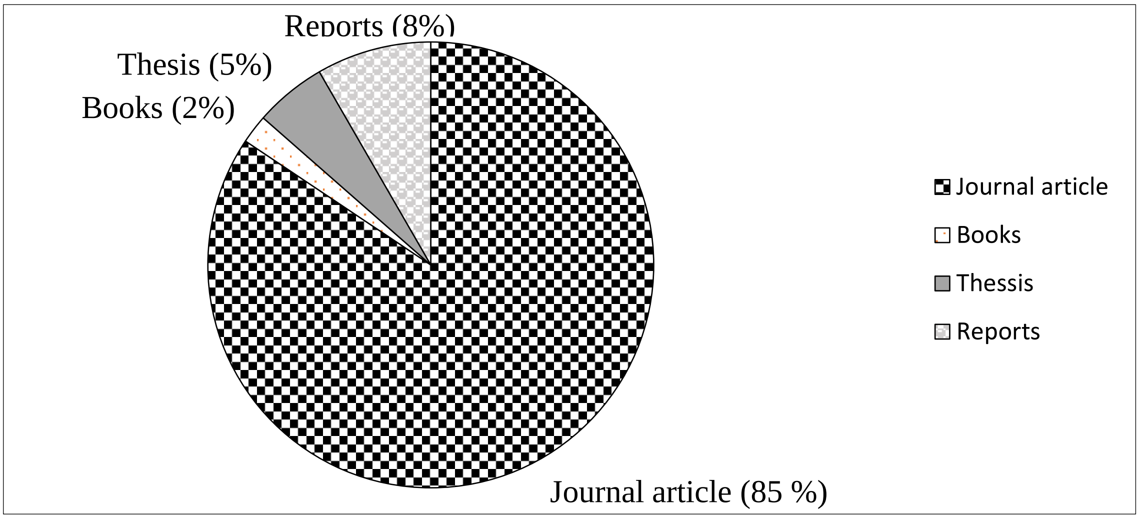

Figure 7. Types of publications concerning U. kirkiana from 1978 to 2023

For the period considered (1978 to 2023; 45 years), the analysis of dates of publication shows the importance of the scientific interest of *U. Kirkiana*. Between 1978 and 2002, there were fewer publications: 2 per decade in average. By contrast, 2003-2007 interval marks a peak in research on *Uapaca* species, with a record of 24 publications, followed by 2008-2012 with 19. In 2023 only one publication appeared(1) (Figure 8). Interest in the *U. kirkiana* species is growing with the increasing trade of *U. kirkiana* fruits and otherproducts for food and medicinal purposes. Note that between 1983 and 1987, there was no publication of articles or documents produced on the species *Uapaca kirkiana*.

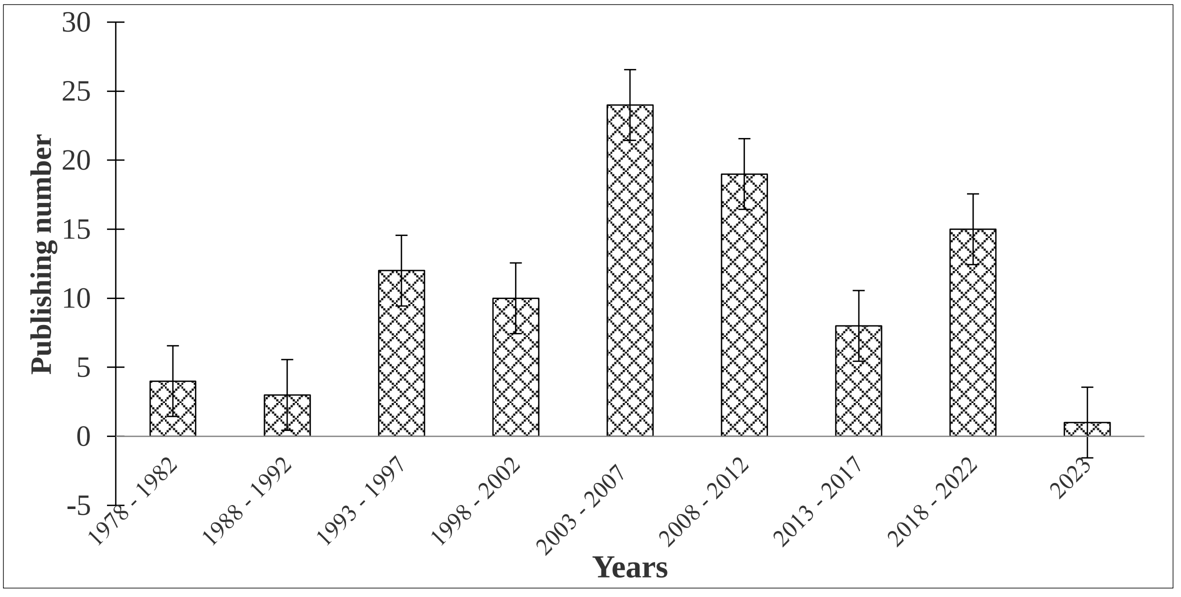

Figure 8: Number of publications from 1978 to 2023 (45 years) on *Uapaca kirkiana*

3.2. Taxonomy

Uapaca belongs to the family of Euphorbiaceae, subfamily Phyllanthoideae in the genus) Antidesmeae, and the sole representative of the subtribe Uapacinae (Webster 1987). *Uapaca* is a Malagasy name for the genus 'Voa-paca' and was used for the Madagascar species, *Uapaca thouarsii*, described by Henri Baillon (1827-1895) in 1858. The genus has 60 species assigned to it (Radcliffe-Smith 1988), but there has been no recent revision on a continental scale and the number of distinct species is probably less. Radcliffe-Smith (1988), revision of the East African members was the first major taxonomic account of the genus for over 50 years. The greatest diversity is in the Zaire Basin and further south in the Miombo region. Many species names are used in ecological and floristic publications from this area but are now considered as synonyms of the oldest name.

Uapaca kirkiana was named by Jean Mueller of Aargau (1864) after Sir John Kirk (1832-1922) who collected the type specimen of the species on 8 March 1862 in the Soche Hills of southern Malawi. As *U. kirkiana* occurs in eight southern African countries, it has many vernacular names, the most common being wild loquat (English), masuku (Malawi, Tanzania and Zambia), nkusu (Tanzania), mhobohobo or muzhanje (Zimbabwe), matu or nt'junku (Mozambique) and mumbola (Angola) (Ngulube et al. 1998).

3.3. Botany and ecological distribution

Morphological descriptions of *Uapaca kirkiana* have been provided by several authors (Drummond 1981; WHO 2003). Perhaps the most comprehensive is the recent review by Radcliffe-Smith (1988). The tree is evergreen or semi-deciduous with widely branched branches forming a dense rounded crown. The trunk is short, reaching a height of 5-12 m and a diameter of 5-25 cm at diameter at breast height (d.b.h.). The bark is dark grey or greyish brown, thick, and deeply fissured. Leaves are simple, large, and alternate arranged in clusters at the tips of the branches, leathery, strongly ribbed, dark green, and with rounded tips. Young leaves are covered underside with a curly layer of hairs. Its wood is light-coloured with white sapwood and has reddish-brown heartwood (Chabwela et al. 2017). It is dioecious with staminate flowers that are born in dense clusters, while the female flowers are solitary. Male and female trees are difficult to distinguish at early stage as Both has are yellowish-green and inconspicuous flowers (Palgrave et al. 1983). Fruits ripen towards the end of the dry season or during the rainy season (Ngulube et al. 1995) (Figure 9). Fleshy fruits (3 - 4 cm in diameter) contain edible pulp which is rich in nutritive substances October–December (Ngulube et al. 1998). The pulp is yellowish and tastes sweet (Chabwela et al. 2017). The fruit contains three to five recalcitrant seeds. These germinate within three months of harvest during the wet season, January–March (Mwamba 1995). Recalcitrant seeds are defined as seeds that do not tolerate desiccation injury and have a short storage life. They must be stored at the lowest non-damaging temperatures (Berjak et al. 2004).

U. kirkiana trees are common in Miombo woodland.Figure 10 shows the natural range of distribution of wild loquat in Africa. The Miombo eco-region is composed of open canopy and broad-leaved forest trees. It occurs on densely populated plains and the lower mountain slopes and covers about 3.8 million km^2 of the Zambezian phyto-region (Chidumayo 1997). It covers seven countries: Angola, Malawi, Mozambique, Tanzania, Zimbabwe, Zambia, Namibia and parts of Democratic Republic of Congo. The genera *Brachystegia, Julbernardia* and *Isoberlinia* dominate the Miombo ecoregion (Chidumayo 1997). The Miombo ecoregion has the highest rate of deforestation in the tropics as a result of increasing human population and economic dependence on natural resources (Campbell et al. 2007).

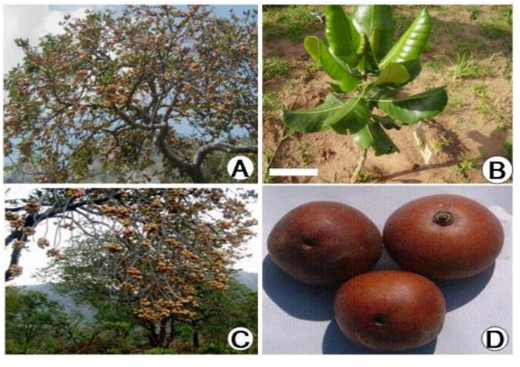

Figure 9. *Uapaca kirkiana* (A) fruiting tree; (B) grafted trees growing at Makoka Research Station in Malawi (two years of post-grafting); (C) a tree with heavy fruit load; (D) mature fruits. (Chawafambira et al. 2020)

Figure 10: Natural range of distribution of wild loquat (U. kirkiana) (source: B. Kokou)

3.4. Importance of *Uapaca kirkiana*

Uapaca kirkiana fruits make a significant contribution to food security, particularly for rural people. They have a considerable potentiality for the improvement of economic security Miombo woodlands (Akinnifesi et al. 2006). Fruits are available when other foods are scarce (Akinnifesi et al. 2004). Consequently, they serve as food reserves during seasonal food shortages during the rainy season, from November to February (Akinnifesi et al. 2006; Akinnifesi et al. 2004; Maghembe et al. 1992; Ngulube et al. 1995). The fruits are widely traded in the Southern Africa countries. They are eaten fresh and processed into juice, jam, and a variety of wines. They are highly valued indigenous fruit trees of the Miombo woodlands and are among the most preferred fruit by communities in southern Africa (Maghembe et al. 1998; Ramadhani 2002). Surprisingly, there is no known commercial cultivation of *U. kirkiana.* All fruit currently marketed comes from wild populations. Recent studies in Malawi and Zimbabwe have shown that the availability of indigenous fruits, especially *U. kirkiana*, reduces the probability of household poverty during a seasonal food shortage by 33% (Mithofer et al. 2006). The *U. kirkiana* trees are also hosts to edible mushrooms that live in a symbiotic association with the trees (Ngulube et al. 1998). The tree and its fruits are also a source of income for the rural communities in southern Africa. In Malawi and Zambia, the fruit is used to make wine and gin and is sold at roadside stalls and in some local markets (Maghembe et al. 1992). The wood of *U. kirkiana* trees also has a high market value for making beehives (Msola 2007).

3.5. Production and cultivation

Widespread cultivation of *U. kirkiana* is limited by lack of knowledge on its biology, ecology, propagation, and management of the tree (Kwesiga et al. 2000; Maghembe et al. 1998). Research at the World Agroforestry Centre in southern Africa has addressed U. kirkiana Domestication by studying factors related to tree selection, establishment, and management, both on-farm and post-harvest, and for market development. Propagation has been based on conventional techniques including seedling, grafting, and air-layering (Akinnifesi et al. 2004). A need has been identified for the development of micropropagation to enable mass multiplication of superior cultivars.

Germplasm of 16 *U. kirkiana* trees was collected, characterized and established in Malawi, Mozambique, Tanzania, Zimbabwe, and Zambia (Kwesiga et al. 2000). This was done with the ultimate aim of domestication. Domestication of *U. kirkiana* is necessary. however, several processes are needed. These include the selection and breeding of superior tree from different provenances, the development of reliable propagation protocols, multiplying and disseminating of germplasm as well as developing orchard management techniques (Kang and Akinnifesi 2000). These processes are necessary to capture superior germplasm onto farmland. Domesticating *U. kirkiana* fruit trees will benefit subsistence farmers through income generation and improved nutrition. For good seed quality, fruits should be collected before natural drop (Ngulube and Kananji 1989). Seed processing involves manual removal of the fruit skin and seed separation of the seeds from the mesocarp by hand washing in water followed by air or sun drying. Small samples can be processed manually, but large quantities may require a depulping machine. The seed of *U.kirkiana* is short-lived. Cold storage does not prolong viability (Maghembe et al. 1994; Ngulube and Kananji 1989). For best germination results, temporary cold storage, if required, should not exceed four weeks. Once processed, the seed should be dispatched for sowing.

3.6. Genetic and population diversity of *Uapaca Kirkiana*

In southern Africa, particularly in Malawi, research has focused on the genetic and morphological diversity of *Uapaca Kirkiana* (Mwase et al. 2006). Genetic and demographic and trait features define the variability of a population (Luck et al. 2003). Population richness, distribution, genetic diversity, and size of a population are the descriptive features of diversity. Population richness is a measure of the number of populations in a locality, while distribution explains how the populations are spread out over an area. Populations can be uniform, clustered, or randomly distributed (Turchetto et al. 2016). The size of a population size is determined by the number of individuals in a population. Genetic differentiation occurs within and between populations and is determined by the amount of genetic diversity. Greater genetic diversity, allows populations to adapt better to ecological changes (Jump et al. 2009). Several studies have used the above traits to assess the extent of diversity within a group of individuals. Luo et al. (2019) assessed the genetic diversity based on allelic characteristics such as expected heterozygosity (*He*), polymorphism information content (PIC), and minor allele frequency (MAF). In another study conducted by Baloch et al. (2017), genetic diversity was determined by calculating the genetic distance among the landraces and then conducting a Neighbour Joining (NJ) tree analysis based on the genetic distance matrix. On the other hand, Mahboubi et al. (2020) assessed genetic variability based on PIC, genetic distance, and cluster analysis using the NJ dendrogram.

3.7. Ecology of *Uapaca kirkiana*

Uapaca kirkiana is naturally found in south of the equator covering Angola, the Democratic Republic of Congo (DRC), Burundi, Tanzania, Malawi, Mozambique, Zambia and Zimbabwe (Akinnifesi et al. 2006). . Its didtribution at low elevations has been reported on the shores of Lake Malawi, while its presence at high elevations has been reported in the highlands of Benguela in Angola, Mbeya in Tanzania, and Mbala in Zambia Ngulube et al. (1995). The whole range of *U. kirkiana* broadly experiences a main dry season of 5-7 months, with a mean annual rainfall between 500 and 1400 mm. Mean temperature ranges from 18 to 29°C, with frequent frosts in the most southerly areas of the range (Ngulube et al. 1995). The tree may occur in extensive pure stands in deciduous woodlands, upland wooded grasslands, and along streams, often on skeletal soils at altitudes of 500-2000 m (Ngulube et al. 1995). It has been used as an indicator of poor soils as it usually occurs in soils with low exchangeable cations and low inorganic matter and macronutrients such as nitrogen, phosphorus, and potassium.

U. kirkiana grows on ferruginous or ferralitic soils that are generally sandy or gravely with good drainage. The species is absent in poorly drained, heavy, and clay soils (Ngulube et al. 1995). According to White's framework, *U. kirkiana* is a species typical to the Zambezian regional centre of endemism and the adjacent transitional centre, the most notable being the Guineo-Congolian and Zambezian regions (Ngulube et al. 1995). It is abundant and widespread in mixed communities of Brachystegia-Julbernardia woodland vegetation. It is usually a dominant or codominant species and is gregarious, forming dense groves. In high-rainfall areas (>1200 mm) it forms pure stands with either closed or open canopies, becoming semi deciduous forest with very sparse ground flora (Ngulube et al. 1995). Bush fires, a typical feature of the miombo woodlands, will affect the young coppice shoots and seedlings, especially when the fire occurs late in the dry season. Fully grown *U. kirkiana* has been said to be moderately fire-resistant (Ngulube et al. 1995). Its fire tolerance has also played a role in the succession of miombo woodlands. *U. kirkiana* was one of the species found occupying an intermediate successional stage between fire-tolerant woodland and fire-sensitive dry evergreen forest (Ngulube et al. 1995).

The main species associated to *U. kirkiana* are Julbernardia and *Brachystegia spp*., *Parinari curatellifolia*, *Pericopsis angolensis*, *Pterocarpus angolensis,* and other Uapaca species (Ngulube et al. 1997). Other plants include *Annona, Burkea, Combretum, Ochna, Ximenia, Vangueria, Lannea discolor, Diplorhynchus, Dalbergia nitidula, Bridelia* and *Pseudolachnostylis maprouneifolia* (Ngulube et al. 1995). Studies that have given quantitative information on the relative abundance of *U. kirkiana* in plant populations are few, and the information given is mostly on the dominant height, basal area, or the number of stems per unit area. Ngulube et al. (1995) give a range of 54-75% representation of Uapaca in natural stands. Low values of 10-27% as well as high values of up to 90% in pure stands have been reported (Chidumayo 1987).

3.8. Ecosystem functions

The most notable important feature of *U. kirkiana* is its association with ectomycorrhizas, some of which have a significant impact on the livelihoods of communities living near the forest where this species grows. Ectomychorrizas are conspicuous on roots at 5-10 cm depth and associations of endo-ectomychorriza have also been reported on the species (Thoen and Ba 1989). Amanita, Cantharellus, Lactarius, and Russula constitute the most common genera of fungi that typically form ectomycorrhizas, especially in the Uapaca-Brachystegia miombo woodlands (Ngulube et al. 1995). Ramachela (2006) recently studied the ecological interactions involved in the establishment and growth of the natural woodland of *U. kirkiana* in Zimbabwe. The study showed that soil pH and potassium had significant effects on mycorrhizal diversity. Several insects, some of which are serious pests, feed on *U. kirkiana* (Sileshi 2014). In winter, the tree is host to the edibles stinkbug *Encosternum delegorguei* (Hemiptera), which in Malawi and Zimbabwe is sold for cash in the market and is an important source of protein and money. Ngulube et al. (1995) have noted associations with vertebrates arising from their role as seed dispersers as they feed on the fruits. The interaction with the natural vertebrate fauna is due to browsing animals such as elephants and eland and the feeding on the fruits by monkeys and baboons, which probably also play a major role in dispersal. As a dominant or codominant tree of the miombo vegetation in hilly sites, it is useful in watershed management and the control of erosion. The tree also improves the microclimate within the canopy because of its dense rounded crown.

3.9. Biology

Uapaca kirkiana is dioecious and the unisexual inflorescences originate from axillary positions among the leaves or more often below them on the second or third season's wood of the branchlets. The spatial distributions of male and female trees in natural populations are largely unreported. In some Zambian populations, male and female reproductive individuals are randomly distributed with a male: female ratio of 1:1, and a mean distance of 11.1 m between the male and female individuals was recorded (Hans and Mwamba 1982). Similarly, a sex ratio of 1:1 in mature *U. kirkiana* trees has been reported in Malawi (Ngulube 2000). Pollination is presumed to be by insects. The most common and diverse groups of insects include bees (Apidae), flies (Syrphidae), beetles (Lagriidae, Chrysomelidae, and Melolonthidae), ants, and wasps. Butterflies are less common but moths are potential pollinators. Flowering coincides with the onset of the rainy season (October/November), and the period extends over the entire 5-6 months of the rainy season. Flowering intensity is variable throughout the period, with the greatest proportion of trees flowering between January and March (Ngulube 1996). Male trees flower earlier than female individuals. Bud development takes about 16 days for male flowers and twice as long for female flowers. During a thesis, female flowers remain open 10-14 days whereas male flowers shrivel within 3-7 days of a thesis. Male flowers have a mild but non-distinctive scent while female flowers have no detectable odor. About 45% of female inflorescences abort (20.7 and 24.8% during the bud and the thesis stages, respectively (Ngulube 1996). *Uapaca kirkiana* fruit is described as drupaceous and borne on a thick, short peduncle, usually less than 10 mm long. The fruits are set between January and February and mature in August and November (Mwamba 1995). Fruit production varies between harvests. Fruit loads exceeding 2000 fruits per tree have been reported in Zaire, Zambia (Mwamba 1995) and Malawi (Akinnifesi et al. 2004). Depending on tree size, there is a variation in fruit load between trees within populations. There is also seasonal variation in fruit production within and between populations in the miombo. The average number of fruits per tree has also been shown to be variable between different tree sizes and even in the same size class. Short trees with small diameters and crowns have fewer fruits than larger trees. The physiological basis for these differences is presumably the large number of available carbohydrates resulting from high photosynthetic activity in large trees (Chirwa and Akinnifesi 2008) and variation in crown vigor between trees in the same size class. The differences reported cannot be attributed to environmental factors because the trees were growing within the same stand, indicating a possible genetic influence.

The mature fruit is described as yellow, yellow-brown, or brown and is 3.3 cm in diameter; it is round with tough skin. Additional fruit color variations have been documented to include cream and brownish-red (rufous) (Mwamba 1995). The pulp is yellow and sweet with a pear-like taste and contains three or four seeds. In some natural populations, there are some slight color differences between individual trees: brownish-yellow and reddish (Hans and Mwamba 1982). The fruit dimensions fall within the 2-4 cm range in length and breadth. There are variations in fruit size, skin, pulp content, and seed weight and volume between and within populations and trees (Mwamba 1995). At maturity, each fruit may weigh 5-50 g. The amount of pulp ranges from 0.2 to 30 g but this varies among sites (Kwesiga et al. 2000). Fruiting is biannual, i.e. alternate fruiting seasons. Some trees produce a mixture of small and large fruits while others habitually produce large or small fruits. At maturity, a hard, thick exocarp encloses a thin, yellow mesocarp about 1.5 mm thick when dry (Radcliffe-Smith 1988). The fruit contains three to five seeds (pyrenes), but three or four is the most common number; they are generally whitish, cordate, carinate, and apiculate with a tough fibrous clerotesta. The four-seeded fruits are larger, have thinner skins, and contain the most pulp (Mwamba 1995). The pulp accounts for 39-45% of the fruit weight. *Uapaca kirkiana* is dispersed by animals; the sugary pulp is attractive to a wide range of mammals and birds. In the natural environment, a large number of birds, ungulates, and primates feed on the pulp, dispersing the seed (after sucking the pulp) as they move from the seed source (Seyani 1996). The seed is white, with a rather brittle seed coat. One side is almost flat and on the opposite side, there is a longitudinal ridge terminating in a sharp edge at the base. The seed has an inner membrane, an endosperm, and two leafy green cotyledons. There are 2500 seeds per kilogram. The seed has no dormancy period and once dispersed, it germinates readily. Fruit maturation and fall coincide with the rainy season, ensuring the immediate availability of appropriate germination conditions. In Zambia, up to 2039 and 1183 new and old seedlings per hectare, respectively, were recorded in a natural population (Mwamba et al. 1992). Seedling growth is better in the open than in the closed canopy. Germination is intermediate between epigeal and hypogeal. The seed coat cracks and the radicle protrudes from the scar end and develops into a taproot. The seed coat splits longitudinally into equal halves and the two cotyledons unfold and expand greatly. Germination is fairly uniform, reaching 30% after 4 weeks and 90% after 6 weeks. The seed does not require pretreatment, but soaking in cold tap water overnight hastens germination (Ngulube 1996). Up to 100% germination has been achieved at Makoka nursery (ICRAF).

3.10. Propagation

Until recently, vegetative propagation techniques have been a constraint to the domestication of indigenous fruit trees. Jaenicke et al. (1998) reported a graft take of less than 10% for *U. kirkiana*. However, these problems have been overcome and grafting success rates are now relatively high (80%) (Akinnifesi et al. 2002). *U. kirkiana* is amenable to clonal propagation and field management. Clonal propagation was used to capture superior *U. kirkiana* clones in Malawi using a participatory approach (Akinnifesi et al. 2002). Tree orchards of superior trees established at Makoka, Malawi, started to bear fruits after 2 years and fruiting became stable after 4 years, with a fruit load as high as 460 in some clones. Rootstocks are propagated from seeds (seedling rootstocks). A medium made of 75% forest soil and 25% sawdust has been shown to produce better soil media for rootstocks. A graft of 80% for *U. kirkiana* using a wedge or splice technique can be obtained (Akinnifesi et al. 2002). The time of grafting and the skill of the grafter have overriding effects on the grafting success of Uapaca. Scions collected and grafted between October and December are best (>80% take), whereas grafting done between January and August has resulted in less than 30% graft take (Akinnifesi et al. 2006; Akinnifesi et al. 2004). The method used to store the scion is a major factor that can affect the lifespan. Research in Malawi showed that keeping scions at room temperature was superior to other storage methods (sand, wet paper, cooler box). Air-layering has the potential for propagating plants with high vigor, and up to 63% rooting of marcotts has been achieved in the wild (Akinnifesi et al. 2002). However, it is still a challenge to achieve good survival of established marcotts. The survival of the rooted propagules in the nursery and ramet survival in the field may decline with time because of the difficulty of tap root development, fertilizer, and mycorrhiza requirements (Akinnifesi et al. 2004). Tissue culture research has also proved to be promising for detecting early stock/scion compatibility in *U. kirkiana* (Mng'omba et al. 2007). The current effort involves the use of tissue culture to determine scion-rootstock compatibility. Compatibility differs between heterografts and homografts, and also between species, provenance, and clones (Mng'omba et al. 2007). However, excessive accumulation of phenolic compounds remains a challenge when using tissue culture to multiply *U. kirkiana*.

3.11. Indigenous knowledge on utilization aspects of U. kirkiana plant parts from Malawi

The utilization of indigenous plants, such as *Uapaca kirkiana*, offers significant contributions to household agricultural production by providing essential nutritional resources, medicinal products, fodder, and materials for various uses. This section synthesizes information from various studies to highlight the multifaceted role of *U. kirkiana* in Malawi and in similar contexts. According to Mukerji (1995) and Tchatat et al. (2006), underutilized food plants are invaluable in supporting household food security, particularly during lean periods. The FAO estimates that 80% of people in developing countries rely on plants for their health and dietary needs. For rural populations, plants like *U. kirkiana* are integral to daily life, fulfilling nutritional, medicinal, and cultural roles.

Nutritional and medicinal uses: In Malawi, indigenous fruits such as *U. kirkiana fruits* are critical for nutrition and food security and provide income for local populations (Akinnifesi et al. 2008). The incorporation of wild fruits into diets could significantly reduce hunger and malnutrition (Bvenura & Sivakumar, 2017; Tuyizere et al. 2021). *U. kirkiana* fruits are rich in nutrients, providing essential vitamins and minerals. The nutritional composition of the fruits includes high water content, crude protein, fats, fiber, and significant amounts of potassium, magnesium, and iron (Saka et al. 2007). Additionally, the fruits have medicinal uses, such as treating diarrhea and boosting the immune system, although excessive consumption can lead to adverse effects like stomach bloating (Ntupanyama et al., 2008b). According to Fanshawe (1972) and Seyani (1996), the leaves, bark, and roots of *Uapaca kirkiana* are widely used in the preparation of traditional medicines. An infusion of the roots is used to treat indigestion and dysentery. The leaves are an effective cockroach repellent in households. However, information on the chemical extracts and the effectiveness of these treatments is not available. Ngulube's (1996) study demonstrates the production of a local blue dye from the roots of *U. kirkiana* and a salt obtained from wood ash for seasoning food. The fleshy fruits contribute substantially to animal feed, albeit for a short period (Ngulube 1996). The new growing leaves of *U. kirkiana* at the end of the dry season is used by cattle as fodder in the absence of more palatable alternatives (Kwesiga and Chisumpa 1992; Rees et al. 1974).

Cultural and social functions: Indigenous plants play a significant role in social and cultural activities. For example, traditional wines in the DRC (Loubelo, 2012) and resin from the frankincense tree in Ethiopia and Eritrea (Kidane et al. 2014) are used in social and religious ceremonies. Similarly, U. kirkiana fruits in Malawi are utilized in various cultural practices, reflecting the deep indigenous knowledge of the environment and plant management (Maroyi and Cheikhyoussef, 2017). According to Ngulube (1996), the thick and broad leaves of *Uapaca kirkiana* are used as packaging for storing processed food.

Economic contributions: *U. kirkiana* fruits contribute to household income through direct consumption and sales. These fruits are marketed fresh and processed into products like jams, fruit juices, and fermented beverages (Akinnifesi et al. 2006). The economic value of these fruits extends to making traditional medicines, repelling household pests, and serving as animal feed (Seyani, 1996; Ngulube, 1996).

3.12. Economic value of *U. kirkiana* fruit in Malawi

The economic potential of *U. kirkiana* is substantial, particularly in reducing poverty and enhancing food security. Wild fruits are often harvested and sold during low agricultural income seasons, making them crucial for household incomes (Akinnifesi, 2008). In Zambia, for example, the marketing of *U. kirkiana* fruits provides significant income for purchasing essential household items (Moombe et al. 2009). Despite their importance, wild fruits are often overlooked by policymakers.

Income Generation: The trade of *U. kirkiana* fruits supports rural livelihoods by generating income that is used for food, school fees, and other necessities. The fruits are sold fresh or processed into various products like wine, which are marketed locally (Ngulube et al. 1995). The potential for commercial cultivation remains untapped, with all current markets relying on wild populations (Moombe et al. 2009). For example, individuals could earn enough money from trading *Uapaca kirkiana* and other fruit products to build a new house and purchase livestock. Despite this, the process of development of the commercial sector seems extremely slow. Lack of policy and therefore prioritization by the government may be one of the main causal factors, along with the low demand for this fruit. However, even if traders earn very little from the sale of the fruit, the value attached to the proceeds is high. Indeed, for those living in abject poverty, even meager disposable income can mean the difference between life and death. Moombe et al. (2009), highlight in their study that traders indicated that *Uapaca kirkiana* trade contributes to a large extent to household income. Ramadhani and Schmidt (2008) also confirmed this observation in Zimbabwe, where fruit traders use money from the fruit trade to subsidize their household incomes. Emerton (1998), demonstrates the importance and role of wild edible products, particularly the fruits of *Uapaca kirkiana*, in food security in times of famine. In these arguments, he emphasizes that the marketing of *Uapaca kirkiana* fruits also employs many people. According to Sunderland et al. (2004) and Haq et al. (2008), this income is necessary to purchase basic household items, etc. following: paying house rent, transportation costs, agricultural inputs, meeting social desires, paying school fees, or providing seasonal income when agricultural labor needs are low. Mithöfer (2005), showed that although the gross margins of native fruit trees are lower than those of livestock and crop production, the labor return is higher. **Employment opportunities:** The wild fruit trade not only supports households directly involved in collection and sales but also creates employment opportunities within the local economy (Emerton, 1998). Processing wild fruits can further enhance income generation and reduce vulnerability to poverty (Mithofer et al. 2006).

3.13. Local ecological knowledge and stand structure of *Uapaca kirkiana* in Malawi

Local ecological knowledge of *U. kirkiana* is crucial for its conservation and sustainable use. Uapaca species are dominant in certain vegetative areas in Malawi and play an essential role in ecological functions such as watershed protection (Seyani, 1996). **Genetic and morphological diversity:** Studies on the genetic diversity of *U. kirkiana* have shown that higher genetic diversity correlates with better adaptation to ecological changes (Mwase et al. 2006; Turchetto et al. 2016). Domestication efforts are necessary to harness superior genetic traits for cultivation (Simons and Levin, 1997).

Ecological roles: *U. kirkiana* trees provide shade, support beekeeping through nectar production, and are associated with mycorrhizal fungi that improve soil fertility (Högberg, 1986; Storrs, 1979). Ecological significance: Ecologically, Uapaca species are vital for watershed protection and maintaining biodiversity. U. kirkiana trees provide habitats for various wildlife and are associated with mycorrhizal fungi, which enhance soil fertility (Högberg, 1986; Pegler & Piearce, 1980). These ecological roles are vital for maintaining the health of the miombo woodlands where they are prevalent. *Uapaca kirkiana* provides good shade in homesteads and farms during the dry and hot season. As a dominant or co-dominant tree of the miombo vegetation in hilly sites, it is useful in watershed management. *Uapaca kirkiana* also provides ideal habitats for fauna and flora. It serves as a host to a hemipterous bug, *Encosternum delegoruri*, during winter (Makuku et al. 1992). These bugs benefit from the protective shelter and the microclimate (morning dew) generated by the dense crowns of the trees. In Malawi and Zimbabwe, these bugs are sold for cash in markets and thus constitute an important source of protein and income for rural communities. The flowers of *U. kirkiana* are a source of bee forage with a good honey flow (Storrs 1979) and thus play an important role in apiculture within the miombo woodland vegetation.

In natural stands, *U. kirkiana* forms an association with mycorrhizae, which is an important feature of forest and woodland ecology (Högberg 1986). Amanita, Cantharellus, Lactarius, and Russula are the major genera of fungi that typically form ecto-mycorrhizas within the miombo woodland vegetation (Pegler and Piearce 1980; Williamson 1981). These fungi, belonging to the Basidiomycetes, are widely collected and consumed or sold in markets during the rainy season. Some are dried and stored for later use or sale, and a limited market for freeze-dried ones also exists. The fungi supply the trees with phosphorus and other nutrients, most of which are utilized by the plants and recycled, but some are left to enrich the soil. Since natural sources of phosphates are finite. *U. kirkiana* may be an important agroforestry tree in maintaining soil fertility in degraded sites, as mentioned in some reports (Kwesiga and Chisumpa 1992; Minae 1994).

3.14. Spatial distribution of current and future potential habitats of *U. kirkiana* in the face of Climate Change challenges in Malawi

Climate change poses significant challenges to the distribution and survival of *U. kirkiana*. Rising temperatures and changing precipitation patterns are expected to impact the species' habitats (Corlett and Westcott, 2013; Stocker et al. 2014). **Climate Change impacts:** Studies predict a contraction in suitable habitats for *U. kirkiana* by 2050 and 2070, primarily due to its semi-deciduous to evergreen nature, which requires higher precipitation (Jinga et al. 2020; Folega et al. 2023). This reduction in habitat suitability is consistent with findings for other tree species in the region (Moat et al. 2019; Bogawski et al. 2019). **Conservation strategies:** To mitigate the effects of climate change, both in situ and ex situ conservation strategies must be developed. These strategies should integrate traditional practices and local knowledge to enhance the resilience of *U. kirkiana* populations (Amahowe et al. 2016; Bufford and Gaoue, 2015).

4. Conclusion

The indigenous knowledge on *U. kirkiana* underscores its importance in nutrition, medicine, culture, and economics in Malawi. The species' ecological role and the challenges posed by climate change necessitate comprehensive conservation and management strategies. By integrating traditional knowledge with scientific research, sustainable utilization and conservation of *U. kirkiana* can be achieved, benefiting both local communities and broader ecological systems. The review highlights *U. kirkiana* as a plant with significant potential, supported by various therapeutic, economic, social, and climate change properties reported in the review. The plant is also known for its abundance of important phytochemical compounds and constituents, which contribute to its observed pharmacological activities. These results suggest that the species is promising and requires special attention. In Africa, the state of knowledge on the loquat (*U. kirkiana*) shows a lack of research on its use and value, socio-economic importance, distribution and structure of the species, the impact of climate change on the species, and domestication. Little research has been carried out into its use, distribution, ecology, and economic value, but no studies have been carried out into its vulnerability, which is the scientific information needed for sustainable management of the species.

U. kirkiana plays an important role in the life of people in Africa and around the world. It is a tree with multiple uses. Scientific work has focused on topics relating to the biological and pharmacological activities, history, and description of the species, as well as its sylviculture, multiplication, and germination. To a lesser extent, this research has also focused on aspects of use and valuation, the impacts of climate change, and the distribution and population structure of the species. Further studies will be needed to fill the gaps that are essential for the development and promotion of *U. kirkiana*. Endogenous knowledge of uses and management, and the species' vulnerability to anthropogenic and climatic pressure, deserve to be investigated. This study will be followed by more research that will allow us to answer a few questions: 1. Is there marketing data: marketing channel, revenue, and players? 2. What is the extent of use of plant parts of the species? Is the use of plant parts sustainable? 3. Is the species vulnerable in its habitat? If so, what factors are responsible for it, and to what extent is it vulnerable to anthropogenic threats? 4. What is the state of regeneration, population structure, and demographic characteristics?

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