EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 4 (Special Issue 2): August 2023

Unlocking the economic potential of *Hyphaene* species known as *mikoche* in Tanzania

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Abstract

Hyphaene, commonly referred to as *mkoche* (Plural *Mikoche*) and in Swahili, is a species belonging to the Palmae (Arecaceae) family and is found in various parts of Africa, including Maputaland coastal plains in southern Mozambique, Turkana, Samburu, and Marsabit in Kenya, and the coastal regions of Tanzania and Kenya. Despite its widespread presence and resistance to climate change, the economic potential of *mikoche* in Tanzania has yet to be fully unlocked. Therefore, a comprehensive literature review was conducted to identify the various uses of the *Hyphaene* tree globally, which could further be fully exploited within Tanzania. The findings revealed that the fruit of the *Hyphaene* tree is a good source of fibre, antioxidants, B-complex vitamins, essential minerals, monosaccharides, essential oil, and flavonoids, which are important compounds for human nutrition and health. In addition, *H. coriacea* produces edible nuts and palm wine in Maputaland coastal plains in KwaZulu-Natal, South Africa, and *H. coriacea* is known to produce edible oil from its nuts. Furthermore, the tree is used as a construction material for shelter, and its leaves are used to make woven products such as baskets, mats, and hats due to their strength and fibre length. Therefore, with favourable conditions for *mikoche* growth in Tanzania, particularly in the coastal regions, *mikoche* can contribute to the economy by using its various parts to produce food and non-food products. However, further research is required to understand the diversity of uses, consumption constraints, and opportunities for *mikoche* as a natural resource in Tanzania.

Keywords: *Hyphaene species, economic potential, food and nutrition, natural resource, climate change*

Received: 27/06/23
Accepted: 06/07/23
Published: 14/09/23

Cite as: *Ahmed et al, (2023)* Unlocking the economic potential of *Hyphaene* species known as *mikoche* in Tanzania. *East African Journal of Science, Technology and Innovation 4(special issue 2).*

Introduction

Hyphaene is among the palm species, a native tree of Sub-Saharan Africa (SSA) and is usually wild or semi-cultivated (Martins & Shackleton, 2017). *Hyphaene* plants are well-adapted to arid and semi-arid environments, making them suitable crops for areas with limited water and other resources (Abdel-Rahman *et al.*, 2018; Fanshawe *et al.*, 1966; Pan *et al.*, 2006). Additionally, they require minimal inputs, such as fertilisers and pesticides, making them a more sustainable option than other cash crops (Gupta & Kushwaha, 2011). Thus, the *Hyphaene* tree has the high economic potential to overcome the problems related to natural resources in SSA due to its food and non-food uses in various communities. For example, its foliage is in high demand for making baskets (Belal *et al.,* 1998; Lokuruka, 2008; Watson & Dlamini, 2003), and its sap is used for wine making (Nguyen *et al.*, 2016), providing supplementary income to local communities. In addition, various parts of the tree are also used in traditional medicine to treat various ailments (Bello *et al.,* 2017; Khalil *et al*., 2020; Shalaby & Shatta, 2013). Moreover, the nut from *Hyphaene Coriacea* is reported to produce edible oil (Ogbole & Ademoh, 2021). Furthermore, a fatty acid profile study by Lokuruk (2008) revealed that *Hyphaene coriacea* nut oil had higher oleic acid content than coconut and palm kernel oil, hence more unsaturated. Therefore, exploitation of the *Hyphaene* tree has great potential to solve natural resource scarcity.

Natural resource scarcity and increased cost of life are interrelated phenomena that can significantly impact individuals, communities, and economies. When natural resources become scarce, the prices of those resources tend to increase, reflecting the increased demand for a limited supply. For example, there has been an increase in the world price of various goods, including food and ingredients worldwide, since mid-2007 (Minot, 2011; Ozili, 2022; Singh *et al*., 2021; Zezza *et al.,* 2009). The driving factors behind price increases are climate change, rising petroleum prices, highly interconnected with food prices through fertiliser and transport costs and increased demand from the emerging biofuels market in the United States and Europe (Minot, 2011; Zezza *et al.,* 2009). Moreover, the ongoing Russian-Ukraine war (Ozili, 2022) and an outbreak of COVID-19 (Singh *et al.,* 2021) highly contributed to the recent global food and energy prices. The increase in the world price of food and ingredients, including edible oil, has shown several economic and social impacts on different countries (Minot, 2011; Zezza *et al*., 2009). Potential impacts include increased inflation, malnutrition due to lower food consumption, and poverty (Dessus *et al*., 2008; Minot, 2011).

On the other hand, climate change significantly impacts natural resources, including land, water, forests, wildlife, and livestock (Dixon *et al*., 2003). Fuel emissions are a major contributor to climate change. When we burn fossil fuels, such as coal, oil, and firewood, gas, carbon dioxide and other greenhouse gases are released into the atmosphere (Kumar & Pooja, 2020). These gases trap heat from the sun and prevent it from escaping back into space, causing the Earth's temperature to rise (Mintzer, 1990). As a result, climate change is causing changes in temperature and precipitation patterns, which can affect water availability, crop production, and the ecosystem (Dixon *et al*., 2003; Kumar & Pooja, 2020). This leads to water scarcity, droughts, floods, and wildfires, which can impact natural resources and the communities that depend on them (Kumar & Pooja, 2020; Watson *et al*., 1998). Furthermore, climate change is causing changes in rainfall patterns, temperature, and humidity, which can impact crop yields, reduce soil fertility, and increase pests and diseases (Dixon *et al*., 2003; Kumar & Pooja, 2020). This can significantly impact food security and livelihoods, particularly in developing countries.

To address the impacts of natural resource scarcity and increased cost of living, diversifying sources of natural resources and developing alternative resources can help to reduce dependence on a limited supply and promote resilience in the face of scarcity (Dixon *et al.*, 2003). Moreover, improving resource efficiency through technologies and practices, such as clean energy efficiency, can help to reduce demand for natural resources and limit price increases (Kumar & Pooja, 2020). For example, to address the issue of fuel emissions and climate change, research and development to transition to cleaner forms of energy, such as bioethanol, is in progress (Murshed, 2022). Currently, bioethanol is intensively produced from corn and sugarcane. However, an agricultural expansion for crops such as corn and sugarcane can result in deforestation, which is one of the main factors causing climate change (Gupta & Kushwaha, 2011; Kumar & Pooja, 2020). Therefore, it is important to take action to mitigate the impacts of climate change on natural resources by promoting sustainable land and cleaner energy such as bioethanol. Section 3.2 discusses the potential of using sap from the *Hyphaene* tree for bioethanol production. Therefore, this paper is anticipated to act as an eye opener to the public within the country and across borders regarding its potential and prompt its exploitation for various economic benefits, including food and nutritional benefits.

Materials and Methods

A comprehensive literature review was conducted using search engines, including Google Scholar, Core, EBSCO, Europe PMC and biorxiv, to identify the origin, various uses and constraints of the *Hyphaene* tree globally and in Tanzania.

Results

Table 1. Summary of the economic importance of the Hyphaene trees

Part	Uses	Country	Reference
Fruit	• Eaten fresh or processed into juice, nectar, or wine. • Dried fruit powder is used as a flavouring agent for food or to make a mildly alcoholic drink by adding water and leaving it to stand. • Dried fruit powder is mixed with wheat flour to produce composite flour with improved dough rheological properties. • Natural source of dye extract.	Senegal, Kenya, Egypt, Sudan, Mozambique and Zimbabwe	El-Beltagi *et al.*, 2018; Abdel-Rahman *et al.*, 2015; Aboshora *et al.* 2015; Mohammed & Uthman, 2015; Abdel-Rahman *et al.* 2014; Eldahshan *et al.*, 2009
Sap	• Consumed fresh or fermented to wine. • Palm wine is a traditional medicine to treat malaria, measles, and jaundice and promote breast milk production in nursing women. • Evaporated to produce sugar	Senegal, Kenya, Mozambique, Zimbabwe, Nigeria and Sri Lanka	Sarma *et al.*, 2022; Martins and Shackleton, 2018; Okon and Okorji, 2014; Bassir, 1968
Nuts	• They are roasted or boiled to remove the shell and then consumed as a snack or ingredient in various dishes. • Source of edible oil for food and cosmetic industries.	The Republic of Congo, Kenya and Malaysia	Ossoko *et al.*, 2019; Lokuruka, 2008
Leaf, bark, and roots	• Aqueous leaf extract of *H. thebaica* has potential applications in pharmacology as anticancer, anti-inflammatory and antibacterial. • Leaves, bark, and roots treat various ailments, including digestive problems, skin conditions, bilharzia and respiratory problems. • The dried leaves make various products, including baskets, mats, hats, and other woven items.	Nigeria, Mozambique and South Africa	Ekalo, 2022; Martins and Shackleton, 2021; Khalil *et al.*, 2020; Bello *et al.*, 2017; Shalaby and Shatta, 2013; Salah *et al.*, 2011; Foote *et al.*, 2003
Wood	• Wood is used as construction materials, furniture-making, firewood and charcoal production.	Mozambique	Martins and Shackleton, 2021

Origin and distribution of Hyphaene trees

Palms are monocotyledonous plants belonging to the family Palmae (Arecaceae), which comprises over 217 genera and 2500 species (Zona, 1997). Among the palms are the African doum palms, represented by the genus *Hyphaene*. Doum palms are known as *mikoche* in *Swahili*, characterised by their distinctive swollen trunks and large, feather-like leaves (Khalil *et al.*, 2020; Orwa et al., 2009). The *Hyphaene* trees need rainfall from 100 to 600 mm and are tolerant to a wide range of soils and very high temperatures (Abdel-Raman *et al.*, 2018). The trees are native to Africa and the Arabian Peninsula (Abdel-Raman *et al.*, 2018; Fanshawe *et al.*, 1966; Pan *et al.*, 2006). The *Hyphaene* genus, however, spreads throughout the rainy tropics in the world in high-rainfall woodland savanna, flood and mountain regions and to a limited extent in dry regions (Abdel-Rahman *et al.*, 2018; Couvreur & Baker, 2013; Hassan, 2017). In the Arabian Peninsula, they are found in arid regions, including Oman and Yemen (Abdel-Rahman, 2018).

Ethnobotanical studies on morphological variations in tropical plants in Benin revealed that local peoples identified morphotypes of the *Hyphaene* species based on the physical characteristics (Assogbadjo *et al.*, 2011). For example, several local trees from different habitats, differing in fruit size and quality, have been recognised (Seltmann *et al.*, 2007). Therefore, the fruit appears to be the most popular discriminatory feature of the *Hyphaene* species (Moussa *et al.*, 1998). In Africa, there are around ten *Hyphaene* species distributed in various regions, including the savannas, woodlands, and coastal regions (Idohou *et al.*, 2015; Martins & Shackleton, 2021). For example, *Hyphaene coriacea* is abundantly available on sand dunes and along creeks behind mangroves from Somalia to Mozambique, South Africa and Madagascar (Martins & Shackleton, 2021) and Turkana, Samburu and Marsabit of Kenya (Lokuruka, 2008). In addition, *Hyphaene thebaica* is widely available in Djibouti, whereas *Hyphaene compressa* is commonly found in the coastal region of Tanzania and Kenya, and *H. petersiana* is found on the shores of Lake Eyasi of Tanzania (Omire *et al.*, 2022; Stauffer *et al.*, 2018).

Discussion

The socioeconomic importance of the Hyphaene trees

The *Hyphaene* genus is a unique and important component of the Arecaceae family and plays an important role in the ecology and livelihoods of the regions in which they are found (Abdel-Rahman *et al.*, 2018; Martins & Shackleton, 2022). For instance, Martins and Shackleton (2021) reported that only 32% of respondents exploited *Hyphaene* coriacea and *Phoenix reclinata* in the Maputaland coastal plains of southern Mozambique. Furthermore, another study by Martins and Shackleton (2022) reported that households adopting a palm-based strategy show between 23% and 60% lower poverty incidence than those adopting alternative strategies. The summary of the economic importance of the *Hyphaene* trees is presented in Table 1.

Food and beverages

Fruit

The fruits of the *Hyphaene* differ in appearance depending on the species. For example, the fruit of *Hyphaene thebaica* is typically yellow, orange, or red (Abdel-Rahman, 2019). The fruit is oblong (size ranges from 5.00 to 8.29 cm in length, 4.62 to 6.43 cm in width and 5.12 to 6.15 cm in thickness), has a tough, fibrous outer layer that surrounds sweet, juicy flesh (Abdel-Rahman *et al.*, 2014). The fruits contain essential micronutrients and bioactive compounds, including vitamins C and B-complex, potassium, calcium, monosaccharides, essential oil and flavonoids, which are beneficial nutrients for health (Chinnamma *et al.*, 2019; Khalil *et al.*, 2020). For example, Islam *et al.* (2022) reported up to 3% folic acid and 46% antioxidant activity mg/100g of African doum fruit. In addition, the fruit is low in fat and calories, making it a nutritious food option for those trying to sustain a healthy diet (Aboshora *et al.*, 2014).

The fruits of the *Hyphaene* trees are a significant food source for humans and wildlife in many regions of Africa and the Arabian Peninsula. The fruits are edible, especially by elephants, baboons, and donkeys, mainly agents of *Hyphaenia compressa* seed dispersal (Ekalo, 2022). The fruit is often eaten fresh or processed into juice, nectar, or wine (Abdel-Rahman *et al.*, 2015; El-Beltagi *et al.*, 2018; Eldahshan *et al.*, 2009). In addition, dried fruit is added as a flavouring agent to food (Abdel-Rahman, 2019). For example, in Senegal, the powder of *H. thebaica* fruit is applied in some industrial stuff as a source of fibre and stabiliser. Moreover, the edible part of the fruit can be crushed and milled or flaked to be mixed with flour and sugar to make *Madeda* drink (Abdel-Rahman *et al.*, 2015), while in Turkana, Kenya, the powder is used to make a mildly alcoholic drink by adding water and leaving it to stand (Abdel-Rahman, 2019). Furthermore, studies on the composite flour of milled wheat with *H. thebaica* fruit powder have shown to increase the dough's rheological properties, total phenolic, total flavonoid, and rising antioxidant action, consequently improving the overall bread quality (Aboshora *et al.*, 2014).

Conversely, the doum fruit contains several antinutritional factors and natural toxins, including tannins, phytic acid, oxalates, and saponins (Gafaar, 2010; Kolla *et al.*, 2021). For example, Aame (2016) found about 2.53 mg/100 g of tannin in doum fruit aqueous extracts. Tannins, phytic acid, and oxalates can reduce the bioavailability of iron, zinc, calcium, and other minerals. Moreover, saponins can cause gastrointestinal distress and may interfere with nutrient absorption. However, antinutritional factors and natural toxins in the fruit mesocarp may generally present in low concentrations and are unlikely to cause harm when consumed in moderation (Ojewola & Scholastica, 2006). Nonetheless, processing such as drying and cooking reduces the antinutrient contents present in food, including doum fruit (Aamer, 2016; Gafaar, 2010; Kolla *et al.*, 2021). Furthermore, the fractions of tannin and flavonoids found in doum fruit have been reported to possess antifungal and antibacterial activities (Aamer, 2016).

Palm sap and wine

Sap is a watery fluid that transports plant photosynthetic products towards various tissues of the palm tree to support growth (Nguyen *et al.*, 2016). The sap tapping method can generally be classified as destructive or non-destructive. Destructive tapping triggers the death of the tapped palm, whereas non-destructive tapping is generally done from the terminal bud, inflorescence, apical meristem or stalk of the *Hyphaene* trees (Francisco-Ortega & Zona, 2013). The yield of sap varies with the species, seasons, part of the tree and time of tapping (morning/evening). The sap can be harvested from three spathes of the same tree for up to 6 months (Foote *et al.*, 2003; Sarma *et al.*, 2022). Palm sap is rich in riboflavin, vitamin B and nicotinic acid, thereby contributing to the diet of people who use it (Sarma *et al.*, 2022). Therefore, palm sap consumption can potentially contribute to nutrients in the diet. The sap is mainly consumed fresh or as fermented wine (Martins & Shackleton, 2018; Sarma *et al.*, 2022). Generally, *Hyphaene coriacea* is favoured over *Phoenix reclinata* for palm wine production (Martins & Shackleton, 2018). Palm wine production from *H. coriacea* and *P. reclinata* is an ancient activity in southern Mozambique, Zimbabwe and other countries in East and West Africa (Foote *et al.*, 2003; Martins & Shackleton, 2018). According to (Cunningham, 1990), palm wine tapping has been practised in south-eastern Africa since the early Iron Age, around 1500 BP. Palm wine from the sap of *H. coriacea and P. reclinata* is used during the traditional ritual of libation (Martins & Shackleton, 2021).

The trade in palm wine is also an important economic activity in many areas, providing income not only to the palm tappers but also to a variety of other market chain participants (Mbuagbaw & Noorduyn, 2012; McKean, 2003; Oyewo *et al.*, 2020; Babitseng & Teketay, 2013). For example, tappers reported earning about US$1878 ± 909 per annum, which accounts for 85% ± 22% of the tappers' annual household income in Mozambique (Martins & Shackleton, 2018). However, sap tapping is destructive to the plant because tapping young stems involves removing the rosette of upper leaves and taking thin slices from the growing shoot cap (meristem) of young stems every day for several weeks to keep the sap flowing for collection (Foote *et al.*, 2003). Therefore, proper cultivation and management of the *Hyphaene* trees are required to support livelihood while ensuring the species' sustainability.

Nevertheless, palm sap is traditionally used to produce syrup and jaggery (brown sugar) by boiling fresh sap in a large pot in Sri Lanka (Everett, 1995; Francisco-Ortega & Zona, 2013). Sap from palms may contain 10 to 20% sugar, depending on the species, time of year, and extraction method (Dalibard, 1999). Fresh, unfermented sap is boiled down to produce syrup or molasses (sometimes called honey) or further refined into sugar (Francisco-Ortega & Zona, 2013). However, sugar cane has replaced palms as a source of sugar in many parts of tropical countries (Francisco-Ortega & Zona, 2013). Nevertheless, due to the increased price of sugar and demand for bioethanol production, adapting technology for sugar-making would contribute to an alternative source of sugar. Furthermore, adapting technology for producing sugar from palm sap can contribute to environmental sustainability by reducing agricultural expansion for crops such as sugarcane, which can result in deforestation (Gupta & Kushwaha, 2011).

Source of water

Generally, palm trees tend to grow close to water, including groundwater and near rivers and streams, sometimes on rocky slopes (Orwa *et al.*, 2009). Therefore, the palms have a high capacity to store water through their stems. The palm stems referred to as trunks vary considerably in dimensions and appearance among species, but generally, they are cylindrical to slightly tapered and occasionally bulging in shape (Broschat, 2013). Generally, *Hyphaene* species have dichotomising trunks whose growth is coupled with developing an independent, adventitious root system (Tomlinson & Huggett, 2012). Therefore, the trunks are characterised by high water and carbohydrate storage for plant use during the drought (Francisco-Ortega & Zona, 2013; Hodel, 2009). This stored water is a valuable resource for humans and wildlife in arid regions and other areas, especially during dry periods when other water sources are scarce. The water stored in the fibrous tissue of the trunks can be accessed by cutting the trunk (Ekalo, 2022; Francisc-Ortega & Zona, 2013). However, overutilising trunk water could result in poor growth or death of the *Hyphene* tree during drought due to reduced metabolic activities.

Nuts and oil

The nuts of *Hyphaene* species are an essential food source for humans and wildlife in many regions of Africa and the Arabian Peninsula (Abdel-Rahman *et al.*, 2014; Islam *et al.*, 2022). The nuts are typically small and hard-shelled, containing a sweet, oily kernel rich in nutrients and flavour (Lokuruka, 2008). Therefore, the nuts of *Hyphaene* are often roasted or boiled to remove the shell and then consumed as a snack or ingredient in various dishes (Ossoko *et al.*, 2019). Generally, doum nuts contain antioxidants and metabolites like tannins, saponins, steroids, glycosides, terpenes, and terpenoids (Islam *et al.*, 2022). In addition, the energy available from consuming the edible portions of the nut is approximately 1300 Kcal/100g (Lokuruka, 2008).

Generally, there is a high import of edible oils in Africa; imports grew by over 10% per year between 2006 to 2015, accounting for 34% of the continent's food imports (Olabisi *et al.*, 2021). Considering that there has been an increase in vegetable oils (soya bean, groundnut, sunflower and palm) prices for the past decades (Gilbert & Morgan, 2010), initiatives are required to stimulate demand for domestic food options that appear to be substituted for imports beyond tariffs (Olabisi *et al.*, 2021). For example, oil extraction from *Hyphaene* nuts can be an essential source of edible oil and income for local communities in many regions in SSA. It can help support sustainable development and improve livelihoods. In addition, oil is a valuable resource for the food and cosmetic industries and is exported to a range of markets around the world.

The oil can be extracted from the kernels by pressing or solvent extraction. For example, Lokuruka (2008) conducted solvent extraction of doum nuts and found that the nut has an oil content of up to 0.4 and 10.3% in the mesocarp and kernel, respectively. However, deshelling the nut for oil extraction from the doum nuts is tedious and time-consuming. To overcome that, Ogbole *and* Ademoh (2021) developed a doum palm deshelling machine with the capacity of deshelling 2376 nuts per hour and 73% efficiency compared to manual shelling. However, the designed machine is size specific for the doum palm available in Nigeria. Therefore, the machine should be modified to consider such variations because the doum nuts have different sizes due to fruit shape across geographical origins, species and seasons (Sola *et al.*, 2006).

Traditional medicine

The use of the *Hyphaene* tree in traditional medicine is based on the belief that plants contain various compounds such as saponins, coumarins, hydroxyl cinnamates, essential oils and flavonoids with medicinal properties (Aamer, 2016). In addition, studies by Bello *et al.* (2017), Khalil *et al.* (2020), Shalaby & Shatta (2013) suggested that *H. thebaica* has potential applications in pharmacology as anticancer, anti-inflammatory and antibacterial. For example, the plant's leaves, bark, and roots are used to treat various ailments, including digestive problems, skin conditions, bilharzia and respiratory problems (Ekalo, 2022; El-Beltagi *et al.*, 2018). Therefore, some studies (Bayad, 2016; Elhaj & ElBagir, 2016) suggested that blood glucose, cholesterol, triglycerides and total fat significantly decreased after eating doum fruits.

On the other hand, palm wine is the obligatory beverage for some traditional medicine in many African societies (Oyewo *et al.*, 2020). For example, it has been used in Nigerian traditional medicine to treat malaria, measles, and jaundice and to promote breast milk production in nursing women (Martins & Shackleton, 2018; Oyewo *et al.*, 2020). Moreover, the resin of doum palm is also reported to exhibit diuretic and diaphoretic properties and is used for treating tapeworms and animal bites (Elegami *et al.*, 2001). In addition, the fibrous tissue of the trunk is used to make poultices and other topical treatments, and the nuts and oil are used in remedies for a range of health problems. For example, charcoal from seed kernels is reported to treat some eye diseases in livestock (El-Beltagi *et al.*, 2018; Abdel-Raman, 2019). Overall, using *Hyphaene* species in traditional medicine is an important component of the culture and healthcare of many regions where they are found and can help support local communities' health and well-being. In addition, further scientific study of the *Hyphaene* plant's medicinal properties may lead to the development of new treatments for various health problems.

Forestry resources
Hyphaene species play an important role in forestry resources in many regions where they are found (Watson & Dlamini, 2003). Using *Hyphaene* species in forestry can help to support sustainable development and improve livelihoods in many regions. For example, agroforestry systems that incorporate *Hyphaene* species can help to provide valuable resources for local communities (Ekalo, 2022; Martins & Shackleton, 2021). The palms are valued for their fast growth and ability to thrive in various conditions, making them well-suited for environment protection, including agroforestry systems, windbreaks, and other forms of land management (Ekalo, 2022; Hassan, 2017; Martins & Shackleton, 2021). For example, *Hyphaene coriacea* is abundantly available in the Maputaland coastal plains of southern Mozambique, providing an array of subsistence and commercial non-timber forest products (Martins & Shackleton, 2021). In addition, the *Hyphaene* species are an essential source of fibre. The palm's trunk comprises fibrous tissue that can be used for various purposes, including construction, rope-making, and basket-weaving (Ekalo, 2022; Martins & Shackleton, 2021). The tree is also a valuable wood source and can be used for firewood and charcoal production. Therefore, using *Hyphaene* species for wood and fibre production can provide a sustainable source of income and reduce pressure on other forest resources (Watson & Dlamini, 2003). Overall, *Hyphaene* species play an essential role in forestry in many regions where they are found and can help to support sustainable land management, improve livelihoods, and conserve natural resources.

Materials for the construction and craft industry
Hyphaene fibres are generally strong and durable, making them well-suited for use in various products. For example, durability and resistance to decay make the wood of *Hyphaene* suitable for use in building traditional houses, fences, and other structures (Belal *et al.*, 1998). Moreover, the wood of the *Hyphaene* is often used for furniture-making and crafts (Belal et al., 1998; Watson & Dlamini, 2003). In addition, dried leaves are used to make various products, including baskets, mats, hats, and other woven items such as anklets and skirts, which are worn during cultural events, including traditional dances (Foote *et al.*, 2003; Martins & Shackleton, 2021). Therefore, using *Hyphaene* wood and leaves for the construction and craft industry can help conserve other natural resources by reducing the need for wood and other materials from other scarce sources (Lokuruka, 1990). Moreover, making various craft products from the *Hyphaene* provides additional income for local

communities, hence helping to support sustainable development and improve livelihoods (Belal et al., 1998; Watson & Dlamini, 2003).

Fuel

Most Sub-Saharan African countries rely heavily on non-environmentally friendly cooking fuels, wood and charcoal due to multifaceted difficulties affording gas and electric fuels (Murshed, 2022; Murshed *and* Ozturk, 2023). Similarly, in some regions, the dried trunks of *Hyphaene* trees are used as a fuel source for cooking and heating (Watson & Dlamini, 2003). In addition, the ability of trunks to burn slowly gives an economic advantage for cooking and heating (Ekalo, 2022). This is particularly important in arid regions, where other sources of fuel may be scarce, and in rural areas, where access to clean energy is limited (Watson & Dlamini, 2003). Therefore, using *Hyphaene* species as a fuel source can help reduce pressure on other forests' natural resources. However, burning wood also releases greenhouse gases, contributing to air pollution and various adverse health impacts (Kumar & Pooja, 2020).

There are ongoing research and campaigns to shift from using forestry and fossils to clean energy, such as bioethanol (Thatoi *et al.*, 2016). As a result, there is also an agricultural expansion for cash crops such as corn and sugarcane for bioethanol production. However, there are also several negative impacts of expanding the use of arable land for cash crops (Gupta & Kushwaha, 2011; Kumar & Pooja, 2020). First, the cultivation of cash crops can often require intensive use of agrochemicals, such as fertilisers and pesticides, which can negatively impact soil health, water quality, and human health. Second, the expansion of cash crops can lead to deforestation and land degradation, significantly impacting biodiversity and ecosystem services, which is one of the main factors causing climate change (Gupta & Kushwaha, 2011). Third, the cultivation of cash crops can often lead to a decline in food crops, negatively impacting food security and local communities.

On the other hand, due to its high content of sugars, *Hyphaene* sap can potentially be used to produce clean energy bioethanol (Nguyen *et al.*, 2016). Bioethanol is produced by converting natural biomass containing sugars or starch via biological processes (Thatoi *et al.*, 2016). Currently, bioethanol is intensively produced from corn and sugarcane. However, an agricultural expansion for crops such as corn and sugarcane can result in deforestation, which is one of the main factors causing climate change (Gupta & Kushwaha, 2011). On the other hand, cultivating *Hyphaene* trees requires less agricultural input (Hamilton & Murphy, 1988). Therefore, bioethanol production from the *Hyphaene* sap can contribute to environmental sustainability. Thus, increased cultivation of *Hyphaene* trees for bioethanol can reduce the cost of fertilisers and pesticides and protect the ecosystem by lowering the residuals from the applied pesticides and fertilisers.

Other uses

Hyphaene has many uses, including food, beverages, construction and craft materials. For example, the fruit has been used as a natural source producing dye-extract for dye-sensitised solar cells (Mohammed & Uthman, 2015). Also, the fruit is used as a raw material to make a black dye often used in the tanning industry (Orwa *et al.*, 2009). In addition, the fruit's seed shell has been used commercially to produce buttons and small carvings (El-Beltagi *et al.*, 2018).

Challenges in the cultivation and utilisation of Hyphaene trees

Despite the numerous benefits of *Hyphaene* trees, several challenges are associated with their cultivation and utilisation. For example, the *Hyphaene* tree can mature up to 8 years to produce fruit, which is about 50 kg per year (Orwa *et al.*, 2009). This long gestation period can be a barrier to widespread cultivation, as farmers may hesitate to invest in a crop that takes so long to yield returns. Moreover, there is still limited awareness, knowledge and technology available for cultivating and utilising *Hyphaene* trees. Unfortunately, no policy or law currently regulates the cultivation, utilisation and conservation of *Hyphaene* trees as a natural resource (Martins & Shackleton, 2017; Omire *et al.*, 2022). This can make it difficult for farmers and other stakeholders to realise the potential benefits of the *Hyphaene* trees. For example, in Tanzania, *Hyphaene compressa* is considered a weed species in large-scale cattle ranching and is intensively treated with arboricides, followed by manual clearing (Tobler *et al*., 2003). Unfortunately, *Hyphaene* trees have a slow growth rate. After germination, only a single strip-shaped leaf is produced, with fan-shaped leaves emerging at ground level 2-3 years later (Orwa *et al*., 2009). Alternatively, due to its high energy and protein content, the *Hyphaene* seed meal can be used to formulate highly nutritious animal feed (2018). Therefore, designing a policy to integrate them into agriculture and livestock-keeping ecosystems would be more advantageous than clearing them.

Nevertheless, a study in south-eastern Zimbabwe by (Sola *et al.*, 2006) reported that leaf harvesting for craft production reduced new leaf production, growth and the availability of other harvestable material. Therefore, efforts should be made to adopt harvesting strategies to ensure a reliable raw material supply for the craft industry. Though, it is difficult to saw timber from the *Hyphaene* trees due to the many tough fibres that constitute the stem. However, sawing timber from the male palm is better than that from the female (Orwa *et al*., 2009). Furthermore, there may be limited access to markets for *Hyphaene*-based products, particularly in remote and rural areas. This can make it difficult for farmers and other stakeholders to generate income from the trees. Therefore, addressing these challenges will require investment in research, technology, market access and collaboration among farmers, researchers, and other stakeholders. Nevertheless, despite these challenges, the potential benefits of *Hyphaene* trees make them a promising crop for sustainable development in Tanzania and other areas where they grow.

Future Perspective Hyphaene trees in Tanzania

Natural resource scarcity and increased cost of living can significantly impact individuals, communities, and economies in Tanzania (Kimaro, 2019). For example, in recent years, severe drought has resulted in food shortage and insecurity, water scarcity, and loss of livestock due to crop failure, loss of pasture, and drying of water sources (Mdemu, 2021). Various strategies can be employed to address these challenges, including research on genetic diversity and population structure, resource conservation, diversification, and improving resource efficiency (Omire *et al*., 2022). Unfortunately, there is limited literature about the economic importance of *Hyphaene* trees in Tanzania. Instead, available literature focuses on botanical records (Barboni, 2014; Kindt *et al*., 2014) and vegetation dynamics (Bourel *et al.*, 2021; Tobler *et al*., 2003). However, the future perspective of *Hyphaene* trees in Tanzania is promising, with the potential to address key challenges in natural resources, food and nutritional security, environmental sustainability, economic development, and climate change adaptation, especially in areas where *Hyphaene* trees are found.

Furthermore, as climate change continues to affect Tanzania, *Hyphaene* trees can be integrated into Climate-Smart Agriculture (CSA) programs. The CSA is a farming approach that aims to sustain and increase agricultural productivity in a changing environment (Kirina *et al*., 2022). *Hyphaene* plants are well-adapted to arid and semi-arid environments, making them suitable crops for areas with limited water and other resources (Fick & Hijmans, 2017), such as fertilisers and pesticides. Additionally, the trees can be grown using sustainable practices, such as intercropping and agroforestry, which can help improve soil health and support biodiversity. Furthermore, the trees can provide shade, improve water retention, and support soil health, all of which can help mitigate the effects of drought and extreme weather.

The fruit of the *Hyphaene* tree is highly nutritious and can be an important food source, especially in rural areas. Therefore, given the current challenges of food insecurity and malnutrition in Tanzania, the widespread cultivation and consumption of *Hyphaene* fruit could help address these issues. In addition, the various products derived from *Hyphaene* trees, such as oil, handicrafts, and building materials, have the potential to create jobs and boost local economies. Nonetheless, *Hyphaene* plants have the potential to play an important role in a circular economy through resource recovery, which is an economic system aimed at minimising waste and promoting sustainable use. For example, the pulp left over from oil extraction can be used for animal feed, and the shells can be used for fuel or charcoal production. By recovering and reusing these resources, the circularity of the ecosystem is enhanced. Therefore, Tanzania could become a leader in producing and exporting *Hyphaene*-based products with suitable investment and support. Furthermore, by prioritising the cultivation and use of *Hyphaene* trees, Tanzania can promote a more sustainable and resilient future for its people and ecosystems.

Conclusion and Recommendations

The literature shows that *Hyphaen*e trees have great economic potential as a natural plant resource. They may provide alternative sources of food, fuel, and construction materials. Those products may provide a significant income source for many people in areas where these trees grow, contributing to local community livelihoods. With favourable conditions for the growth of *Hyphaene* trees in Tanzania, particularly in coastal regions, there is potential to unlock the potential *Hyphaene* trees in Tanzania to cultivate it as a commercial crop. Thus, further research is required to understand the diversity of uses, consumption constraints, and opportunities for *Hyphaene* trees in Tanzania. However, there are concerns about sustainability, as overutilisation can be destructive to the trees if not properly managed. Therefore, the following recommendations can be drawn:

Proper cultivation and management of *Hyphaene* trees are necessary to ensure their sustainability while supporting the livelihoods of local communities. Sustainable harvesting practices should be adopted to prevent overexploitation, such as tapping only mature trees and allowing for adequate regeneration time. Efforts should be made to develop value chains and market linkages to improve the income and profitability of those exploiting *Hyphaene* trees and trade.

More research is needed to better understand the economic potential of Hyphaene trees beyond traditional uses, including the potential for other products such as oil and fruit mesocarp in several food formulations. Given the potential economic benefits of *Hyphaene* trees, policymakers and stakeholders should work to support the sustainable use and management of these trees while also protecting them from deforestation and habitat loss. Therefore, future development plans and policy interventions should be created to consider the *Hyphaene* species as a natural resource and agricultural crop with the potential to contribute to people's livelihoods and poverty alleviation in Tanzania.

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