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Chapter

# Macadamia Nuts as a Supplement to Cereal-Based Diets in Malawi

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## Abstract

Macadamia is a high value tree crop with rising global demand. As a leading producer, Malawi has seen rapid expansion of macadamia orchards, indicating the crop's growing economic and nutritional importance. Macadamia nuts serve as a means of income generation and provision of high-quality nutrition among producers and consumers. As a consequence of these benefits, macadamia nut production is rising within the country. Rising domestic and international demand suggests macadamia production will help in economic growth in production areas. Integrating macadamia nuts into local diets could also provide nutritional benefits, allowing Malawi to simultaneously improve well-being and prosperity. To fully utilize this potential, Malawi needs strategic expansion plans for the crop. A comprehensive assessment of current and future suitable production areas is necessary. By matching production capacity to area's ecological conditions, yields can be optimized within sustainable limits. With mindful, coordinated support for the nascent macadamia industry, Malawi can leverage this crop for healthier, more resilient communities.

**Keywords:** macadamia, Malawi, livelihoods, diets, economic

## 1. Introduction

Addressing global food security is a significant challenge that we face today. The world's population continues to grow, driving changes in food consumption patterns. Food security is simultaneously threatened by land degradation and the negative impacts of climate change. Through the sustainable development goals (SDGs), the international community has committed to ending hunger, food insecurity, and all forms of malnutrition by 2030 [1]. However, the FAO [2] argues that the world is falling behind in achieving these goals, especially in Africa, where roughly one in four people face hunger.

Agriculture plays a crucial role in Africa, contributing to both food security and economic growth. The sector employs approximately 65–70% of the continent's labor force and accounts for 30–40% of gross domestic product (GDP) [3]. Smallholder production dominates and provides up to 80% of the food consumed across Africa [4]. Furthermore, over 75% of Africa's poorest people live in rural areas where smallholder agriculture is the primary economic activity.

Considering smallholder agriculture's centrality to Africa's economy and food systems, improving productivity and sustainability of the sector is critical. Enhanced and adaptive smallholder farming systems can simultaneously help in achieving SDGs including poverty reduction, food and nutrition security, and climate action. For example, increasing smallholder efficiency and climate resiliency can boost yields, reducing hunger and raising farmer incomes. Scaling up climate-smart agricultural (CSA) practices can also help to transform smallholder agriculture systems into a more sustainable and profitable sector in response to climate change while diversifying sources of household nutrition [5–7].

## 2. Background on Malawi

Malawi is a country in southern Africa, bordered by Mozambique to the south and east, Tanzania to the north and northeast, and Zambia to the northwest (**Figure 1a**). The country's terrain is highly varied, featuring the lows of the Great Rift Valley, which contains Lake Malawi and the Shire River valley, as well as plateaus, rift escarpments, and mountains with elevations ranging from 1000 to 1500 meters above the sea level (m.a.s.l.) and peaks as high as 3000 m.a.s.l. The country has a total area of 118,484 km$^2$, with 80% (94,449 km$^2$) dedicated to settlement and agricultural production (**Figure 1b**). Water bodies cover the remaining area, particularly Lake Malawi.

Malawi's population has been rapidly growing and is estimated to be over 22.8 million (www.imf.org/en/Countries/MWI). Nearly 83% of the population lives in rural areas [8]. Agriculture remains the core source of income for the majority of Malawians, accounting for over 90% of the population and contributing to approximately 82.5% of the country's foreign exchange earnings [9, 10]. The economy of Malawi is valued at over $12.6 billion by GDP (**Figure 2**).

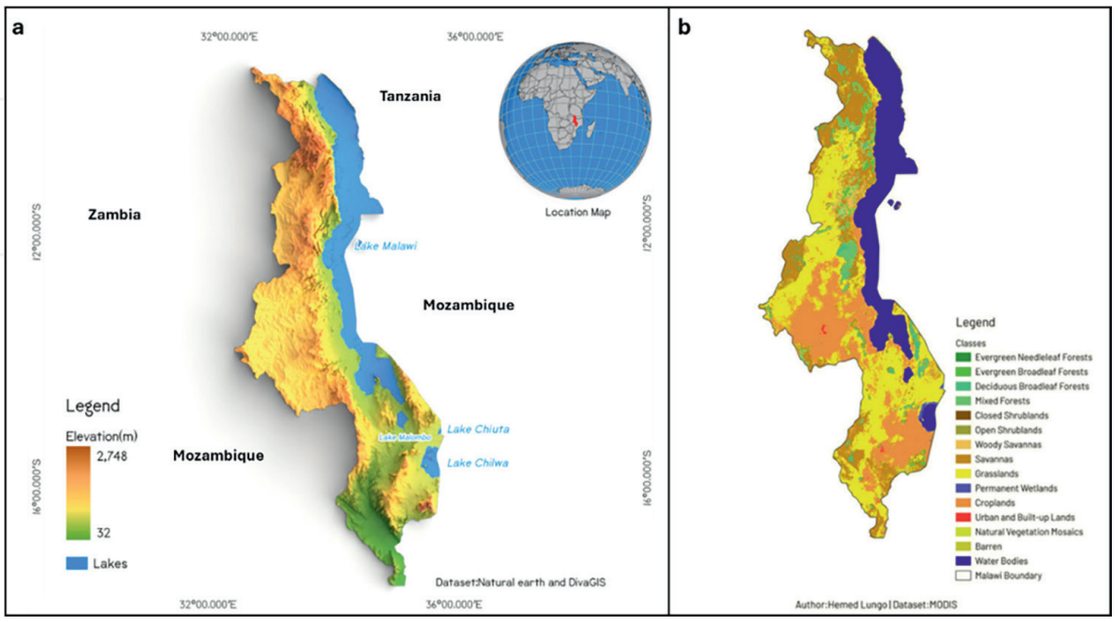


**Figure 1.**
*(a) Geographic location and topography of Malawi. (b) Landcover/land use classification.*

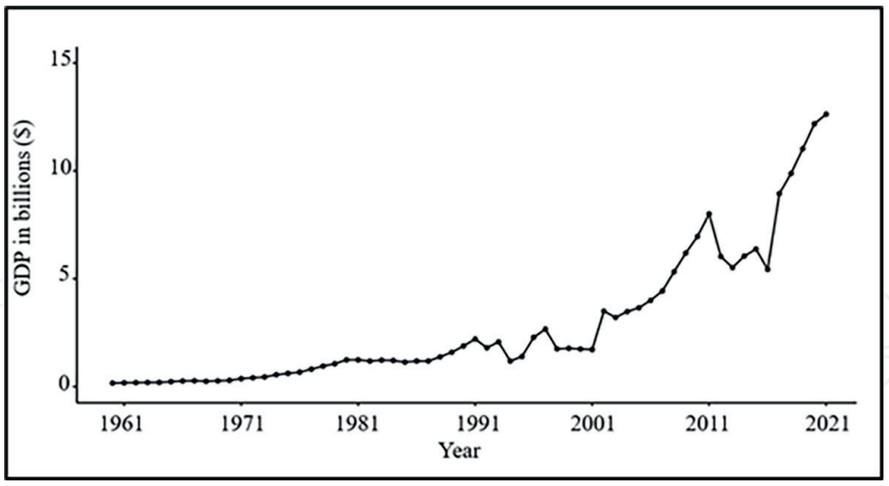


**Figure 2.**
*Malawi GDP performance (data sourced from the World Bank).*

## 2.1 The role and structure of the agriculture sector in Malawi

Agriculture forms the backbone of the economy and society of Malawi. Approximately 85% of households, across the country, are dependent on agricultural activities for their livelihoods and survival, especially rural communities [11, 12]. In addition to driving food security and rural incomes, the sector contributes over 30% to Malawi's total GDP. As such, a thriving and sustainable agricultural sector is critical for realizing Malawi's long-term economic development and reaching several SDGs, especially those on food security and climate action.

Malawi's agricultural sector comprises two distinct subsectors: commercial estate and smallholder producers. The distinction is principally reflected in the tenure systems under which land is cultivated [13, 14]. The commercial estate subsector encompasses medium and large-scale commercial estates ranging from 100 to over 10,000 ha, with land tenure systems primarily based on leasehold or freehold. Commercial estate producers are engaged in the multiplication of certified seed and cash crop production for domestic and export markets and are classified as having high input and high productivity [15–17]. Tobacco has been Malawi's main cash and export crop since the 1800s, falling under the commercial estate subsector [18].

Smallholder farmers, estimated to be two million farm families, cultivate about 4.5 million hectares of land in the country [14, 19–21]. The subsector is characterized by small-scale, subsistent farming, with the average smallholder farm size being less than 0.8 hectare (ha) [22, 23]. Smallholders collectively occupy 80% of the agricultural land in the country. Furthermore, smallholder production contributes approximately 25% of the country's GDP, 95% of the total agricultural labour force, and nearly 70% of agricultural produce, especially common beans, groundnuts, maize, soybeans, sunflower, and tobacco [24].

Despite the important contributions of the smallholder subsector to Malawi's food security and economy, production volumes from each farmer are small, and many are food insecure annually [25, 26]. This is attributed to three key factors. First is the utilization of traditional crop production practices, such as the use of handheld implements for farming and over-reliance on seasonal precipitation. Secondly, limited access to inputs and finance for the farming venture leads to low use of fertilizers and

chemicals such as pesticides and herbicides. Lastly is the lack of crop diversification among the smallholders. These factors make Malawi's smallholder farmers increasingly vulnerable to natural and economic shocks, with climate change expected to worsen the situation [12, 27]. Therefore, the subsector must prepare and adapt for sustainable food security and economic development in the country.

### *2.1.1 Common crops grown in Malawi*

Malawi's agricultural production is mainly oriented toward maize for food and tobacco for exports. Maize accounts for over 54% of the national caloric intake [28] and is extensively cultivated across Malawi. The crop thrives in various agroecological zones, from low-lying plains to highland areas [29–31]. Cassava is another vital food staple, providing around 15% of calories [32], and is commonly grown along Lakeshore plains and Upper Shire valley agroecological zones (AEZ) where its drought tolerance is beneficial. AEZs are geographical areas (**Figure 3**) with similar climatic conditions that can support rainfed agriculture [33].

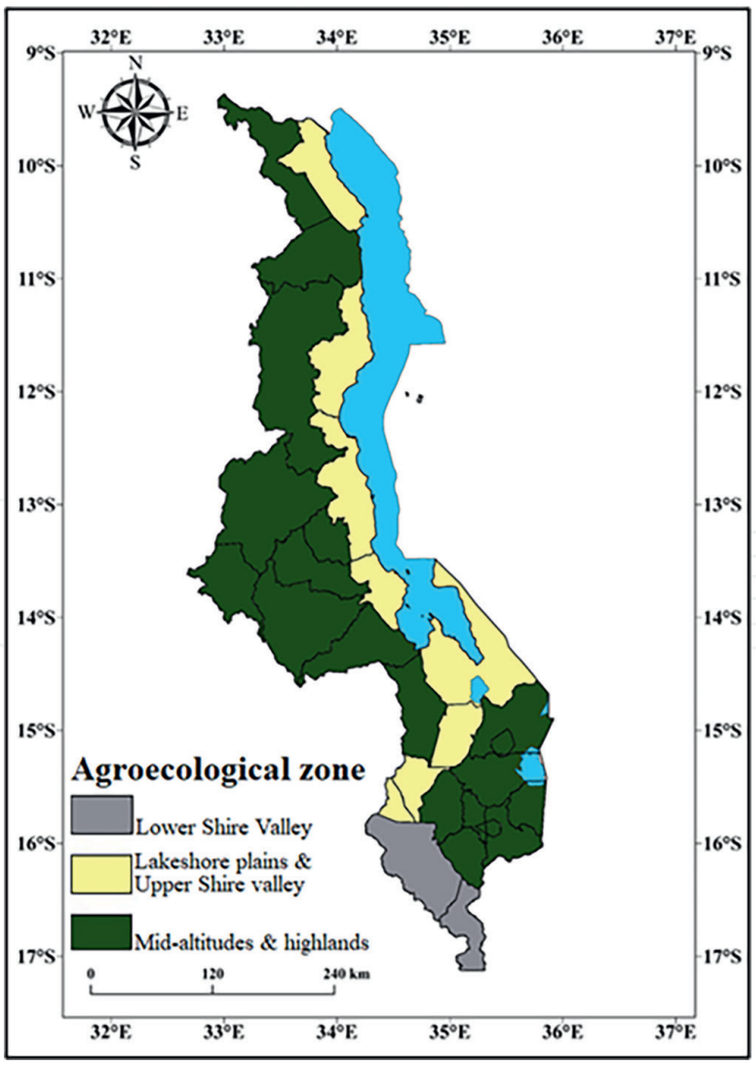


**Figure 3.**
*Agroecological zones in Malawi.*

Rice is also primarily produced in wetland regions near Lake Malawi and along the Shire River, taking advantage of abundant water access [34]. Sorghum and millet constitute traditional cereal crops in Malawi, occupying around 5% of cropland, generally in low-lying regions where moisture retention in soils enables reliable harvests [11, 35]. These food crops are essential sources of calories, nutrition, and resilience for smallholder farmers across the country. Their capacity to tolerate various marginal conditions makes them important components of diverse, sustainable cropping systems.

Until recently, the main cash crop in Malawi has been tobacco, and currently, 95% of the production output of the crop is by smallholders [18]. Moreover, tobacco has been one of the country's main agricultural exports for several decades [36, 37]. However, with the declining global demand for tobacco products and increasing international pressure to reduce tobacco usage, smallholders in the country require alternative cash crops for their survival [36, 38].

Recognizing the need for crop diversification, the Malawian government and other stakeholders are advocating for crops such as coffee, groundnuts, macadamia nuts, soybeans, and sunflower as suitable supplements to the smallholder maize-based diets and as alternative cash crops to tobacco and tea. Macadamia nuts have been highly recommended as they are nutrient-dense, require minimal maintenance, and fetch high market prices [39]. Moreover, the first harvest of the crop is in the lean period (January to February) when annual staple crops are not matured, and, thus, macadamia is an essential resource for improving food security when other food is in short supply and expensive.

### 2.2 Climate change and agriculture in Malawi

Climate change, caused by human activities, has become an undeniable reality. Evidence shows that agricultural production is already being affected by climate change. This is especially true in many parts of Africa, particularly among smallholder farming households [40, 41]. Malawi is particularly vulnerable to climate change due to high poverty levels, limited finances and technology, and a heavy reliance on a predominantly rainfed agricultural sector [7, 42].

Climate change threatens Malawi's economic growth, long-term prosperity, and the livelihoods of an already vulnerable population [43]. Localized droughts and floods reduce crop yields or result in total crop failure, worsening Malawi's food security [44, 45]. Furthermore, there has been a significant increase in extreme weather events, such as heatwaves, droughts, flash floods, and tropical cyclones in the country, from just one during the 1970s to over 40, dominated by floods between 2000 and 2022 [46, 47]. Climate change projections for Malawi suggest possible yield losses of 50% of maize, 45% of tobacco, 12% of groundnuts, 22% of soybeans, and 9% of potatoes by the 2050s, with adverse implications on food security [12, 48].

Malawi's temperatures have already risen by ~0.9°C from 1960 to 2021 (**Figure 4**). Results of 34 climate models provide with higher certainty that temperatures in Malawi will likely increase by 1.5, 2, and 2.3°C by 2030, 2050, and 2070, respectively, above the temperatures of the pre-industrial periods [49]. Such warming will likely have detrimental effects on the agricultural sector if there is low policy implementation effectiveness by the government. Some detrimental impacts may include crop failure, increases in crop pests and diseases, and a reduction in suitable areas for various crops [50]. For example, every degree day above 30°C results in a 1 to 1.7% reduction in maize yields [51].

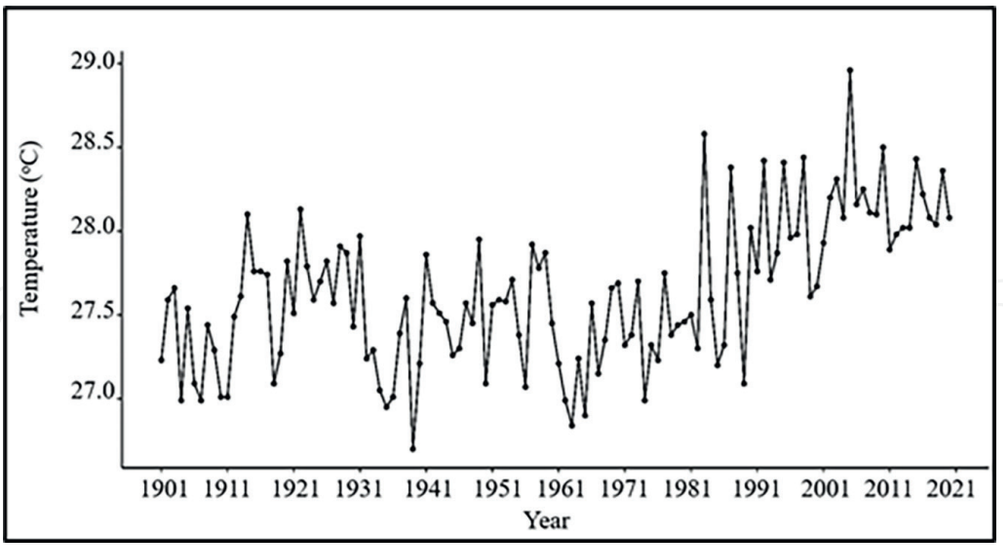


**Figure 4.**
*Historical average annual temperatures for Malawi (World Bank Group climate change knowledge portal).*

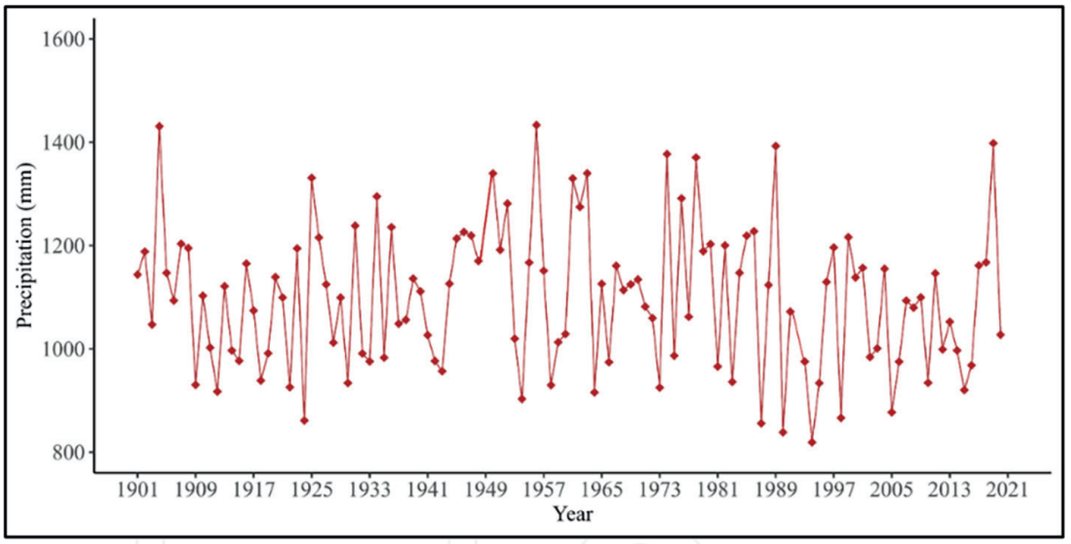


**Figure 5.**
*Historical annual average precipitation for Malawi (data sourced from: World Bank group climate change knowledge portal).*

> *"The past decade has witnessed a significant increase in temperature compared to my youth in the 1950s. Unfortunately, these climatic variations have had an adverse impact on my crop yields. In the 2018–19 growing season, we faced the challenges posed by cyclone Idai, and this year (2022), we have encountered the impact of cyclone Ana, both of which have resulted in flooding, leading to the loss of my crops especially annuals and damage to property." (EJZ_01).*

Malawi's rain-fed smallholder agriculture is highly vulnerable to shifts in precipitation and increased frequency of droughts and floods [52, 53]. Historical data show declining rainfall since 1960 (**Figure 5**), especially in southern and northern regions [43]. Decreases are evident for annual and seasonal precipitation (March to December), while slight increases are evident for the highest precipitation months of January and February [43, 54].

Extreme weather events like tropical storms Ana, Idai, Kenneth, and Freddy have caused massive flooding and crop destruction in recent years, leaving many homeless and food insecure, as well as loss of life. The El Niño dry period in early 2024 has also led to failed maize crops and replanting. Despite these climatic shocks, farmers who have diversified into several crops, particularly perennial crops, have reported being somewhat resilient (HIMACUL manager, pers. comm).

> *"Macadamia smallholders were better off in terms of resilience to cyclones Ana and Idai. This is because the macadamia trees and crops under the tree were not severely affected by the cyclones. Farmers were able to harvest some of their field crops, in addition to macadamia. The staples were used for food, and macadamia was sold for income. On the other hand, non-macadamia smallholders lost half or all of their entire crop, which rendered them food insecure." (EJZ_03).*

Climate projections indicate that Malawi will experience a decrease in the average number of precipitation days and an increase in the duration and intensity of precipitation by the 2050s [44, 45]. Seasonal distribution of precipitation will become stronger, with the rainy season receiving a higher proportion of rain and the dry season receiving less. It is projected that the reduction in precipitation will be more pronounced in the southern region of the country (−5.1%) than in the central (−2.8%) and northern (−1.8%) regions.

### 2.3 Status of food security in Malawi

Food security is defined as the condition where "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [55]." This definition describes the "Four Pillars" of food security: availability, access, utilization, and stability.

Food insecurity is a serious challenge in Malawi, as most agricultural production falls short of its potential due to climate change, soil fertility, and management practices [56]. Maize is a critical aspect of food security among Malawians, with access to and sufficient output of this staple being vital determinants [57]. This is reflected in a common Malawian saying:

> *"Ngati sunadye nsima ndiye kuti siunadye tsiku limenelo," (if you have not eaten maize porridge for a day, you are starving). This quote highlights the significant role that maize plays in the daily lives and overall welfare of Malawians.*

Many smallholders in Malawi struggle to meet their daily subsistence needs due to climatic shocks, primarily unpredictable precipitation patterns, and heatwaves. A less predictable rainy season for smallholders makes planning challenging. This is because farmers rely on knowing when the wet season will begin to sow their crops, apply fertilizers, and harvest during dry periods. Thus, less predictability makes crop yields more variable and vulnerable to post-harvest losses with farmers becoming food insecure.

Nearly 80% of rural individuals, particularly smallholder farmers, in Malawi are net buyers of maize, but their ability to buy adequate food is hindered by high market prices and limited household purchasing power [58]. Consequently, smallholders are the most vulnerable to chronic and transitory food insecurity due to their limited

capacity to cope with climatic and economic shocks. For instance, the 2017–2018 growing season saw a 22.1% decline in maize production. This was attributed to severe droughts and flooding coupled with fall armyworm (*Spodoptera frugiperda*) damage [59]. As a result, over a million rural Malawians required humanitarian assistance to meet their food and nutritional needs.

To achieve food security among smallholders, agri-food systems in Malawi must become more efficient, inclusive, resilient, and sustainable. This can be made possible by implementing climate-smart agriculture (CSA) practices [60]. CSA practices support the FAO Strategic Framework 2022–2031, which considers the interlinkages in agricultural productivity, environmental impact, and social sustainability. Thus, CSA practices are a viable option for achieving food security and resilience to climate change at the community level. Some of the CSA strategies include agroecology, agroforestry, conservation agriculture, crop diversification, and regenerative agriculture [60].

## 3. Nutritional challenges in Malawi

Malawi faces significant nutritional challenges that originate from a combination of factors. These challenges include poverty, limited agricultural productivity, inadequate access to healthcare, and environmental stressors [19, 46]. Malnutrition remains a pervasive issue affecting all age groups, with children under five and pregnant women being particularly vulnerable [21]. Malnutrition contributes to high rates of stunting, wasting, and underweight [61]. Insufficient dietary diversity, poor infant and young child feeding practices, and lack of access to clean water and sanitation exacerbate the problem.

Central to addressing Malawi's nutritional needs is the diversification of the cereal-based diets prevalent in the nation. Cereals especially maize form the staple food for the majority of the population, but they lack essential micronutrients crucial for health and development [62]. While maize provides energy, it is deficient in key nutrients like vitamin A, iron, and zinc [63]. The prolonged consumption of cereal-dominated diets contributes to micronutrient deficiencies, leading to adverse health outcomes such as anemia, impaired immune function, and impaired cognitive development [64].

The predominance of cereal-based diets reflects dietary habits, socio-economic factors, and agricultural practices. Limited access and utilization of a diverse range of foods, particularly fruits, vegetables, fish, and animal-source foods, further compounds the challenge of meeting nutritional requirements. Moreover, poor soil health and fertility which are widespread in Malawi contribute to poor nutrient content of crops [55], exacerbating the deficiency in essential micronutrients.

To address these challenges, integrating nutrient-rich alternatives like macadamia nuts in the Malawian diet remains a viable solution. Macadamia nuts are rich in essential nutrients such healthy fats, proteins, dietary fiber, vitamin E, magnesium, phosphorus, and potassium [65, 66]. Consequently, incorporating macadamia nuts into the diet diversifies nutrient intake and provides a sustainable source of essential nutrients. Furthermore, promoting the production and consumption of macadamia nuts aligns with efforts to address malnutrition, improving food security and climate resilience in Malawi [67]. By leveraging the nutritional benefits of macadamia nuts, Malawi can mitigate the nutritional challenges and enhance the overall health and well-being of its population.

### 3.1 Macadamia

Macadamia species are native to Australia and were named by Ferdinand von Mueller in 1857 as a dedication to Dr. John Macadam, who was the Secretary of the Philosophical Institute of Victoria at the time [68]. Though originating in Australia, large-scale commercial cultivation of macadamia nuts first happened in Hawai'i in the 1880s [69, 70]. Since then, macadamia cultivation has spread globally, with major producers now including Australia, Brazil, China, Colombia, Costa Rica, Guatemala, Hawai'i, Kenya, Malawi, and South Africa. There are also expanding industries in Argentina, Fiji, Jamaica, Mexico, Mozambique, Myanmar, Nepal, New Zealand, Swaziland, Tanzania, Venezuela, Vietnam, Zambia, and Zimbabwe (**Figure 6**).

### 3.2 Botanical classification

Macadamia belongs to the *Proteaceae* family, subfamily *Grevilleoideae*, and tribe *Macadamieae* [71]. Eight macadamia species have been described, six of which are native to Australia and two to the Indonesian island of Sulawesi [68, 71]. *Macadamia tetraphylla* and *Macadamia integrifolia*, indigenous to Australia's east coastal rainforests, produce edible kernels [72]. Hybridization between the two species occurs freely, which is an essential source of variability for macadamia cultivar selection [73]. The other macadamia species (*ternifolia, jansenii, claudieana, grandis* [Australian], *whelanii,* and *hildebrandii* [Sulawesi]) are inedible due to high concentrations of cyanogenic glucosides, which are toxic to humans and livestock [74].

### 3.3 Structure of macadamia trees

Commercial macadamia varieties grown under ideal management conditions may attain a height of over 20 metres (m) with a spread of 15 m at 20 years [70]. Mature leaves are sclerophyllous, which allows them to resist collapse after turgidity loss caused by moisture stress; thus, macadamia leaves do not display stress until it is excessive and irreversible [75]. The proteiod root system of macadamia trees with

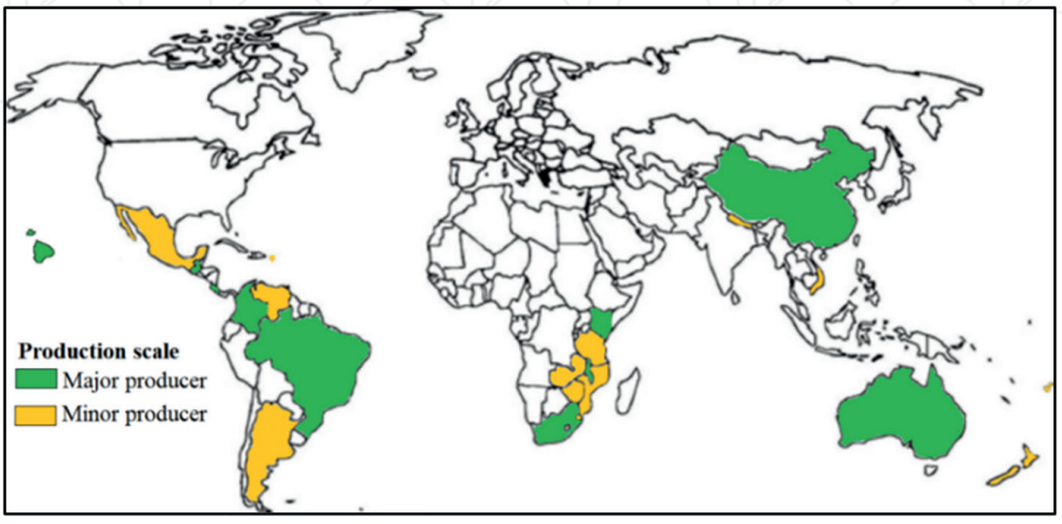


**Figure 6.**
*Global macadamia growing areas.*

clusters of feeder roots near the soil surface also helps the tree cope with extreme weather and reduces soil erosion [75].

### *3.3.1 Macadamia flowers and fruit*

Macadamia trees produce large amounts of flowers. However, only a small proportion, approximately 30%, develop into mature nuts [76]. Macadamia flowers are borne in clusters on pendant racemes (**Figure 7**). The macadamia fruit ranges in size from 1.2 to 2.5 cm and comprises an embryo (nut or kernel), testa (shell), and a pericarp (husk).

### *3.3.2 Nutritional content of macadamia nuts*

Macadamia nuts have an exceptional nutritional profile, rich in healthy fats, plant-based protein, and essential micronutrients [65, 77]. Nevertheless, the content of various chemicals and nutrients in macadamia nuts can vary considerably depending on the variety, seed maturity, growing locations, and growing conditions [66, 78, 79]. Thus, the results of proximate analysis of macadamia nuts carried out in different places and at different times can produce different results. For example, of all the nuts, macadamia nuts have the highest total fat content (≥75%), owing to their high amounts of monounsaturated fatty acid (MUFA) [74]. Nuts are also rich in carbohydrates, proteins, and dietary fibers (**Table 1**).

## 3.4 Healthy benefits associated with macadamia nuts

Regular nut consumption (a handful every day) is associated with many health benefits. Macadamia nuts contain an array of beneficial nutrients and bioactive compounds that promote human health and help prevent chronic diseases when consumed regularly. Despite their high fat content, studies have shown macadamia nuts have positive health effects attributed to their rich composition monounsaturated

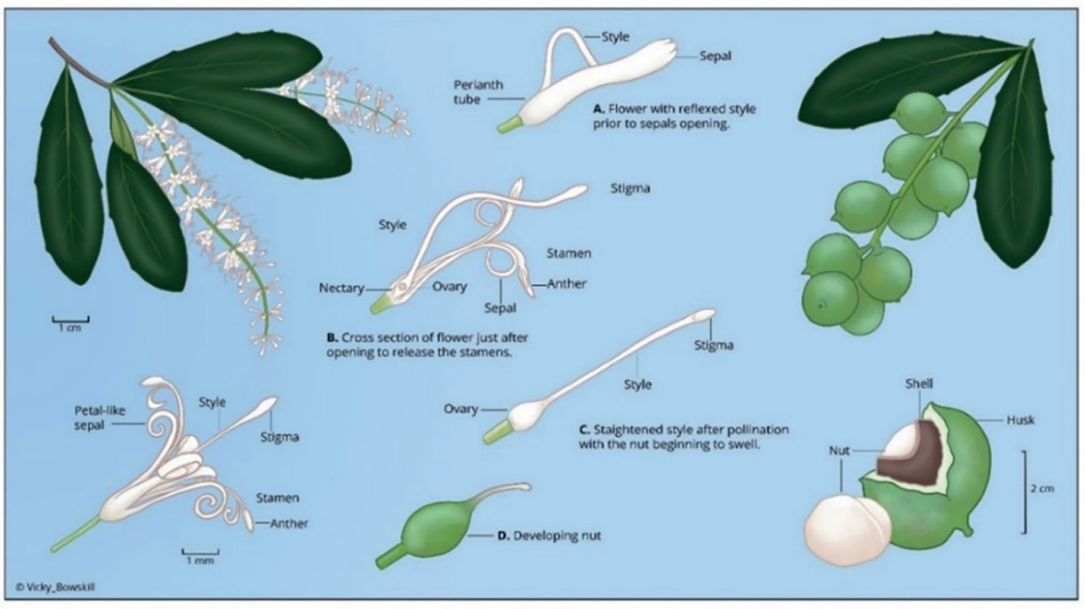


**Figure 7.**
*Schematic diagram of macadamia floral parts.*

| Content per 100 g | AMS | USDA | SAMAC |
|---|---|---|---|
| Protein | 9.2 | 7.9 | 9.4 |
| Fat (total oil) | • 74.0 | • 75.8 | • 75.0 |
| • Monounsaturated | • 60.0 | • 59.3 | • 84.0 |
| • Polyunsaturated | • 4.0 | • 4.0 | • 3.5 |
| • Saturated | • 10.0 | • 12.1 | • 12.5 |
| Ash | 1.3 | 1.3 | 1.6 |
| Carbohydrate (total) | • 7.9 | • 13.8 | • - |
| • Sugar | • 4.6 | • 4.1 | • 4.8 |
| Dietary fibers | 6.4 | 8.6 | 7.7 |

**Table 1.**
*Nutrient content of macadamia nuts (%).*

fatty acids (MUFA), proteins, fibers, vitamins, minerals, antioxidants, and other phytochemicals.

Documented effects of macadamia nuts include improved markers of metabolic health, such as weight management, insulin sensitivity, blood lipid levels, and heart disease prevention. Eating macadamia can also regulate good gut health because they are high in fiber, therefore aiding in digestion and boosting healthy gut flora. Hence, their incorporation into diets is essential.

### *3.4.1 Macadamia nuts and heart disease*

Consumption of macadamia nuts has been linked with some potential benefits for heart health. Multiple nutrients found in macadamia nuts, including vitamin $B_6$, iron, and manganese have been associated with improvements in lipid profiles by reducing levels of "bad" cholesterol (low-density lipoprotein cholesterol/LDL), while maintaining or even increasing levels of "good" cholesterol (high-density cholesterol/HDL).

High levels of HDL lipoprotein cholesterol are associated with a lower risk of heart disease and other cardiovascular problems. For example, consuming macadamia nuts for 5 weeks, compared to a similar diet without nuts, reduced arterial stiffness and wave velocity – two indicators of cardiovascular health risk [80]. One way macadamia nut consumption (as part of a healthy diet) helps persons with hypercholesterolemia is through favorable modification of the plasma lipid profile. For example, 4 weeks of intervention resulted in 3% reduction of total plasma cholesterol concentrations in humans [81].

Bioactive compounds present in macadamia nuts like tocotrienols and flavonoids also contribute to cardioprotective effects. These compounds exhibit antioxidant and anti-inflammatory properties, which help reduce oxidative stress and inflammation, two key factors responsible for the development of heart disease. Overall, the evidence from recent studies suggests that incorporating macadamia nuts into the diet may be a simple yet effective dietary strategy for reducing the risk of heart disease and improving heart health outcomes.

### *3.4.2 Macadamia nuts and body weight*

The nutritional profile of macadamia nuts, especially their high monounsaturated fat content, has significant impacts on how they can affect body weight and

composition. Several human trials have shown that including macadamia nuts in diets does not result in weight gain compared to different control diets, even when the total calories and fat intake are the same across groups for several weeks. This highlights the potential benefits of macadamia nuts in promoting fat oxidation and influencing metabolism, due to their unique fatty acid composition and bioactive compounds like palmitoleic acid.

### *3.4.3 Macadamia nuts and platelet aggregation*

Macadamia nuts contain high levels of oleic acid, magnesium, and phytosterols which reduce platelet aggregation, a crucial factor in cardiovascular health. Platelet aggregation is the formation of a blood clot (thrombus) within a blood vessel or the heart. Thrombus formation is normal and an essential part of the body's response to injury. However, thrombus formation occurring inappropriately within blood vessels can lead to blockages, disrupting blood flow, leading to serious health problems. In a randomized controlled trial, Garg et al. [81] found that incorporating macadamia nuts into diet results in a significant reduction in platelet aggregation among individuals with elevated cardiovascular risk factors.

### *3.4.4 Macadamia nuts and oxidative stress*

Oxidative damage occurs when there is an imbalance between free radicals and antioxidants in the body. Free radicals interact with and damage various cellular components, including proteins, lipids, and DNA. Studies have shown that regular consumption of macadamia nuts significantly increases the amounts of antioxidants in the body, thereby reducing the risk of oxidative damage. Antioxidants are molecules that neutralize free radicals by donating electrons, thereby preventing them from causing damage to cells and tissues.

Oxidative damage results in the development of various chronic diseases, including cardiovascular disease, cancer, neurodegenerative disorders (such as Alzheimer's and Parkinson's diseases), and aging. As a result, regular consumption of macadamia nuts helps in the prevention of these chronic diseases.

### *3.4.5 Macadamia nuts and inflammation*

Inflammation is the body's natural response to injury, infection, or irritation. Acute inflammation is a short-term response that helps the body defend against harmful stimuli and promote tissue repair. In contrast, chronic inflammation is a persistent and prolonged inflammatory response that can occur when the immune system is activated for an extended period. Subsequently, chronic inflammation can result in pathogenesis of many diseases, including cardiovascular disease, diabetes, rheumatoid arthritis, inflammatory bowel disease, and certain types of cancer. It can also lead to tissue damage, dysfunction, and the progression of underlying health conditions.

However, the monounsaturated fats and omega-3 fatty acids found in macadamia nuts have been reported to contribute to anti-inflammatory properties in human cells. These fatty acids help modulate inflammatory pathways and reduce the production of pro-inflammatory cytokines, thus reducing inflammation in the body. A study by Xiao et al. [82] found that macadamia nut consumption resulted in decreased levels of inflammatory markers, such as C-reactive protein, in individuals with

hypercholesterolemia, further supporting the anti-inflammatory effects of macadamia nuts. Moreover, an unusual omega-7 monounsaturated fatty acid (palmitoleic acid), to which macadamia nuts have a natural abundance, has been reported to generate numerous beneficial biological functions, especially its ability to increase insulin sensitivity and to reduce the risk of diabetes [83].

#### *3.4.6 Macadamia nuts and gut heath*

Macadamia nuts are rich in dietary fibers, which play a crucial role in promoting healthy digestion and maintaining optimal gut function. Dietary fiber provides nourishment for beneficial bacteria in the gut microbiota. This leads to the production of short-chain fatty acids (SCFAs), which are essential for gut health. Diets rich in fiber promote the growth of beneficial bacteria such as *Bifidobacterium* and *Lactobacillus* while inhibiting the growth of harmful bacteria. Creedon et al. found that consumption of macadamia nuts increases the production of SCFAs in the gut, leading to improved gut microbiota composition and function.

Fiber content in macadamia nuts also helps regulate bowel movements and prevent constipation, promoting overall gut motility and health. Additionally, the fiber in macadamia nuts contributes to a feeling of fullness and satiety, which may aid in weight management and promote overall digestive well-being.

### 3.5 History of macadamia production in Malawi

The origins of Malawi's macadamia production are not well documented. Researchers believe the crop was first introduced in the country in the early 1950s [84]. At the time, commercial estate producers, particularly, Naming'omba Tea Estate Limited (NTEL) in Thyolo district and Kawalazi Estate (KE) in Nkhata Bay district primarily used macadamia trees as boundary markers to prevent neighboring communities from encroaching on estate lands.

The decline of the tung oil industry in the mid-1950 to 1970s led to the growth of the macadamia nut subsector in Malawi [68, 85]. By the beginning of the 1980s, three commercial estates in the country were operational, and the first macadamia factory was established on NTEL [86]. Smallholder macadamia production started around the same time as the commercial estate sector, but significant growth was observed in the 1990s [68, 85, 87]. These smallholder farmers obtained their seedlings from either commercial estate producers or the research stations. Nevertheless, production by smallholders remained small and insignificant.

Realizing the potential of smallholder macadamia production to Malawi's economy and food security, the government of Malawi began the promotion of the crop in the central (Ntchisi and Dowa) and northern (Mzimba, Nkhata bay and Rumphi) districts of the country [88] from 2001 under the Macadamia Smallholder Development Project (MSDP). Smallholder macadamia in Neno and Mwanza districts started in 1992.

### 3.6 Current trends in macadamia production in Malawi

Although initiated and established by the estate sector, the macadamia nut industry in Malawi is currently thriving in both commercial and smallholder sectors. Currently, Malawi is the world's seventh largest macadamia nut producer [89]. The country has the potential to become a top macadamia producer in the next decade [89]. This is attributed to the availability of suitable land for production, particularly

among smallholders. Zuza et al. [50] found that 57% (53,925 $km^2$) of Malawi's land area is climatically suitable for macadamia production.

Currently, there are eight major commercial producers of macadamia nuts in Malawi who also facilitate with processing and marketing of the crop (Gala Macs, Conforzi Estate, NTEL, Eastern Produce, Plantation General International, KE, Sable Farming, and Tropha Estates), alongside some medium-scale and smallholder farmers spread across the country [39]. Moreover, the country's macadamia industry is expected to continue expanding, with farms previously used for tobacco production being converted or diversified to macadamia production [58].

### 3.7 Macadamia cropping systems in Malawi

Macadamia production in Malawi is divided into three main types: large-scale commercial estates, medium-scale, and smallholder producers [27, 67]. Commercial estate and medium-scale producers typically establish extensive monoculture plantations of macadamia orchards across hundreds of hectares. Their production is highly intensive, often irrigated and mechanized aimed at global exports.

Medium scale and smallholder macadamia farmers use a mixture of cropping systems, including monocultures and agroforestry. The agroforestry systems consist of macadamia trees intercropped with either fruit trees (e.g., bananas, citrus, and mangoes) or fertilizer trees, along with understory crops. Smallholder farmers have different reasons for such diverse cropping systems, like improving soil fertility, increasing yield, diversifying income sources, and resilience to climatic shocks.

> *"One advantage of macadamia agroforestry is the year-round crop harvest. I am preparing to harvest the cabbages, and I already had my first macadamia nut harvest last December. I find the prices for macadamia to be highly competitive compared to other cash crops like groundnuts and soybeans. Additionally, I have a reliable market through HIMACUL." (EJZ_04).*

### 3.8 Uses of macadamia in Malawi

Malawi's macadamia producers benefit from the versatile uses of macadamia nuts, contributing to their economic prosperity and food security. Commercial estate and medium-scale farmers capitalize on the lucrative global demand for the nuts, primarily using them for export markets. The nuts are aggregated, shelled, packaged, and exported especially to South Africa and Europe, fetching premium prices due to their high nutritional value and distinct flavor profile.

Macadamia nuts play a vital role in the livelihoods of smallholder farmers across Malawi. These smallholders use macadamia nuts for income generation and to supplement their maize-based diets [39, 84]. The crop is harvested during the lean period (January to February) when annual staple crops are not matured, and thus, it is an essential resource for improving food security, both as a source of food when other food is in short supply and expensive and as a cash crop in the country.

Macadamia production is also a means for smallholder farmers to adapt and build resilience to climate change. Despite facing challenges such as flooding and droughts, farmers find dependency on macadamia nuts during difficult times. As such smallholders rely on the crop for both sustenance and income, even when other crops fail.

> *"Despite the flooding that destroyed my maize field, I can still depend on my macadamia trees. I already harvested the first batch of macadamia nuts, keeping some for consumption and selling the surplus for income while I wait for the second and third harvests. This means I have an additional crop that provides both food and income for my family. This comes in handy during the month of January where I have to pay school fees for my children, buy fertilizers for the maize crop and buy extra maize to last till April." (EJZ_05).*

Moreover, farmers view macadamia cultivation as a long-term investment. Farmers receive incentives for environmental stewardship, such as carbon sequestration by macadamia trees, motivating them to continue cultivation and pass on knowledge to future generations.

> *"When I initially began growing macadamia with the Macadamia Smallholder Development Project, it was merely an experimental venture. However, I now view macadamia as my retirement crop. In addition to being a source of food and income, I receive incentive payments for the carbon sequestration my macadamia trees accomplish." (EJZ_06).*

Additionally, the dried husks and shells of macadamia nuts are a sustainable source of fuelwood, offering longer lasting and more efficient fire than traditional alternatives like firewood and charcoal. By using macadamia husks and shells, farmers reduce pressure on natural forests for fuelwood, contributing to efforts in reducing deforestation. Lastly, by intercropping macadamia trees with other crops, smallholders optimize land use efficiency and diversify their agricultural portfolios, ensuring sustainable and resilient farming practices.

### *3.8.1 Consumption of macadamia nuts in Malawi*

Macadamia nuts are an essential source of food and nutrition among smallholders and consumers in Malawi. The nuts are consumed both in raw and roasted form (**Figure 8**). Elsewhere, they are also used as additives in the confectionary sector

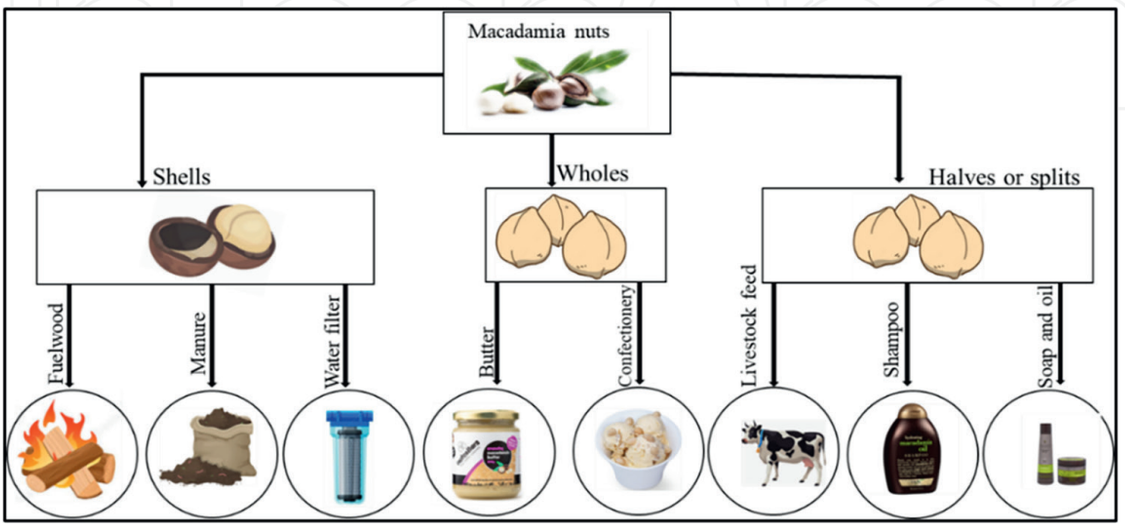


**Figure 8.**
*General uses of macadamia nuts and shells in Malawi.*

for cakes, ice cream, and macadamia butter. Macadamia halves are mostly used to produce cooking oil and cosmetics such as shampoo, soap, and sunscreens. The cake is used as animal feed.

Smallholder farmers and consumers in Malawi have cited multiple benefits associated with macadamia nut consumption. The predominant reason driving consumption is the nutritional benefits of nuts. For example, findings from a study conducted by Zuza [90] revealed that a significant majority, approximately 61% out of 144 participants, consumed macadamia nuts primarily for their health and dietary value. This emphasizes the nuts' potential to nutritionally complement the country's cereal-heavy diets. Therefore, there exists a pressing need for broader promotion of macadamia production to meet the growing demand for these nutritious nuts and to enhance dietary diversity nationwide.

> *"I consume macadamia nuts because they have many medicinal benefits, including lowering blood pressure." (EJZ_07).*

Beyond nutrients, macadamia accessibility facilitates consumption, especially for communities situated near production areas. This underscores that easy access and affordability motivates the use of nuts to supplement other foods. Therefore, in addition to nutritional merits, convenient availability makes locally harvested macadamias an important dietary component. As one farmer testified

> *"Meat and fish are quite costly in this area. So, I get most proteins and other nutrients from macadamias instead." (EJZ_08).*

## 3.9 Preparation methods of macadamia nuts in Malawi

Macadamia nuts are an important food source in Malawi [27, 39]. As production and availability of the nuts has increased locally, consumers have developed a variety of preparation methods to incorporate the nuts into traditional dishes and meals. These innovative techniques allow consumers to capitalize on the nuts' nutritional benefits while fitting them into local culinary culture.

Understanding macadamia usage is vital and can inform efforts to promote nuts for food security and nutrition goals. Moreover, documenting the preparation methods preserves valuable cultural knowledge on adapting the formerly exotic nuts into indigenous cuisines. This information could help nutrition programming and interventions to apply appropriate processing methods when utilizing macadamia nuts to combat malnutrition. Below is a summary on how macadamia is incorporated into Malawian diets.

### *3.9.1 Macadamia flour*

Macadamia flour is a popular nutritious supplement made by households milling nuts with their maize. The resulting fortified flour is used to cook enriched traditional staples like "nsima," porridge, and relishes. Thus, the addition of macadamia flour boosts the nutritional value of these regular dishes by increasing healthy fats, vitamins (especially $B_6$), minerals (manganese, iron, and magnesium), carbohydrates, and dietary fibers [80, 83]. Macadamia also acts as a flavor enhancer [65]. The accessibility of milling allows farmers and consumers to easily produce this beneficial

supplement for both health and taste improvements. Consequently, incorporating more macadamia nutrients through flour represents a valuable usage that can expand with rising production, especially increasing nutrition security for rural communities in the country.

> *"One common dish I love to prepare is boiling pumpkin leaves in combination with a half cup of macadamia flour and a touch of salt, which is eaten with nsima or potatoes and red beans." (EJZ_08).*

### *3.9.2 Macadamia oil*

Macadamia nuts have the highest fat content of any nut, which is advantageous for the production of macadamia oil [91]. Communities in close proximity with the Highlands Macadamia Cooperative Union Limited have access to an oil press, enabling them to extract oil from harvested macadamia nuts. This oil is used as a healthy cooking base, further diversifying their culinary applications. Pressing oil reduces purchases of other vegetable oils, saving households money for other needs. The byproduct of oil production is defatted macadamia meal, which is then used to bake traditional "chigumu," bread, and as animal feed.

### *3.9.3 Macadamia nut snacks*

Macadamia nuts are an important snack among Malawian consumers, especially children. While raw nuts are a popular choice, they can also undergo various flavor enhancements. Dry roasting is a common method used to intensify their flavor profile. Recently, individuals have the option to purchase macadamia nuts already roasted and seasoned, including varieties such as salted, smoked, and barbecue flavor. While, macadamia nuts are predominantly consumed roasted, the roasting process is highly likely to induce chemical changes in the lipids, and the consequential flavor modification is often rated well [92]. In fact, unsaturated fatty acid and mineral content was significantly increased rather than when eaten raw or boiling [93].

### *3.9.4 Macadamia butter*

Macadamia nuts are providing Malawian smallholder farmers an opportunity to diversify the prevalent peanut-based butter diets with macadamia nut butter. The high oil content of macadamia nuts allows farmers to transform their harvest into butter through a simple yet value-adding grinding process [94]. Compared to mainstream groundnut butter, macadamia nut butter delivers superior health properties due to a richer composition of heart-healthy MUFA and antioxidants [91, 94]. It also provides a richer, creamier base, and mild, buttery taste profile that complements multiple uses like spreading on bread and baking.

Through the use of traditional mortals and in some cases small-scale grinding mills, enterprising smallholders are able to manufacture their own macadamia nut butter, generating extra income while meeting urban consumer demand for specialty spreads. The emerging niche product simultaneously diversifies ground-nut-dominated markets and farmers' income streams. Production can expand through cooperative partnerships and value chain support. Hence, the promising local

manufacture and sales of macadamia nut butter illustrates the crop's opportunities to drive agricultural and food product diversity in Malawi.

## 4. Conclusion

Macadamia is a highly valuable crop in Malawi. The nuts contribute to local diets by providing a rich source of healthy fats, vitamins, proteins, and micronutrients, as well as diversifying farm incomes. As both domestic and international demand for nuts rises, its production has the potential of driving economic growth in rural areas across the country. However, to fully realize the potential of macadamia production, Malawi must undertake strategic efforts to promote its expansion. Careful consideration must be given to the current and projected suitable areas for production in light of environmental and socio-economic factors. By promoting the production of the nuts in areas where they are adapted, Malawi can maximize productivity while ensuring sustainable agricultural practices. Therefore, integrating macadamia nuts into Malawian diets as a cereal-based supplement has the potential to enhance the well-being of the people, while fostering economic growth.

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## Conflict of interest

The authors declare no conflict of interest.

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