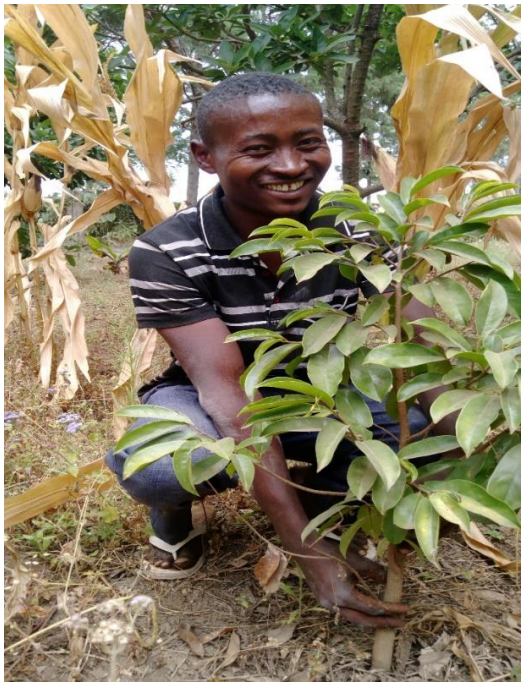
NEGLECTED AND UNDERUTILIZED SPECIES (NUS) FOR IMPROVED FOOD SECURITY AND RESILIENCE TO CLIMATE CHANGE

A Contextualized Learning Manual for African Colleges and Universities



Editors

Wilson Kasolo, George Chemining'wa and August Temu

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African Network for Agriculture, Agroforestry & Natural Resources Education

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Preface

Archaeological studies reveal that sedentary living started around 25,000 BC. However, the practice of farming probably began around 10,000 BC, as studies of the Natufian people of Eastern Mediterranean show (https://en.wikipedia.org/wiki/Sedentism). Around the same time, The Beja nomads of North-eastern Africa are known to have exported cattle, sheep, and goats to the Middle East in those early years. Domestication of crops through cultivation took place in different parts of the world at different times. Thus, a huge variety of crops and livestock were already domesticated by 2500 BC. Through time, the demand for food has kept rising due to the burgeoning human population, leading to huge advances in research to raise productivity of few crops and livestock.

Of the 5,000 food crops estimated to exist worldwide the global food system currently relies on only 12 crops and five animal species to provide 75% of the world's food. Four crops—rice, maize, wheat and potatoes—make up more than 60% of our energy intake (FAO, 1998). Furthermore, these crops have undergone major genetic improvements, and are produced under highly intensive systems where fertilizers, pesticides and growth hormones are applied to ensure high productivity. Unfortunately, this comes with very high costs to human health and environmental degradation. Coupling this with the rapid changes in climate, there are concerns on the future quality of life on earth.

Globally it is estimated that there are over 12,000 edible species of plants and animals that are currently neglected and underutilized. Many of them are highly nutritious and some of them can withstand floods and droughts and therefore are useful for climate change adaptation. These Neglected and Underutilized Species (NUS) are good news to humans. Their proper domestication and improvement are of prime importance in diversifying food security initiatives, improving nutrition and enhancing our capability to adapt to climate change.

Unfortunately, the NUS have not been taught at colleges and universities largely because their importance was not realised earlier on, and therefore research into their agronomy has lagged. Recognizing their rising importance, in 2016 ANAFE convened workshops of agricultural educators in Africa who endorsed the ideas of developing a curriculum on NUS to fill the yawning knowledge and expertise gap. ANAFE supported the curriculum development process and the first NUS curriculum was produced and is being adopted by many colleges and universities in Africa. However, educators are searching for suitable learning resources to use in the teaching processes. This learning manual is the first such resource developed by ANAFE, thanks to support from Fondazione Edu an Italian partner. The learning resources cover very few crop and animal species. ANAFE organized this manual using experts from colleges and universities in Africa, who collaboratively shared resources available in reports, research papers, internet etc. to compile credible knowledge.

As indicated above, there are many more species that need to be studied and the knowledge shared. It is hoped that many more stakeholders will provide support for the development of learning resources covering more NUS species and the writing of manuals for farmers and extension workers to support domestication cultivation for full realization of their value chains.

Prof. August B. Temu

Acknowledgement

ANAFE Secretariat deeply appreciates its 147-member universities and colleges spread in 37 countries in Africa, for inspiring the interest in NUS education, and continued support of ANAFE activities. We acknowledge the encouragement and continued guidance from the ANAFE Board Chair and the entire Board. We are also thankful to the following institutions and organizations that allowed their staff to participate in this initiative as authors of the various chapters of this manual:

1. Universtiy of Nairobi, Faculty of Agriculture, Kenya
2. Bioversity International, Italy
3. Sokoine University of Agriculture, College of Forestry, Wildlife and Tourism, Tanzania
4. Makerere University, School of Forestry, Environmental and Geographical Sciences, Uganda
5. University of Ghana, College of Basic and Applied Sciences, Ghana
6. Africa Centre of Excellence for Innovative Rodent Pest Management and Biosensor Technology Development, Sokoine University of Agriculture, Tanzania

This initiative would not have been successful without the financial support of Fondazione Edu of Milan Italy. Fondazione Edu was created in 2006 with the aim of promoting access to higher education in Africa. Through a scholarship program, Fondazione Edu has provided students in several African countries, with the opportunity to access academic education in their countries of origin. Fondazione Edu's commitment has a focus on technical-scientific and agronomic studies, to foster the acquisition of professional competencies that can better contribute to the economic development. The Foundation also promotes research and analysis on African tertiary education related issues. The ANAFE Secretariat and the entire ANAFE fraternity are very grateful to Fondazione Edu for this support. We also deeply appreciate Ms Valentina Mutti and Ms Chiara Piaggio of Fondazione Edu for their guidance and encouragement in this initiative.

The authors of the chapters of this manual are greatly commended for the effort made in producing the materials. ANAFE also acknowledges Prof. August Temu, and Prof. George Chemining'wa for reviewing the draft manual and for the editorial support.

The materials used in this manual are based on published works by various scientists and institutions. While all sources are acknowledged, we also formally acknowledge all these scaientists and institutions and hope that they are proud to see their work reaching college and university classrooms for generations to come.

There were logistical support requirements related to the development of this manual, which were all meticulously handled by the ANAFE Secretariat Staff. We are grateful to Ms Josephine Oyoo and Moses Gachie for relentlessly ensuring that all logistical requirements were in place.

Table of Contents

Chapter 1

Introduction to Neglected and Underutilized Species (NUS)

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Keeping curricula relevant: teaching neglected and underutilized species

Curriculum development and reviews keep higher education programmes relevant and attractive to students. Curriculum reviews integrate new topics, processes or teaching methods into programmes and courses, often in response to scientific progress, policy trends or changing job markets. Climate change and gender are two examples where such 'mainstreaming' into agricultural education is underway. The expansion of agroforestry education in Africa, led by the African Network on Agriculture, Agroforestry and Natural Resources Education (ANAFE) since the early 1990ies, is another example.

Whether curriculum development concerns a new programme or course, or the review of existing ones, universities need to stay alert and respond to needs for upgrading curricula as new knowledge, insights and practices come/arise. The area of neglected and underutilized species, or NUS for short, has recently emerged as one such topic for higher agricultural education. There are many reasons: the role of agricultural diversification for sustainable development, reducing economic and climatic risks in fam ily farming, business opportunities from local to international levels, links between nutrition and agriculture, attention to culture and traditions, and inclusive gender considerations are some of the drivers of change. These are good reasons why agricultural higher education should look beyond the staple crops and commodities that dominate their programmes and include NUS in the teaching and learning.

A *Curriculum guide on neglected and underutilized species: combating hunger and malnutrition with novel species*, was published by ANAFE in 2016. Using the examples of fruits and nuts, vegetables, rodents, and insects, within a value chain approach, the Guide is a flexible framework for introducing modules on NUS into courses and programmes. Each module introduces the specific value chain, provides key learning objectives, suggests practicum, gives a synopsis of the module and informs on useful references and web resources (Temu et al., 2016).

This teaching manual is a companion to the curriculum guide, going deeper into each module as well as adding a new module on cereals and pseudocereals. The Manual provides insights, case studies and examples that enrich each module. The five modules presented can serve as a

flexible starting point for developing NUS curricula, adapted to the unique context and objectives of each educational programme.

The objective of the Teaching Manual is to accelerate the mainstreaming of NUS education at African universities and technical colleges. To this end, the Teaching Manual:

- Serves as resource material for teaching NUS at colleges and universities, accompanying the NUS curriculum developed by ANAFE in 2016.
- Shares information and creates awareness on the potential to further develop and create an enabling environment for NUS value chains.
- Stimulates research on NUS among faculty and students.

This manual has six chapters, covering general introduction, fruits and nuts, vegetables, cereals and pseudocereals, rodents and insects.

Chapter 1. Introduction sets the scene. The Introduction to Neglected and Underutilized Species (NUS) provides a multi-disciplinary background to the topic. The focus is on enhancing the use of a wide range of species, via a value chain approach. The Chapter discusses the role of higher education in the promotion of NUS, and discusses the challenges involved.

Chapter 2. Fruits and Nuts describes the importance of neglected fruits and nuts to livelihood and development, using case studies from across Africa. The identification of selected fruits and nuts, including their cultivation and challenges, are explained. The module ends with a detailed introduction to the management of two species: African breadnut (or breadfruit) (*Treculia africana*) and soursop or custard apple (*Annona muricata*), covering ecology, botany, physiology, phenology, germplasm, propagation, protection, harvesting and storage, processing and value addition, marketing and certification.

Chapter 3. Vegetables covers the importance, cultivation and value addition of selected NUS vegetables that contribute to the livelihood of low-income families in sub-Saharan Africa. In Africa, vegetables are cultivated widely in most backyards or are collected from the wild all year round. They form an important part of the human diet as they contain a wide range of nutrients and fibers. The management of selected vegetables is covered in the module, including leaf amaranth, Jew's mallow or jute mallow (*Corchorus olitorius*) and *Moringa Oleifera*.

Chapter 4. Cereals and pseudocereals introduces several NUS belonging to this important family of crops. Cereals belong to the grass family (*Gramineae*) and are grown for their edible, starchy and, sometimes, high-protein content. Pseudo-cereals are not members of the grass family and are grouped with cereals based on use rather than biology of the plant. NUS cereals and pseudocereals can have excellent nutritional and health benefits; some are widely recognized as 'supergrains' or 'superfoods'. The module describes several of these supergrains in detail, including grain amaranth, buckwheat, finger millet, proso millet, quinoa and tef.

Chapter 5. Rodents gives a comprehensive overview of this source of food and income, commonly consumed in many African communities. The module introduces several species of rodents including the African giant pouched rats, reported in about 29 countries, cane rat or

grass cutter, distributed throughout sub-Saharan African, and the multimammate rat, which is trapped and eaten by local communities in the region.

Finally, **Chapter 6. Insects** discusses insects as food and feed, a trend that has recently gained global recognition. Traditionally consumed in many countries around the world, the rearing of insects can expand to help address the interrelated challenges of food security, poverty, nutrition and climate change. In the feed industry, nutrient-rich and sustainably produced insect-based feed has great potential. The module highlights several species or groups of species with good potential for value chain development: African palm weevil, termites, crickets and Mopane worms.

Neglected and underutilized species: an introduction

The term neglected and underutilized species (NUS) was first used in 1999 (Eyzaguirre et al. 1999) to refer to a category of wild and cultivated plant species characterized by two main aspects: the 'neglected' status and the 'under-use' dimension. 'Neglected' underlines the low level of investment in research and development (R&D) on such crops, when compared with mainstream commodity crops. 'Under-use' refers to their untapped livelihood potential. Researchers and practitioners have also used many synonyms, including minor, under-used, under-exploited, under-developed, orphan, promising, lost, alternative, traditional, niche crops, crops of the future, future smart food. All these terms are context-specific and loaded with heavy cultural meanings; they are not understood in the same way by everyone. To ensure the same level of understanding, it is important to qualify NUS based on a few specific features, listed as follows:

- Poorly addressed by R&D: Their exclusion from the Green Revolution's efforts left these species much behind in terms of advancing their conservation, cultivation, harvest, postharvest processing, and marketability. Equally scarce are studies on their contribution to food and nutrition security, gender roles, and policies and legal frameworks related to their use.
- Appreciated by local consumers: NUS are an integral part of local culture, widely used in traditional food preparations, associated with social and religious ceremonies, and increasingly in the spotlight of efforts for revitalizing local food cultures.
- Resilient and adapted to agro-ecological niches and marginal areas: Supported by an increasing number of scientific findings, local growers recognize the comparative advantages of NUS in terms of adaptation to climate change and resistance to a number of biotic and abiotic stresses, which makes them perform comparatively better under lowinput and biological agriculture techniques.
- Cultivated using ecotypes or landraces: There has been very limited breeding of NUS; the degree of genetic improvement in these species is generally low. Hence, most material is represented by non-improved varieties, landraces and, often, semi-domesticated material. For these reasons, their competitiveness in modern agricultural systems is limited.
- Cultivated and utilized drawing on indigenous knowledge: Most NUS are cultivated relying on farmers' traditional knowledge, which is fast eroding due to cultural and demographic change. This, in turn, contributes to a marginalization of NUS and loss of their genetic diversity at inter- and intra-specific levels.
- Hardly represented in ex situ gene banks: A direct consequence of the low priority these crops receive in national and international research programs, NUS are poorly represented in ex situ gene banks. Consequently, the genetic diversity of NUS is maintained mostly in

situ and on-farm and (possibly) in private seed collections; a condition that has important implications for their conservation modalities.

- Characterized by fragile or non-existent seed supply systems: Largely cultivated within the informal seed system, the seed supply of NUS is erratic and often coupled with poor seed quality. Both conditions that have negative impacts on their performance.

Trends, roles and potential

One of the greatest challenges modern societies face is the narrowing down of the range of crops and varieties we rely upon for the food and nutrition security of our planet (PrescottAllen and Prescott-Allen 1990, Frison et al. 2011). Of the 5,000 food crops estimated to exist worldwide and the several thousand others harvested directly in the wild (PROTA, 2010), the global food system relies currently on very few: 12 crops and five animal species provide 75% of the world's food, and just four crops—rice, maize, wheat and potatoe—make up more than 60% of our energy intake. The shrinking of our food basket is unabated (Bioversity International, 2017) along with an increasing homogeneity in global food supplies (Khoury et al., 2014). Because of this trend, production systems are becoming more vulnerable to climate change and socio-economic shocks. Farmer assets and income generation options are being reduced and consumers have fewer choices for a nutritious and healthy diet.

But why is all this happening? The causes are numerous and highly interlinked, ranging from the ever-growing globalization of agricultural markets dominated by few commodity crops, to the standardization of production and food systems, loss of market competitiveness for traditional crops, widespread cultural erosion linked to loss of traditional knowledge, less appreciation of indigenous crops and changes in eating habits resulting from modern lifestyles. All these forces are contributing towards the displacement of local species from the table and their inevitable loss in natural ecosystems and in agricultural fields.

These traditional species are not included in the Green Revolution paradigm. They have been left at the margin of research and development efforts, failing to gain prominence even in national markets. Depending on the context, they are referred to as neglected, orphan, promising, underdeveloped, niche, alternative, new crops, or crops of the future. The term 'neglected and underutilized species' (NUS), best captures their marginalization (i.e. neglected in research and development) and their under-used status (i.e. underutilized in economic and social terms), while at the same time reminding us of the neglected people for whom they are invaluable livelihood assets (Padulosi et al., 1999 and 2008).

Compared to mainstream crops, the NUS are primarily constrained by inadequate information on their cultivation and use, disorganized or non-existent markets, low germplasm representation in *ex situ* genebanks, lack of high-quality seeds and improved varieties, and labour-intensive cultivation and processing (Padulosi et al., 1999; Akinnifesi et al., 2008; Kahane et al., 2013). On the other hand, given the limited body of knowledge on a NUS, targeted research can address bottlenecks in their value chains, with fast results. Also, some consumers perceive them as 'food of the poor'. But such perceptions can change through education and awareness raising campaigns (Padulosi and Hoeschle-Zeledon, 2004).

On the positive side, local communities appreciate NUS for their nutritional properties, as invaluable ingredient in many food preparations, for their high adaption to agro-ecological niches, good level of resilience to climate change and ability to grow in marginal lands and in low-input agriculture (Jaenicke and Hoeschle-Zeledon, 2006; Padulosi et al., 2013, Bvenura and Sivakumar, 2017). Owing to their great diversity and multiple ecosystem services functions, many NUS are also helpful in enriching the soil with atmospheric nitrogen and reducing risks associated with pests and diseases and shortage of water (Nuez et al., 1997).

Although NUS have not been extensively characterized in terms of their nutritional profiles, available studies clearly indicate their nutritional superiority when compared with commodity crops (Weinberger and Swai, 2006; Smith and Longvah, 2009; Arora, 2014). Such traits are very valuable in regions afflicted by seasonal hunger during the period that precedes the harvest of main staples. Furthermore, recent nutritional studies provide evidence that NUS are a source of important micro-nutrients in areas where staple crops may fail or produce comparably lower yields (Padulosi et al., 2015; Sood et al., 2015). Production of quality food and not just quantity is a new agricultural paradigm where NUS can express their full potential within an alternative, diversity-driven Green Revolution.

Traditional agricultural systems in Africa are typically characterized by modest plots of land grown with a diverse portfolio of species meant to satisfy different needs of the household (subsistence needs, trading of products in local markets, etc.). Such plots may contain cereals, pulses, vegetables and fruit trees, condiments and aromatic species, fiber crops and a diversity of species planted for their aesthetic, cultural or social values. NUS are a consistent part of this non-commodity portfolio, which contributes to maximize returns to land, labor and other inputs, especially in marginal areas.

Some NUS species can thrive in marginal lands and in low-input agro-ecosystems where they have developed comparative advantages over major crops during centuries of natural and human-made selection. Minor millets, cultivated in poorest soils of high and hilly lands of India and Nepal (Bhag Mal, 1994, Padulosi et al., 2009), and native fruits of Brazil grown in marginal soils of poverty-stricken areas (Gamarra-Rojas et al., 1994) are two examples. Most NUS are cultivated without using pesticides as farmers are too poor to afford these inputs and furthermore, being far less demanding than commodity crops, their inclusion into agricultural systems contributes to reduced soil nutrients depletion (NRC, 1993). Their ability to perform reasonably well in low-input agriculture is also being applied in organic farming, providing interesting income opportunities for small-holder farmers.

NUS gaining respect nationally and internationally

Although calls for greater attention on NUS started already more than 30 years ago (Arora, 1985), it is only in the last ten years that they have been gaining greater respect in national and international fora, because of the growing debate over more resilient and nutritious food systems while adapting to climate change. Strategic frameworks for their use enhancement include those of Jaenicke and Hoescle-Zeledon (2006) and Padulosi et al. (2013 and 2014).

Owing to the multiple livelihood benefits associated to their use, the promotion of NUS is also consistent with several key policy frameworks and agreements, including:

- The Sustainable Development Goals (SDGs) (especially no. 2, 7, 12, 13, 15 and 17).
- The Aichi Biodiversity Targets (Target 13).
- The FAO Global Plan of Action on Plant Genetic Resources for Food and Agriculture (PGRFA) (Priority Activity no. 11) (FAO, 2011).
- The International Treaty on PGRFA.
- The 2016-2020 Strategic Plan of the UN Standing Committee on Nutrition (UNSCN). Ignored by policy makers and largely excluded from research and development agendas, NUS need attention in terms of conservation of their genetic resources, cultivation, harvest, postharvest, marketability and ways to harness their good nutritional profiles to achieve food and nutrition security. Enabling policies and legal frameworks to incentivize their wider use are also needed. Most NUS species are cultivated relying on farmer-based knowledge, which is fast disappearing due to pervasive cultural erosion, a situation leading, in turn, to reduced use of agrobiodiversity and the loss of both inter- and intra-specific genetic diversity of many NUS.

From a socio-anthropological perspective, NUS also play an important role. They keep centuries-old traditions alive, manifested in unique cultural events such as seed- and food fairs, social and religious rituals, and food preparations. All this helps safeguard territorial identity and raises the self-esteem of local populations, the guardians of both the genetic diversity of NUS and the knowledge associated with them (Smith et al., 2006).

Promotion of NUS requires the adoption of innovative inter-disciplinary, holistic and participatory approaches across the value chain. Professional capacity in most National Agricultural Research Systems (NARS) to implement such approaches is still limited and needs to be strengthened. Greater deployment of NUS in value chains is also a strategic way to empower women, indigenous peoples, rural youth and other vulnerable groups who depend on such crops for their livelihoods. Economic empowerment should be at the core of these actions, and interventions should aim at leveraging local agrobiodiversity, promoting market access, agro-processing and value addition, paying attention to business skills development and market orientation. These actions should be designed through a culture-sensitive lens. Actions along the value chain of NUS should be driven by equity considerations and inclusion of vulnerable groups. The scope of this Teaching Manual is therefore highly relevant.

Role of education on neglected and underutilized species: needs and challenges

Global and regional trends, educational responses

This Teaching Manual was prepared against a backdrop of rapid change in Africa's educational landscape which, in turn, reflects changes in food systems, industry, services and demography.

Enrollment in tertiary education is increasing in low- and middle-income countries globally, as result of higher attendance in secondary education, and higher transition rates from secondary to tertiary education, which in turn are linked to a range of economic and cultural drivers. In

sub-Saharan Africa, demographic change and a large young population will increase the demand for higher education further (World Bank 2017).

The need for educational change is also highlighted at high policy level: A briefing from the World Economic forum recommended that '…Africa's educators should design future-ready curricula that encourage critical thinking, creativity and emotional intelligence as well as accelerate acquisition of digital and STEM (science, technology, engineering and mathematics) skills to match the way people will work and collaborate in the Fourth Industrial Revolution' (Word Economic Forum, 2017). The blend of 'soft' skills and technical competence is noteworthy.

In the agriculture sector, the largest in many African economies, the need for innovation is significant, and linked to the achievement of the Sustainable Development Goals (SDG). The Africa Agriculture Status Report 2017 points out that 'Africa's food systems are undergoing a period of dynamic change which is creating many new growth opportunities, but whose full exploitation requires an agricultural transformation'. The report emphasizes that agriculture must be much more market driven and cover the whole food system, not just agricultural production. The growth of small farms and small and medium enterprises (SMEs) is an important pathway for achieving this transformation (AGRA, 2017). Small farms are also in focus at global level: the UN General Assembly has adopted the Decade for Family Farming (2019-2028), recognizing that family farms produce more than 80% of our food, in terms of value. Yet, close to 80 per cent of the world's extreme poor live in rural areas and work in agriculture (UN, 2018).

The obvious, but oddly neglected, link between agriculture and nutrition is also high on the policy agenda, to address malnutrition in all its forms. Many organizations, including the International Fund for Agricultural Development (IFAD) and the World Food Programme (WFP), are mainstreaming nutrition into their agricultural programmes. Higher education programmes need to put more focus on the nutrition outcomes of agriculture.

Universities are key players in promoting NUS, through participation in research, involvement in outreach activities, and through education and training. Teaching NUS at undergraduate and graduate levels will draw the learners' attention to the potential of these crops. Graduates may become self-employed NUS entrepreneurs in the process; others will use their insights on NUS in private- or public-sector employment. Either way, the teaching on NUS crops brings a balance to agricultural education that has been skewed in favor of few staple crops and commodities.

Context matters: value chain approaches and an enabling environment

In the experience of Bioversity International, an international research organization that has worked on NUS for over 20 years, the promotion of NUS works best when a value chain approach is used. This way, the views of all involved stakeholders in the value chain can be taken into account, problems jointly analysed, conflicts resolved, and solutions agreed upon. A multi-stakeholder platform involving value chain actors including producers, processors, consumers, private sector, supporting organizations and policy actors, etc., is the key vehicle for this dialogue. This means that the capacity to facilitate dialogue in multi-stakeholder

platforms is an important skill to develop in graduates interested in NUS. 'Soft' skills and technical capabilities go together.

Likewise, attention to the enabling policy environment is essential, as countries agricultural policies, programmes and incentives tend to favour the main species while paying limited attention to the NUS. Capacity is therefore needed to analyse the enabling environment in which a NUS value chain operates and engage in policy consultations that help address emerging issues. In this respect the NUS value chain process has much in common with the approach of the Tropical Agriculture Platform (TAP), a G20 initiative aiming to contribute to the development of national capacities for agricultural innovation in the tropics. At the core of the TAP 'Common Framework on Capacity Development for Agricultural Innovation Systems' is to simultaneous address capacity needs at individual, organizational and enabling environment levels (Tropical Agriculture Platform, 2016). The strengthening of NUS education in African universities and technical colleges can then be viewed in the light of broader initiatives on agricultural innovation and transformation.

Using this Training Manual creatively

African colleges and universities have started using the earlier mentioned Curriculum Guide to introduce NUS in various courses, but much work remains, given the long cycle of curricula reviews. A sustained effort is needed to keep the momentum and seize new opportunities for integrating NUS in courses and programmes. This Teaching Manual, and the promotion of it in various forums, is serving that function. Used creatively and flexibly the Teaching Manual can assist and inspire universities and technical colleges in promoting the benefits of NUS not only through education but also, importantly, through research, development and business.

One way to use this guide, among many, could be to pick a set of NUS from this Manual that are well known to staff and students and build the course or programme around those. Taking a value chain approach and analysing constraints and opportunities in collaboration with farmers and value chain actors could provide a very rich source of learning. A rapid appraisal of a selected NUS value chain at a local market is a practical and useful way to start. This would help the learner explore aspects of demand and consumer preferences – an extremely important aspect – linked to supply, quality and price, among others. Then, capturing the wealth of knowledge from current NUS farmers would provide insights in the production side. A look at the service providers for the NUS value chain can capture yet other dimensions in need of strengthening. National and international business opportunities in 'novel products' could be other entry points. All of this could lead to an analysis of constraints and how to address them, and a reflection on what competencies graduates would need to facilitate the value chain upgrading process.

The work on NUS value chains will also generate a wealth of 'researchable' problems that lend themselves to interesting research projects for students and staff. As most NUS are very little researched, quick progress can be made, for example via post graduate research projects. Finally, by linking education and the private sector the NUS can present excellent opportunities for entrepreneurship and agribusiness education. The step from an MSc thesis on, for example, product development of grain amaranth towards starting a small business may not be a long one.

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Chapter 2

Neglected and Underutilized Fruits and Nuts

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Overview

This chapter introduces the basic concepts of neglected and underutilized fruits and nuts with case studies from across Africa. It describes the importance of the fruits and nuts to livelihood and development. The botany, propagation and on-farm cultivation challenges are explained. For some selected species the ecology, physiology, phenology, protection, harvesting, storage, processing, value addition, marketing as well as certification are discussed.

Importance of fruits and nuts

There are many plant species for fruits and nuts from forestry, agriculture and other allied land uses which have been used to sustain human livelihoods for centuries. Most of these species have however, been neglected and consequently underutilized although they could play key roles in sustaining livelihoods and contribute to development. Underutilized fruits and nuts can either be wild harvested, locally cultivated and utilized, cultivated and new uses identified or cultivated in a place, but values proven elsewhere under similar geographical conditions.

Edible fruits and nuts especially those from the wild have been important to the rural people not only as nutritious food and medicine but also as sources of income. About 30,000 edible plant species are known out of which 7,000 are utilized as food and only 103 plant species contribute to over 90% of the world's calories. This shows that most of fruits and nuts particularly those from the wild are not known and hence neglected and/or underutilized.

The neglected and underutilized fruits and nuts could play key roles in contributing to food and health security as well as poverty alleviation while stabilizing our environment. Commercial extraction of wild fruits in some African regions as per luocha et al. (2016) is still low despite their importance in providing food security, nutrition and contribution to poverty alleviation. Access to market information is still poor, users lack processing technologies and skills, value chains are weak. Besides, the product standard requirements hinder entrance of the NUS fruits and nuts into markets.

Currently cultivated fruits and nuts, and challenges

Most of the neglected and underutilized fruits and nuts can be easily cultivated. However, research on proper propagation methods as well awareness of the potential users is crucial. Further, cultivation of the wild species is vital as it will reduce pressure on extraction thereby enabling conservation of wild resources. Some fruit species like *Syzigium marangese, Psidium guajava, Eriobotrya japonica, Mangifera indica, Citrus sinensis, Carica papaya, Passiflora* spp*., Persica Americana, Annona squamosa, Manilkara sapota and Carica limon* have been cultivated in Kenya due to their potential for food and market opportunities.

The major challenges in promoting cultivation of neglected fruits and nuts have been the loss of local knowledge regarding their identification and utilization potential, limited research and development, inadequate efforts to promote their cultivation, absence of processing and commercialization efforts, (including value addition), localized marketing system with low quality products and uncompetitive and unorganized value chains. The consequences are inefficient commercialization and unsustainable utilization. Most of the neglected and underutilized fruits are seasonal in terms of availability and harvesting and storage is still problematic. Generally, there has been underestimation of the neglected species utilization due to lack of full botanical data, inadequate scientific information on the food and nutrition value, inadequate promotion, stigma attached to the resources being food for the poor and high rate of ecosystem degradation and habitat destructions. All these pose challenges when it comes to promotion of the neglected fruits and nuts to tap their full potential.

Underutilized Fruits and Nuts

Some species of fruits and nuts have been documented in Africa. These are *Adansonia digitata* (Baobab), *Annona squamosa* (Custard apple), *Artocarpus heterophyllus* (Jackfruit), *Carissa edulis* (Natal plum), *Lagenaria sphaerica* (Wild calabash), *Tamarindus indica* (Tamarind), *Syzigium cuminii* (Jewish plums) and *Ziziphus sp*. (Ber, jujube). Other include Desert dates (*Balanites aegyptiaca* (L.) Del.), *Balanites rotundifolia* (van Tieghem) Blatter, Wil almond/bird plum (*Berchemia discolor* (Klotzsch) Hemsl), desert water melon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai), musk melon (*Cucumis melo* L.), Velvet tamarind (*Dialium guineense* Willd.), *Garcinia buchananii* Baker, Rusty-leaved lannea (*Lannea schimperi* (Hochst. ex A. Rich.) Engl.), Indian fig (*Opuntia ficusindica* (L.) Miller), Devil's Claw (*Proboscidea parviflora* (Woot.) Woot. and Standl), Mongongo (*Schinziophyton rautanenii* Hutch. ex Radcl. -Sm), *Ziziphus spinachristi* (L.) Desf.

In the tropics, Pareek and Sharma (2009) documented more than thirty plant families of neglected fruits and nuts (Table 2.1).

Table 2.1: Plant families and genus of NUS in the tropics

Family	Genus
Apocynaceae	Aegle, Acrocomia, Adansonia, Allaeanthus,
Anacardiaceae	Anacardium, Anacolosa, Ananas, Annona,
Annonaceae, Araceae	Antidesma, Arenga, Argania, Artocarpus, Asimina
Balanitaceae	Astrocaryum, Averrhoa, Baccaurea, Bactris,

Bombaceae	Bertholletia, Blighia, Borassus, Borojoa, Bouea,
Boraginaceae	Bromelia, Brosimum, Butyrospermum, Byrsonim
Bromeliaceae,	Calocarpum, Canarium, Capparis, Carica, Cariss
Burseraceae, Cactaceae,	Caryocar, Caryodendron, Casimiroa, Cecropia,
Caricaceae,	Ceratonia, Chrysobalanus, Chrysophyllum
Caryocaraceae,	Citrofortunella, Citrus, Clausena, Coccoloba, Cola
Chrysobalanaceae,	Cordeauxia, Cordia, Couepia, Coula, Couma,
Dilleniaceae, Ebenaceae,	Crataegus, Cynometra, Cyphomandra, Dacryodes,
Elaeagnaceae,	Dillenia, Dimocarpus, Diospyros, Diploknema
Elaeagnaceae,	Dillenia, Dimocarpus, Diospyros, Diploknema
Elaeocarpaceae,	Dipteryx, Dovyalis, Durio, Elaeagnus,
Euphorbiaceae,	Elaeocarpus, Emblica, Ensete, Eugenia, Euryale,
Flacourticeae, Guttiferae,	Euterpe, Feijoa, Feronia, Ficus, Flacourtia, Garcinia,
Lauraceae	Genipa, Gnetum, Grewia, Grias, Guazuma,
Lecythidaceae	Hovenia, Hylocereus, Inga, Inocarpus, Irvingia,
Leguminoseae	Lansium, Lecythis, Licania, Litchi, Litsea, Lucuma
Malpighiaceae	Macadamia, Madhuca, Malpighia, Mammea,
Meliaceae, Moraceae,	Balanites, Mangijera, Manilkara, Matisia,
Myrtaceae, Musaceae,	Mauritia, Melicoccus, Monstera, Moringa, Morus
Olacaceae, Oxalidaceae,	Muntingia, Musa, Myrciaria, Nephelium,
Palmae, Pandanaceae	Noronhia, Oncoba, Opuntia, Pachira, Parinari,
Passifioraceae, Rutaceae	Parkia, Parthenocissus, Passijlora, Pereskia, Persea
Salvadoraceae,	Phoenix, Phyllanthus, Physalis, Pithecellobium,
Sapindaceae, Sapotaceae	Platonia, Pometia, Pourouma, Pouteria, Prosopis,
Solanaceae,	Psidium, Punica, Quararibea, Rheedia,
Sterculiaceae, Tiliaceae,	Rhodomyrtus, Ricinodendron, Salacca, Salvadora,
Urticaceae, Verbenaceae	Sandoricum, Santalum, Semecarpus, Sicana, Stelechocarpus, Solanum, Soleirolia, Spondias, Strychnos, Synsepalum, Syzygium, Talisia, Tamarindus, Telfairia, Theobroma, Trapa, Treculia, Triphasia, Ugni, Vangueria, Vitex, Vitis, Ximenia, Ziziphus.

Source: Pareek and Sharma (2009).

In South Africa, du Preez (2003) mentions eighty underutilized fruits used in the rural areas of Africa to include *Carissa macrocarpa* (num num), *Carpobrotus edulis* (sour fig), *Dovyalis caffra* (kei-apple), *Grewia flava* (velvet raisin bush), *Harpephyllum caffrum* (wild plum), *Nylandtia spinosa* (tortoise berry), *Olea africana* (wild olive), *Syzygium cordatum* (waterberry), *Osyris compressa* (colpoon), *Carissa bispinosa* (num num), *Carpobrotus edulis* (sour fig), *Muraltia spinosa* (tortoise berry), *Chrysanthemoides monilifera* (bietou), *Grewia occidentalis* (crossberry), *Olea europaea* subsp. *africana* (wild olive) and *Chironia baccifera* (Christmas berry) as fruits with potential health benefits to communities.

A total of fifty-seven (57) indigenous fruit species have been recorded as edible among rural communities in Mwingi district, Kenya. The common species in the district are *Tamarindus*

indica, *Adansonia digitata*, *Balanites aegyptiaca*, *Berchemia discolor*, *Grewia tembensis*, *Grewia villosa*, *Opilia campestris*, *Premna resnosa*, *Tenantia senii* and *Vitex payos* (Simitu, 2011). Furthermore, about 75 Strychnos species have been recognized in the woodlands of Southern Africa as producing edible fruits. The commonly consumed species are *S. innocua* (syn. *S. madagascariensis*), S. *cocculoides*, *S. pungens* and *S. spinosa* (Mwamba, 2006).

In Tanzania wild fruits which are often neglected and underutilized are reported to be used as food, beverages, and sources of essential oils for cooking. The main fruits are *Adansonia digitata* (beverage, oils, food), *Allanblackia stulhmanii* (oils), *Parinari curatefolia* (oils, beverages), *Cordia sinensis* (food), *Azanza garckeana* (food), *Uapaca kirkiana* (food), beverage), *Rhus vulgaris* (food), Vitex spp. (food), *Strychnos cocculoides* (food, beverage), *Tamarindus indica* (beverage) and Sclerocarya subspecies *birrea*, *caffra*, and *multifoliolata*.

Some nuts species have been documented in Africa and they include *Jatropha curcas* (Physic Nut) and *Kerstingiella geocarpa* (Kersting's groundnut), Bambara Groundnut (Vigna subterranea L.) Verdc., Betel Nut (Areca catechu), Macadamia Nuts (*Macadamia integrifolia* and *M. tetraphylla*), Cashew Nut (*Anacardium occidentale* L.), Maya nut (*Brosimum alicastrum*), Malabar chestnut (*Pachira aquatica*), Kersting's groundnut (*Macrotyloma geocarpum*), Argan (*Argania spinosa* (L.) Skeels), Club wood (*Carapa procera* DC.), Yeheb (*Cordeauxia edulis* Hemsley), *Treculia africana* (African breadnut) and *Irvingia gabonensis* (Aubrey-Lecomte ex O. Rorke) Baill.(Dika nut). The latter species is also recognized in Africa for production of wild fruits known as African Bush mango.

Management of selected species

African breadnut (Treculia Africana Decne)

This species is known across Africa for its nutritive and medicinal benefits. The nuts are utilized as food as well as other traditional uses. For example, some African tribes eat the nuts as dessert after roasting or boilingthem. Others grind the nuts for soup and/or produce baked food varieties in forms of bread and paste (Nwabueze, 2006; Nwabueze and Maduebibisi, 2007; Nwabueze et al., 2008). Some tribes in Nigeria use the powdered seeds to make a non-alcoholic beverage known as almond milk for breakfast as well as weaning food (Nwabueze, 2006; Okeke et al., 2008; Enibe, 2007).

In Africa the species is claimed to be utilized for hastening and stimulating skin, hair and bone growth including medicinal values to cure malaria, cough, rheumatism and diabetes. A decoction of roots is reported to be used for anthelmintic and febrifuge, caustic sap treats carious teeth. A bark decoction treats cough and whooping cough; ground bark mixed with oil treats swelling, leprosy and is also consumed as a laxative. The fruits are often hard and fibrous, big and up to 8.5 kg weight. The nuts are said to be a good source of edible proteins worldwide producing nutritious and oil rich foods.

Research shows that the pulp of the fruit is not edible by humans but is suitable for livestock, the tree produces many nuts with 12-23% protein and up to 15% fat. Therefore, the nuts form an important part of diet. The sap of the male tree is said to be caustic and toxic while that of

female tree is said to be utilized medicinally (Barwick, 2004). Environmentally, the African breadnut trees are used for fencing (41). The tree is also used in soil conservation especially the litter as mulch and for intercropping systems in agroforestry.

Ecology: The species often occupies riverine, mixed evergreen, areas or swampy forests and woodland at altitude between 1300 - 1500 m. The species performs well in areas with mean annual rainfall ranging from 1200 to 3000 mm, and temperature range between 21 – 35ºC. It also grows well in a variety of soils but preferably deep moisture retentive soils requiring partial shade or full sunlight. Research indicates that under favourable climatic and soil conditions, 120 – 200 kgs of dried seeds can be harvested per year/tree. Under favourable climatic conditions fruit collection throughout the year is possible.

Botany: *T. africana* is an evergreen tree, large, fluted bole, growing wild in forests and wet areas. The trees grow to between 15 and 30m height, although in some cases they can reach 50 m (Ruffo et al., 2002). It belongs to the family Moraceae, genus Treculia. Leaves are globose large, borne in leaf axil or older wood and branches, dark green above and lighter below; inflorescences unisexual and/or bisexual. Fruits are round, big and greenish yellow; spongy texture when ripe with abundant edible seeds which are dicotyledonous in nature. The tree species is common in tropical Africa from Senegal to Sudan, Uganda and Kenya, Angola, Malawi, Zambia and Mozambique.

Phenology: *T. africana* flowers between July and October depending on geographical conditions. The ripening of fruits is mainly during rainy season for most tropical countries especially in December and may persist up to July. According to Orwa et al. (2009), if not directly picked from the tree the ripe fruits fall and become food for small animals that are vectors for seed dispersal.

Germplasm: The seeds of *T. africana* are othordox implying their ability to survive drying and/or freezing during ex-situ conservation. Adindu and Williams (2003) suggested further studies to determine appropriate moisture content for storage of *T. africana* seeds to ensure better handling. However, germination of above 80% has been recorded for freshly collected seeds sown in medium and fine sands (Dickens, 2013). Dickens suggests that since the species seed storage has deleterious effect on the germination, storage beyond two weeks is discouraged and seeds need to be sown soon after extraction from the fruit pulp especially on fine sand. Six varieties of the species exist to include *T. africana* var. *africana* Decne. ex Trec., *T. africana* var. *inversa* J.C. Okafor, T. *africana* var. *madagascarica* (N.E. br.) C.C. berg., *T. africana* var. *sambiranensis* (Leandri) C.C. Berg., *T. africana* var. *ilicifolia* (Leandri) C.C. Berg. and *T. africana* var. *mollis* (Engl.) Leonard are taxonomically differentiated based on the size of the fruit, leaves and hairiness branchlets.

Propagation: The species is common in the wild but can be cultivated or semi-cultivated around homestead or left in farms for protection especially where clearance for agriculture is done. Cultivation of the species can be done by seedling through pot or direct spot sowing to site. Seed pre-treatment is not required. Propagation by budding, cuttings and shield grafting is also possible. Despite the species potential little efforts to propagate has been done across Africa and in some areas the species is endangered requiring protection from loss due to deforestation and other threats. Okafor et al. (2016) observed that full strength MS basal medium provides

optimum growth for *T. africana* regeneration *in vitro*. This implies the species can also be propagated using tissue culture method especially where mass propagation is required.

Nutrient management: The agronomic studies by Enibe et al (2007) indicated that seed sterilisation aids in production of lower number of deformed seedlings.

Harvesting and storage: The nuts from *T. africana* are obtained after picking ripe fruits from the tree where processing is mandatory to separate the pulp and seeds through maceration in water. The seeds are later roasted to enable peeling of the small nuts. It is claimed that falling fruits should not be collected since they can be fatal. The peeling can be done manually or by use of simple machines. Shelled nuts often don't last long in hot and humid tropical conditions. It has been observed (Okonkwo and Ubani, 2012) that the shelf-life of the dehulled *T. africana* seeds is shorter (i.e. 9 months) than that of the whole seeds (i.e. 24 months in cool dry place).

Processing and value addition: The primary processing for *T. Africana* is for food, and it involves soaking the seed nuts. Preconditioning of seed nuts may be done in warm water before malting (Ejiofor and Okafor, 1997) or soaking in hot water to improve dehulling process (Odeamelam, 2000) as well as enhance some functional properties of flour from the seeds. Postharvest losses often occur for the species due to poor handling and preservation. According to Ijeh et al. (2010), boiling and drying at high temperature reduces selenium and iodine content and may cause seed losses. The duration of cooking affects odour and colour of the final product from the seeds (Ragone, 2011). All in all, cooking and roasting of seeds have been claimed to improve its nutritional qualities as food. In terms of value addition, researches in Ghana (Appiah et al., 2011) have shown that production of *T. africana* and soybean composite in a ratio of 9:1 improves the breakfast meal. Seed gum from the species has shown positive results to serve as local alternative binder in metronidazole tablet production (Uzondu et al., 2014). It is important to note that processed *T. africana* seeds must meet required standards for food safety and quality in both national and international markets.

Marketing: T. africana is a commercially important species especially in West African countries due to its contribution to income at household level. In the whole marketing process, the fruits are gathered, processed, seeds stored and packed, transported and traded at destination. Its potential for health and economic gain makes the species highly demanded in African local markets. If promoted and marketed the demand-supply gap may widen up. Moujekwu et al. (2017) recorded a monthly net marketing income of N 37,569 for wholesalers and N 75,754 for retailers in Anambra State of Nigeria. Engagement of communities in the trade on the seed of *Treculia africana* as a very high profitable venture and can generate substantial income.

Soursop (*Annona muricata L.*)

Soursop, also commonly known as Custard apple, is a tropical species belonging to family *Annonaceae* and currently neglected and underutilized across Africa. It is popular due to its many medicinal uses. Over 200 chemical compounds are reported to be identified and isolated from the fruit. Phytochemically, *A. muricata* is rich in secondary class metabolite compounds such as alkaloids, saponins, terpenoids, flavonoids, coumarins and lactones, anthraquinones, tannins, cardiac glycosides, phenols and phytosterols (Gavamukulya et al., 2014). The most

important bioactives are the alkaloids, phenols and acetogenins (Coria-Téllez et al., 2016; Gavamukulya et al., 2017).

The Soursop fruits are often eaten fresh or squeezed to produce juices. It serves as a good source of vitamins, dietary fibre and minerals. It also provides flavour, aroma and texture to the pleasures of eating food. The species is claimed to have anticancer and antioxidant capabilities (Luzia et al., 2012); especially for treatment of breast cancer. It is said to be more effective than chemotherapy (Oberlies et al., 1997; Cassileth, 2008). According to Khaitadul (2009), the soursop fruit and its juices are also taken as medicine for worms and parasites, fevers, to increase lactation after childbirth, and as an astringent for diarrhoea and dysentery. In Tanzania, Othman et al. (2014) noted that *A. muricata* fruits have valuable role in fulfilling daily human diet needs and serves as a healthy medical supplement for certain ailments.

Traditionally in tropical regions, *A. muricata* have been identified to treat diverse ailments including pain, respiratory and skin illnesses, internal and external parasites, bacterial infections, hypertension and inflammation using its leaves, bark, roots, fruits or seeds (Badrie, 2010). The most widely used preparation in traditional medicine is the decoction of bark, root, seed or leaf where applications do vary from one geographical location to another. In Uganda for example, Ssenyange et al. (2015) noted that all parts are used to treat malaria, stomach ache, parasitic infections, and diabetes. The use of leaves to treat malaria has also been very important in Cameroon, Togo, and Vietnam (Boyom et al., 2011; Nguyen-Pouplin et al., 2007; Pieme et al., 2014; Ross, 2010). In Ghana also, *A. muricata* with other plants are decocted into a mixture and used in bath for pregnant mothers prior to birth (Asase et al., 2012). Of recent, the medicinal uses of *A. muricata* leaves have been treatments for hypertension (Bidrie and Schauss, 2010; Hajdu and Hohmann, 2012; Ezuruke and Prieto, 2014), diabetes (Bidrie and Schauss, 2010; Badrie, 2010; De Souza et al., 2011; Ezuruke and Prieto, 2014; Mootoosamy and Mahomoodally, 2014) and cancer (Alonso-Castro et al., 2011; Atawodi, 2011; Badrie, 2010; Monigatti et al., 2013; Gavamukulya et al., 2014; Moghadamtousi et al., 2015).

Some studies have demonstrated the species anti-hyperglycaemic, anti-hyperlipidemic, antimalarial, anti-parasitic, antibacterial, insecticidal, molluscicidal and antiviral properties (Khan et al., 1998; Antoun et al., 1999; Alali and Liu, 1999; Hamizah et al., 2012; Ezirim et al., 2013). *A. muricata* has also been reported to show insecticidal activity from all its parts including the seeds, leaves, barks, stems, roots and flowers (Laetemia and Isman, 2004; Bobadilla et al., 2005; Predes et al., 2011); antiviral activity in vitro against the herpes simplex virus (Padma et al., 1998). Anti-tumoral activity has been reported for extracts and some isolated acetogenins of *A. muricata*. According to studies by Hamizah et al. (2012) *A. muricata* leaves showed greater anti-tumor activity in murine models than curcumin, a known natural chemopreventive. *A. muricata* has also been used in agriculture as an intercrop plant with larger fruit trees such as mango, avocado, and santol (Koesriharti, 1991).

Ecology: This underutilized fruit tree species is reported to grow well in the moist, humid tropical and subtropical lowlands, temperature range between 25°c - 30°c, rainfall above 1000 mm and performs well in sunny environments (Orwa et al., 2008; Subhadrabandhu, 2001; Barwick, 2004) A. muricata is also reported to grow best in moist but well-drained, sandy loam with a pH in the range 5.5 - 6.5 i.e. Light-textured, alkaline soils (Huxley, 1992; Subhadrabandhu, 2001; Barwick, 2004). According to (Barwick, 2004), the species is claimed

to be drought torelant, able to survive in dry soil conditions sheding many leaves if the situation is prolonged.

Botany: *A. muricata* is a small, slender, upright, evergreen tree that can grow 5-10 m in height and 15 cm in diameter. It belongs to the family of Annonaceae and is the tropical semi deciduous tree with the largest fruits in the Annona genus (Ukwubile, 2012; Alawode, 2013). The trunk is straight with smooth bark; grey-brown, rough and fissures with age. Cross sectionally, the inner bark is pinkish in colour and tasteless. Leaves are oblong to oval, glossy dark green in colour without hairs. Flowers are terminal or lateral, large; stalks stout, green and rough on the outside with three inner petals, narrow, concave with fingernail-shaped base and overlapping edges (Figure 2.1). Fruits are large 14-40 x 10-18 cm (Figure 2.1); weigh up to 7 kg, ovoid, heart shaped, grows from the style, pulp white, fibrous and juicy; with dark brown or black shiny seeds. The species is widely distributed and native to sub-Saharan Africa countries. The species is known to be cultivated in Africa (mainly the warm lowlands of eastern and western Africa), temperate and tropical Asia, Australasia, North America, the south-central Pacific Islands, the Caribbean, and Mesoamerica.

Leaves and fruit fruit section Flower

Figure 2.1: Illustration of *Annona muricata* leaves and flower fruit

Physiology and phenology: A recent study (de Oliveira and Lameira, 2017) on water and light stress interaction appeared to influence the development of *A. muricata* especially during the early stages of growth, in terms of photosynthetic capacity, transpiration, stomatal conductance and leaf temperature aspects. All in all, the species seems to be more tolerant to water stress due to drastic reduction of the stomatal conductance and transpiration rates. The species reported physiological aspects, suggests different ways of cultivation and water supply. Under moisture stress the species is deciduous (drops its leaves). For *A. muricata*, sporadic flowering and fruiting may happen throughout the year if conditions are favourable e.g. pollination efficiency and nutrient status. According to Orwa et al. (2008), the species fruit may contain 55–170 black seeds when fresh and turn light brown when dry.

Germplasm: *A. muricata* seeds are orthodox in nature, able to tolerate desiccation to 5%. Long-term storage under ideal conditions has been reported to be possible (Orwa et al., 2008). Seed

germination has been found to be affected by the moisture and oxygen content, due to the structure of the seed and high content of the lipid. The optimal condition for seed germination above 90% is 30 °C without scarification (Corchuelo and Villamil, 1998). Despite the importance of *A. muricata*, in most tropical countries of occurrence, improvement of its germplasm has been limited thus, hindering its effective conservation and utilization. A recent genetic diversity study (Thanachseyan et al., 2017) revealed a relatively limited genetic diversity within selected *A. muricata* accessions with respect to *A. cherimola* markers.

Propagation: The species can be propagated clonally through budding and grafting techniques on seedling stocks or commonly raised from seed (Morton, 1987). Seeds may be sown directly into the field or in a nursery bed (Barwick, 2004). The seed of many species in the genus Annonaceae has hard seed coats and hence the need for scarification before sowing to speed up germination. According to Orwa et al. (2008), scarification can be done by pouring a small amount of nearly boiling water on the seeds, care being taken not to cook them; and then soaking them for 12 - 24 hours in warm water. Air layering has also been reported to be possible, though the success rate has been considered minor. If the species is planted within 30 days of harvest, 90 percent of the seeds can be viable and germinate in 15–30 days. Some seeds will stay viable up to 6 months; and require washing before planting.

Nutrient management: Moderate application of fertilizer and manure has been found to increases fruit production for *A. muricata* especially during the early stages of growth (Orwa et al., 2009) to ensure vigorous growth. According to Bareja (2010), fertilizer application to the species can start a month after planting using ammonium sulfate (21-0-0) at the rate of 100-150 grams per tree. The rate can be increased annually until the start of the fruiting stage at which time 250-300 grams of complete fertilizer (14-14-14) could be applied. This amount can also increase every year from 1.5 to 3 kg plus 200-300 kg of muriate of potash (0-0-60). To ensure supply of micronutrients; organic fertilizers can be incorporated in the fertilization plan.

Protection - pests, diseases and weeds: According to Orwa et al. (2008) *Bephata maculicollis*, *Ceconata annonella*, Talponia *backeri*, *Thecla ortygnus*, scale insects and Mediterranean fruit fly are some of the insect pests which infest *A. muricata*. Other serious pests include the trunk borer Cratasomus spp. and other fruit borers in the orders Coleoptera, Diptera and Lepidoptera. Mousebirds do also attack the tree species. Heavy attack of the fruit tree by the fungus *Colletotrichum gloeosporioides* has been reported.

Harvesting and storage: Harvest of the fruits occurs after skin colour changes from light to a slightly yellowish-green. Fruits of the Annonaceae are often manually harvest either through cutting the stalk. Pruning with scissors leaving 0.5 to 1 cm of stalk has been suggested (Sinthiya and Poornima, 2017) to keep away from loss in weight and post-harvest fungal diseases. Depending on the situation, harvesting by climbing the tree, using a ladder or a picking pole with a hook and a basket at its end has also been a practice. Harvest of *A. muricata* is more difficult and time-consuming than other Annona fruits since its trees are often taller with larger fruits. However, since ripe fruits from the species when left unharvested do fall off naturally, rot and unmarketable; it is suggested that they be picked up and destroyed to avoid spread of pests and diseases throughout the field (Sinthiya and Poornima, 2017).

Generally, it takes 4 or 5 days for the fruit to fully ripen after picking. Once harvested, the fruit softens in 4–7 days and has a shelf life of up to seven days depending on the maturation stage

during harvest (Paull, 1998; de Lima, et al. 2003). The optimal edible stage is 6–7 days after harvest. A shelf life range of 4 to 8 days for *A. muricata* fruit ripened at 25°C has been reported (Espinosa et al., 2013) signifying a highly perishable product. Tovar-Gómez et al. (2011), pointed out a postharvest loss of 60% due to the perishable nature and the physical fragility of this fruit, causing the exportation to be undertaken on the day of harvest via airplane at a temperature of 13°C. Refrigeration could be another option for maintaining quality and reducing the rate of deterioration (Valero and Serrano, 2010). Information on the refrigeration temperatures required for increasing the shelf life of *A. muricata* fruits is inadequate.

Processing and value addition: Most of the Annonaceae fruits are perishable products; storage for a long period is limited. The shelf life of Annona fruits can be prolonged through processing into products such as juices, jam and jellies. This not only enhances the shelf life of products but also builds good markets relative to utilization in raw form (Sinthiya and Poornima, 2017). Further research is needed on the fruits value addition including processing, packaging and storage.

Marketing: Across Africa the demand and supply of *A. muricata* has been low because the products whether raw or semi-processed are retailed at local markets and sometimes along highways. Wholesale is often rare and depends on availability of customers for large scale processing. Generally, sales of the fruits are often slowly developed since local communities who consume the fruits have their own trees. A study by Love and Paull (2011) in Hawaii noted a growing demand for the fruit and its use in hotels for a broader range of culinary creations. The authors further report that growers in the area package similar-sized fruits for delivery to wholesalers at 2 – 3.50 USD per pound sold; and a few growers sell by weight at farmers' markets.

Macadamia nut (Macadamia tetraphylla L.A.S. Johnson)

Macadamia tetraphylla is among the neglected and underutilized valuable nut tree species introduced in across tropical countries from North America. This species together with *Macadamia integrifolia* and *Macadamia ternifolia*are are of importance due to their commercial values. Small scale farmers do depend on the species for income and other livelihood security due to its low-input investment (Waithaka, 2001). The nuts may also be eaten raw, dry roasted as snacks, used in bakery products, ice cream, confectioneries, in the restaurants and food service industries. *M. tetraphylla* for example, has been used as food to supply calories and essential nutrients such as vitamin B, Iron and magnesium to mention a few. According to USDA (2014), the nuts from Macadamia species are good sources of fat (76%), carbohydrates (14%), dietary fibres (9%) and protein (8%). Furthermore, in contrast with other common edible nuts like cashew nuts, the Macadamias contain high fat content (i.e. monounsaturated and omega-7) linked to reducing cholesterol in blood and low protein. According to Gitonga et al. (2017), Macadamia species have enormous potential for poverty reduction due to the high value of its products and its low requirement for external inputs. In Kenya as per Rotich (2004), Onsongo (2003) and Kiuru et al. (2004), Macadamia seem to be a growing agro-processing industry attracting niche markets in Europe. Due to this, the area under macadamia has increased from 469 ha to 8000 ha between1989 and 2003. *M. tetraphylla* is also grown as ornamental due to its glossy leaves and attractive flowers, timber, charcoal from shells, wind break, bee forage as well as in cosmetics (Mbuya et al., 1994).

Ecology: *M. tetraphylla* occurs in warm sub-humid and humid zones, withstanding mild frosts but for a short period. It prefers areas with well distributed rainfall (i.e. 700 – 2600 mm) mostly throughput the year, at altitude range of 0-2000 m a.s.l. The species grows well in areas with temperature range between 15 – 29^{o}C. It prefers soils which are well-drained with pH of not less than 5.5, fertile red loams or alluvia (Orwa et al., 2008). This evergreen tree species has been introduced in the coffee-growing areas of the Tanzanian highlands for production of its valuable nuts (Mbuya et al., 1994). Commercially, Macadamia is mostly grown in Australia, Hawaii, South Africa, Kenya, Guatemala, Malawi, Brazil, Zimbabwe and Costa Rica in order of level of production (Wilkie, 2008). Macadamia species are also grown in small scale in New Zealand, Mexico, Jamaica, Fiji, Argentina, Venezuela and Tanzania (Wasilwa et al., 1999).

Botany: *M. tetraphylla* is a small to medium sized tree, 15 – 18 m tall; evergreen, low branching but densely branched tree with a diameter at breast height reaching maximum of 45 cm. It belongs to the genus Macadamia in the family Proteaceae has a commercial lifespan ranging from 40 – 60 years (Cooke et al., 2009). The mature species has greyish-brown bark which can be smooth or finely wrinkled and hairy shoots when young. Leaves are simple, oblong about 25 cm long and 5 cm wide with rigid texture. The flowers are white or purple slender, drooping spikes. Fruits are hard roundish nut, greyish-green when young and turning brown when mature. Upon drying the husk turns black and contains a hard-shiny brown nutshell (Figure 2.2). Mature seeds often fall to the ground and collected to extract white kernel seed within (Mbuya et al., 1994; Orwa et al., 2008).

Inflorescence Fruits Nuts

Figure 2.2: Macadamia inflorescence, fruits and seeds (nuts)

Physiology: The physiology of subtropical evergreen fruit trees is not as well understood as that of deciduous species which have been extensively researched (McFayden et al., 2011). Plants are thought to grow slowly in cultivation where seedlings take over 6 years to produce their first fruit. However, pruning of the species with mechanical hedging has been observed to control the tree size for efficient orchard management (Possingham, 1986; McFadyen ,2006). According to McFadyen (2006), mechanical pruning of the tops of macadamia trees causes vigorous regrowth and reduces yield significantly.

Phenology: *M. tetraphylla* flowers amid August to October and fruits are reported to ripen in January (Orwa et al., 2008). While rainfall is claimed to influence the flowering season; drought may reduce vegetative flushing. Late season flowering can also occur when the species

trees are later irrigated or encounter heavy rainfall (Kawate and Tarutani, 2006). Temperature, water and nitrogen availability have been reported to affect the vegetative flushing in Macadamia trees (Olesen et al., 2006).

Germplasm: The genetic improvement of Macadamia trees has been done on introduction, selection from existing germplasm and characterization using agro-morphological traits. This process is however, slow for commercial planting. Moreover, morphological traits alone are influenced by environmental factors, which in turn limit their utility in describing the potentially complex genetic structures that may exist between and within species.

Propagation: Macadamia trees can be propagated using direct sowing method or artificially through grafting. Grafting is often constrained by requirement for long nursery period of between 18 - 24 months, skilled manpower, material inputs and space (Gitonga et al., 2017) compared to seedlings of other fruits which take 12 - 15 months in the nursery. Seeds are best sown soon after ripening in warm conditions, with dehusked seed being able to germinate rapidly at 25°C. *M. tetraphylla* can be successfully propagated through tissue culture. However, successful *in vitro* culture of the species can be based on basic empirical experimentation to optimize on the nutritional, growth regulator and culture growth conditions of the plant at each stage of the culture process.

Nutrient management: Macadamia trees require fertilization especially in young stages to facilitate good growth and production. It is claimed that slow discharge of fertilizers in a ratio of 2:4:1 or 1:1:1 of nitrogen-phosphorus-potassium provides good results depending on soil and location. It is recommended that applications of fertilizer be done three to four times per annum, increasing at the rate of the square of the trunk circumference until the trees mature (Hamilton et al., Undated).

Protection: Macadamia tree parts such as flowers, fruits, foliage and twigs are attacked by pests and diseases affecting growth and reducing productivity. Fungal diseases such as *Phytophthora cinamomi*, husk spot, blossom blight and husk rot are also known to infest *M. tetraphylla* trees (Mbuya et al., 1994). Other important insect pests of macadamia trees include southern green stinkbug (*Nezara viridula*), tropical nut borer (*Hypothenemus obscurus*) and litchi fruit moth (*C. ombrodelta*). Raceme and blossom blights caused by *Phytophthora capsici* are the most serious diseases especially in areas where there is lots of moisture due rainy or foggy environments as well as warmer conditions at lower elevations (Kawate and Tarutani, 2006). Weed management is also important in Macadamia nut production due to water and nutrients competition. Weeds further, provide shelter for insect pests and predators enhancing damage, hindering pest management initiatives as well as interfering with harvesting. The impacts of nematodes on macadamia production are unknown (Kawate and Tarutani, 2006).

Harvesting and storage: Once Macadamia nuts are mature and fall from trees they are collected by hand. Collection should be done immediately before nuts begin to mold, germinate, or become rotten. In difficult terrain, the use mechanical shakers to collect the nuts from the trees or mechanical harvesters to pick fallen nuts off the ground become inevitable (DAFF, 2015; Kawate and Tarutani 2006; Muthoka et al., 2008). Storage of harvested products is recommended to be in a cool, dry environment with very low moisture and oxygen in order to retain its original quality for a period of twelve months. According to Kawate and Tarutani (2006) deterioration may occur if kernels are packaged in poor quality materials such as

Polythene bags reducing shelf life considerably to less than a month before actual loss of eating quality is realized.

Processing and value addition: The Macadamia nuts value chain has been reported to include producers of nuts, processors who dry, crack (dehusk), sort, cook, roast, grade, package, store and distribute macadamia nuts; processing factories which market and sell final products to fresh produce markets, wholesalers, supermarkets, retailers and informal markets before reaching the end users (consumers). Husking is recommended to be done within 24 hours after harvesting to prevent development of off-flavours. The husked nuts should be dried in wire-bottomed trays under shade for about 2 weeks or in a forced-air dryer for 3 days at 100° F. Dried kernels are processed by roasting them in refined cooking oil for 12 to 15 minutes at 275° F, or dry roasting in a forced-air oven (DAFF, 2015).

Marketing: According to Muthoka et al. (2008), the Macadamia value chain in Kenya is short, with farmers at the primary end who produce, harvest, dry and store ready for sale. The dried nuts are later sold either on farm or purchased for processing by secondary actors such as companies or individuals via middlemen. Generally, the authors report that productivity is low for small holder farmers and the quality of nuts produced is inferior in contrast with large scale producers.

Success Stories

Macadamia farming and major processing operations – Case of Kenya Nut Company

Macadamia are among the highly-priced nuts in the world, attracting customers in the international market. Kenya Nut Company is one of the biggest producers of processed Macadamia nuts that are exported to markets in Europe and North America. The company produced and distributed seedlings to farmers and about 1150 ha of Macadamia trees were grown in plantation.

In 1974, the company built a small-scale Macadamia processing unit, and is currently exporting macadamia nuts with the brand "***Out of Africa***". Annually, 1000 metric tonnes of Macadamia nuts are produced, 2500 people are employed with a turnover of about 1.5 billion Kenyan shillings. **Source**: http://www.farmerstrend.co.ke/ .

Mongongo nut (Schinziophyton rautanenii (Schinz) Radcl.)

Mongongo nut is a neglected and underutilized multipurpose tree species which offers considerable health, economic and ecological benefits to people who depend on it for livelihoods. In Southern Africa especially Botswana and Namibia, Bushmen who are hunter-gatherers have been using the edible nuts from the species (locally known as Manketti or Mongongo nuts) as staple diet due to their flavour, easy storage and ability to remain edible for a longer period. Furthermore, the fruit pulp which tastes like dates though less sweet, is often eaten raw, cooked, or used to produce a strong local alcoholic brew (Facciola, 1998). Some communities across Africa where the tree species is available utilize the seed oil for soups to add nutrients (Curtis and Mannheimer, 2005; Chidumayo, 2016). The fruits are quite useful especially in times of drought when agricultural crops fail to satisfy local people needs. In some southern African countries including Namibia, the wood is used for carving and

furniture making; for construction of fishing floats, dart and drawing boards due to its light weight as well as crates and coffins. In Zambia the wood from S. *rautanenii* has been reported to be used for carpentry, making musical instruments, curios and toys and board games (Coates-Palgrave, 2002; Chidumayo, 2016).

According to Zimba et al. (2005) and Chivandi et al. (2008), in Zimbabwe, the oil from the species nuts is traditionally used for cooking and as a body rub in the dry seasons to clean and moisten the skin. The oil is also used in the production of lubricants, soaps and personal care products (Lautenschläger, 2003; IFAD, 2008; Nemarundwe et al., 2008) due to presence of fatty acids (i.e. linoleic, oleic, palmitic, linolenic, and erucic acid) and topical treatment for hair dandruff, muscle spasms, varicose veins and wounds (Zimba et al., 2005; Chivandi et al., 2008).

The fruits can also be dried and ground into a powder for use in porridge as a good source of carbohydrates, potassium and thiamine (Ruffo et al., 2002) as well as consumed as sweetmeats. Traditionally roots from *S. rautanenii* have been utilized across Africa for handling stomach pains and the nuts are often tied around the ankles to relieve leg pains. Phytochemical compounds mainly alkaloids, flavonoids, anthraquinones, coumarins and triterpenenes, are known to provide either chemo-preventative activity against cancer initiation and progression and antiproliferative properties have been reported from the species (Dushmemamria, 2014). The species also has potential use in desert encroachment prevention, sand dune stabilization, and arid land reclamation and soil erosion control. Cuttings have been reported in Angola for live fences (Facciola, 1998).

Ecology: Generally, the species performs well in arid to moist tropical and subtropical areas. It occurs in altitude range between 200 to 1500 m above sea level and grows well in areas with annual rainfall between 200–1000 mm. It also grows best in areas where temperatures range between 18°c - 30°c, although it can tolerate 10°c - 40°c.The species is reported to be widely distributed in subtropical southern Africa from, Southern Tanzania, southern Democratic Republic of Congo, Angola, Botswana, Namibia, Zimbabwe, Mozambique, Zambia, Malawi and northern South Africa. It is also commonly found on sandy soils in deciduous woodland, along rivers, on wooded hillsides, short grassland with scattered trees, often on Kalahari Desert (Chapano and Mugarisanwa, 2003; Heath and Heath, 2009).

The species requires well-drained soils, not compacted clay soils or areas subject to flooding or waterlogged and prefers a pH in the range 6.5 – 8.0 (Bonifacio et al., 2000). Strong winds are often reported to cause immature fruits to drop. The growth from seedling to sapling stage depends very much on the fire regime prevailing in the area. Fires reduce young saplings back to ground level if their bark is too thin to protect them (Chapano and Mugarisanwa, 2003; Heath and Heath, 2009).

Botany: *S. rautanenii* (Schinz) Radcl. is synonymous to *Ricinodendron rautanenii* Schinz; part of the Euphorbiaceae family. The species is a large rounded or spreading deciduous, dioeciously tree (locally known as known as *Mongongo* in Zambia and *Manketti* in other African countries). The species is of the monotypic genus Schinziophyton that reaches a height of 7–25 m, though is often smaller. The species trunk can reach 100 cm diameters at breast height with thick whitish, pale grey or pale golden-brown bark often peeling, dark-green leaves, and small whitish-yellow flowers (Vermaak et al., 2011). Flowers are unisexual on different

trees, calyx and ovary densely covered in golden-brown to rusty stellate hairs (Radcliffe-Smith, 1996; Setshogo, 2005). Leaves are distinctively hand-shaped spirally arranged along, hairy leaf stalks (Figure 2.3a). Fruits are egg-shaped, covered with grey-green hairs and skin turn hard, tough and brown when mature (Figure 2.3b). The species starts to bear fruits at 25 years producing up to 950 kg of edible nuts per hectare per annum (Graz, 2002).


a

b

Figure 2.3: *Schinziophyton rautanenii* leaves (a) and mature fruits (b)

Physiology: The tree species is well adapted to semi-arid environment. It develops a long taproot that reaches ground water. The species has a thick trunk that stores moisture and thick bark that protects the tree species from evaporation and from damage by wild fires (Radcliffe-Smith, 1996; Setshogo, 2005). Fruit production from the species has also been directly linked to the amount of rain received in previous season, with crop yields being higher in years following heavy rains (Graz, 2002).

Phenology: The species is a dioecious with both male and female forms needed if fruit and seed are to be produced. The species flowers in September to December. The young fruits fall from the tree in April to May onwards and ripen to red-brown on the ground causing the flesh to become soft (Childes, 1989; Vermaak et al., 2011). According to Ruffo et al. (2002), the trees are thought to start flowering and fruiting when about 20 years old and can live up to 100 years. Fruit production is closely linked to the amount of rain of the previous season, with crop yields higher in years following heavy rains. High rainfall after flowering on the other hand has been found to damage the developing fruits, as do fires late in the dry season (Graz, 2002). Fruits are often eaten by elephant and ostrich, which disperse the seeds. Due to the high sugar contents of the flesh, the fruits are often picked up and chewed by antelopes and porcupines (Ruffo et al., 2002).

Germplasm: *S. rautanenii* seems to be a widespread species and not documented to be threatened by the collection of its fruits for nuts, thus not in danger of genetic erosion. The Tree Seed Centre in Namibia (Graz, 2002) is reported to store a comprehensive seed collection. However, with the ongoing increase rate of anthropogenic activities across Africa leading into serious forest degradation and deforestation, the need for future conservation of the gene pool for this neglected and lesser utilized nut species is vital.

Propagation: The species can be propagated using vegetative methods such as cutting as well as direct seed sowing. For the later method, germination is erratic and may take place over an extended period if pre-treatment is not done. For easier germination the woody endocarp is

suggested to be removed or the seed end cut off to expose the kernel prior to sowing. Alternatively, the seeds can be soaked in water for a week followed by storage under high temperature and humidity for two days to reach better germination. Removal of the shell prior to sowing and treatment with ethylene has been found to increase germination by 80% or more within 6 days (Geldenhuys, 1975). All in all, the rate of non-surviving seedlings in the field for direct sown seedling is often high but once a seedling has been established it needs little attention (Childes, 1989) since they quickly develop deep roots.

Generally, artificial germination of the species is reported to be difficult, thus, a need for future research. Little improvement in germination rate has been noted when the seeds from the species pass through the digestive system of an elephant (Geldenhuys, 1975). In nursery conditions seedlings seem to grow slightly faster under moderate shade but it is not clear if this is a result of low light requirement or of reduced evaporation (Childes, 1989).

Protection: High rainfall after flowering has been found to damage the developing fruits, like late fires in the dry season (Childes, 1989), hence reduced nuts production. A range of fungi and insects also do attack the seed and wood of this tree species (Parker, 1978).

Harvesting and storage: Harvesting of *S. rautanenii* nuts starts at the end of the rainy season when fresh fruits have fallen and ripen on the ground, where they are simply picked up. Collection continues until the end of the dry season. Collected fruits are often cooked to soften the skin and allow easy peeling to obtain the nuts. Seeds do remain viable for up to two years when stored at 10°C (Geldenhuys, 1975).

Processing and value addition: Traditionally, nuts from this species have been used for subsistence at household level with limited sale to generate income. Currently, after realization of the species potential, processing is done at local level where stones are used to crack the nuts for production of quantities to cater for household consumption as well as sale. Several approaches to value addition have been promoted by PhytoTrade Africa where the nuts are often broken by the primary producers, core part extracted and later sold to a PhytoTrade member, who then processes the essential oils. Large quantities of oil are sold to a commercial partner in South Africa who refines it for sale to the cosmetics industry outside the country. The emergence of new markets for natural products and organic production has contributed towards promoting the commercialization of the nuts for livelihoods security of communities in countries like South Africa (Nemarundwe et al., 2008).

Marketing: Scanty information exists on the species demand and supply though literature show that some African countries have developed products from the nuts and attracted some markets even at international level. For example, in South Africa, patents exist for the nuts oil containing products as a possible component in topical formulations such as an antiparasitic formulation and a soap bar for microdermabrasion (Lucka and Mullen, 2010). Further marketing studies for the species to have clear database is required in terms of market assurance, standards, certification and patenting in areas where the species are found.

Case studies – Indigenous Knowledge of Edible Mungomu Tree in Central Mozambique

Source: Saxon and Chidiamassamba (2005).

Schinziophyton Rautanenii, locally known as Mungomu in Macossa, is a tree that produces a nut best known as one of the staples of the diet of the Kung Khoi-San tribe in the Kalahari Desert. The nut, recognized in English as the Manketti Nut, supplies up to three quarters of the dietary needs of this tribe. In Mozambique, it occurs irregularly in hot dry areas on poor soils, north of the Save River. It is recorded from Chibabava, Nhamatanda, Gorongosa, and Macossa Districts in Central Mozambique, and from Tete, Nampula and Cabo Delgado Provinces. The tree is found in both sporadically and almost pure stands. Saxon and Chidiamassamba (2005) reviewed and documented the local knowledge base on the Mungomu tree in the district of Macossa to establish variations in socio-economic context of the communities. The study focused on the Mungomu (*S. rautanenii*, synonymous to *Ricinodendron rautanenii*), a tree of the Miombo vegetation group that is known by the peoples of southern Africa as an important source of food, and easily worked wood. The study also looked at how the nut is used by local people and at its importance for food security. It was found that the majority of residents who stayed longer in the area were knowledgeable about the Mungomu tree and its nut Ngomu. Consumption was however declining due to the use of oilseeds from other plants like peanuts, and the high energy spent in cracking the nuts of Mungomu.

Challenges in cracking the nut were found to be the main barrier to maintaining, or possibly commercializing and fully optimize the utilization of Ngomu. The kernel was used to enrich sauces, to accompany meat, fish, and vegetables as well as produce oil. It has been noted that not all the parts of the Ngomu are used by the population of Macossa. The roots, the leaves, and the fruit pulp are often discarded. Several people mentioned eating the fruit pulp, but it was very astringent, contrasts with the experience in Namibia and Zambia, where the pulp is widely used for making moonshine (illegal distilled alcoholic drinks). Only three parts of the tree are used: the trunk, the nut shell, and the kernel. The trunk is a source of a very lightweight wood, used for the making of doors, musical instruments (“varimba”, “marimba”, “mbira”), cooking utensils (“ndiro”, “luko”), toys, stools, and still condensers (“mukondu”). The hard-external shell was reported to be used by traditional healers as a component of their divining “bones” (“ntsango”). Hunters use the nut casing as an amulet (a hole is made in the casing and a string tied around the waist) for good luck in hunting and fishing. The nut casing is also used as fuel. People were not aware of the nutritional value of the different species of fruits, roots, and wild vegetables known and used principally in times of food shortages. Consumption was noted to increase in difficult times, such as droughts and during the civil war. It was revealed that knowledge about the Ngomu did not vary according to the age of the respondents but rather according to where they came from. Farmers living in areas where the tree does not occur knew less about its uses. Although men have a general knowledge about Mungomu tree, women are the main users and managers of Ngomu. They are responsible for its collection, its preparation/processing and its sale.

In utilizing Ngomu as food, the local communities developed a set of processing technologies that vary in different areas of the district. In the locality of Nhacassoro and the surrounding areas of Gorongosa there were evolutions, bringing improvements in the processing methods. While in the rest of the district the nut was cracked using an axe and a stick with very low productivity, in Nhacassoro, the consumers of ngomu use two rocks, a big one and a small one, to crush the nut, with higher out turn. Three basic forms of cracking the nut to get the kernel of the Ngomu were documented:

i) An axe and stick were used in a very slow process with the added risk of incurring cuts to the hands. It had the advantage of producing a higher percentage of whole nuts. The nut was held against the upturned axe blade and then hit with the stick.
ii) A large and a small stone are as used to crush the nut, in a much faster process. It had the disadvantage of crushing the kernel as well, with some mixing of the endocarp, or inner shell, with the kernel. This system is mainly used in Nhacassoro.
iii) The whole nut is roasted in a fire, to facilitate the removal of the outer shell or exocarp. This system is also better known in Nhacassoro.

Once the kernel is extracted with one of the procedures described above, it can be used in various ways, according to the needs of the user. It can be eaten raw or roasted, the kernel can be turned into a paste to use as a sauce thickener/flavouring, or oil can be extracted from it.

The division of labour in relation to Mungomu and Ngomu was observed to base on gender. Men cut the trunk and then work with the wood. They locate Mungomu groves and alert women to the availability of Ngomu. On the other hand, women, helped by children, harvest, transport and process the Ngomu. Although men sometimes help during the harvest, women are the main actors in the collection, transformation and preparation of the ngomu. As a result, women have a more focused knowledge of the food uses and processing of the kernel. They can describe the processes of cracking the nut, preparing the ngomu, and Ngomu Oil extraction. The centrality of the women in the culture of Ngomu consumption makes her the main agent for preservation and transmission of the Ngomu culture to the younger generations.

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Chapter 3

Neglected and Underutlized Vegetables

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Overview

Vegetables contain a wide range of nutrients and fiber and constitute a major part of the human diet. In Africa, vegetables are cultivated widely in backyards or collected from the wild year-round. Commercialy cultivated vegetables are generally exotic and include cabbage, carrot, garlic, green pepper, onion and tomato while those used for subsistence tend to be indigenous and may be cultivated or collected from the wild. These include amaranthus, bitter leaf, corchorus, garden egg, leaf gourd, moringa, roselle and taro. They have received inadequate research attention and are frequently regarded as neglected and underutilized species (NUS). However, they are of significance in human diet, animal feed and in the mitigation of climate change. They also have potential to contribute to house-hold income and to food security. This chapter covers the importance, ecology, nutrient management and value addition of selected NUS vegetables used in sub-Saharan Africa. Relevant case studies have also been reviewed.

Importance of Vegetables

A vegetable is described as any herbaceous plant having parts that are used as food. Thus, any plant or plant part that is consumed fresh, cooked or pickled either as a side dish or in salads, or stews soups is considered as a vegetable. Sometimes vegetables serve only as a relish to garnish food. Vegetables are usually consumed with starchy staples or meat products to facilitate digestion and make such foods more palatable (Grubben, 1977). Vegetables could be immature fruits or seeds of certain cereals or legumes, mature fruits, roots, tubers, corms, bulbs, stems, leaves or flowers (Rice et al.,1990, Sinnadurai, 1973). The parts of a plant which are eaten are usually high in water volume and low in calories and dry matter content (Rice et al., 1990). The high content

of water in vegetables creates challenges with storage and hence vegetables must be processed before storage if they are not being consumed fresh. Processing methods include drying and making into powder or paste, pickling and freezing. However, processing reduces the nutritional quality of these vegetables compared to consumption of fresh produce. Vegetables are a major source of vitamins and minerals and play vital roles in the diet of many consumers (Keatings et al., 2011). Some vegetables also contain small amounts of protein and dietary fiber. They are known to prevent constipation, add to the bulk of food consumed and extend digestion thus reducing hunger pangs (Sinnadurai,1973, Rice et al., 1990). The high dietary fibre in vegetables helps in the digestion process by trapping carbohydrates during digestion (Jenkins et al., 2003). Vegetables have also been reported to neutralize acids released in the stomach during the digestion of proteins. Certain vegetables also contain antioxidants such as hydro soluble vitamins, carotenoids, glucosinolates and other plant phenols which are therapeutic. The activities of these antioxidants prevent the formation of reactive oxygen, nitrogen, hydroxyl and lipid species, by scavenging for free radicals or by repairing or removing damaged molecules (Kaushik et al., 2015). This helps to maintain good health and prevent diseases by controlling blood sugar levels and reducing the risk of diabetes and heart related problems (Jenkins et al., 2003). In a study conducted by Boeing et al. (2012), it was observed that there is a positive correlation between the intake of vegetables and fruits and the risk of several chronic diseases which indicated that an adequate daily intake of these foods promotes good health.

Vegetables can be cultivated either in home gardens, on subsistence scale or on commercial scale either for local market or for export. Farmers grow different kinds of vegetable crops that provide leaf, stem, flower, fruit or seed for consumption and sale. These vegetables have varying soil requirements and growing seasons enabling farmers to cultivate different vegetable crops throughout the year. This ensures regular and steady income to farmers (Saavedra et al., 2014). The cultivation of vegetables has been reported to provide income for many rural households, contributing in Ghana to about 60% of the house-hold income (Danquah-Jones, 2000; Owusu-Ansah et al., 2001). There are three major groups of vegetables (Rice et al., 1990):

a. Wild collections also categorized as weeds
b. Indigenous collections often gathered but may also be cultivated
c. Exotic vegetables which are often cultivated but also imported

Exotic vegetables cultivated in Africa include asparagus, aubergine, beetroot, brussel sprouts, butternut squash, cabbage, carrot, cauliflower, celery, chives, cucumber, French beans, garlic, leek, lettuce, okra, onion, pea, pepper, pumpkin, radish, shallots, spinach, sweet corn, sweet potato, sword beans, tomato, and turnips. Indigenous cultivated vegetables include African night shade, African yam bean, amaranthus, bitter lemon, colocasia, corchorus, *egushi*, leaf gourd, melon, moringa, roselle, spider plant, and xanthosoma. The wild types comprise purselane, shea, water leaf, and wild lettuce. Although these are all collected in the wild, they may also be cultivated.

Challenges of vegetable production in Africa

Factors that affect the production of vegetables may be categorized under three sections: Abiotic, biotic and socio-economic. Abiotic factors comprise climatic and edaphic factors. Climatic factors

include temperature, rainfall, atmospheric humidity, wind speed and day length. Edaphic factors include drainage, pH, salinity, soil fertility, soil structure and water holding capacity. Biotic factors include biological elements that limit crop growth and yield such as insect pests, diseases, weeds and nematodes.

Socio-economic challenges include the loss of indigenous knowledge and limited technical knowledge by farmers, insecure land tenure, inadequate supply of certified seeds, expensive and inadequate supply of agrochemicals and fertilizers, insufficient labour availability due to rural urban migration, reduced interest in farming especially by the youth, poor and unavailable processing units, poor market value chains, poor credit facilities, and export constraints such as stringent guidelines for good agricultural practices. Other socio-economic challenges include the mismanagement of pesticides, perceived low status of certain indigenous vegetables, use of polluted water for irrigation, over-exploitation of wild vegetable resources and the lack of political goodwill to support specific vegetable species. These challenges could be overcome by the creation of awareness on the importance of vegetables in human diets, development of capacity for their conservation and use, promotion of research and value addition, strengthening of market chains and policy support from governments.

Underutilized Vegetable Species

Vegetable species that are not among the major cultivated and widely used species are referred to as underutilized species. Such species are marginalized and are often not given due research attention and may not be included in policies (Padulosi et al., 2013). Usually they are non-commodity crops and may belong to domesticated, semi-domesticated or wild species. Underutilized vegetables are often managed by traditional systems while processing and marketing involve indigenous knowledge. However, when managed well, these species could contribute considerably to risk mitigation in agricultural production systems. In recent years their contribution to climate change mitigation has come to the fore. They have been reported to improve nutrition, generate income, maintain ecosystem health, promote cultural diversity, and empower the poor and marginalized in the society (Padulosi et al., 2013). Some of the neglected and underutilized vegetables worldwide are given in Table 3.1, while Table 3.2 gives some of the neglected and underutilized vegetable in Ghana.

Management of selected neglected and underutilized vegetables

Amaranthus (Amaranthus spp.)

Importance: Amaranthus, also known as leaf amaranth, is the most commonly grown leafy vegetable in the lowland tropical areas of Africa and Asia (Schippers, 2000; Sinnadurai, 1971). It is an important vegetable consumed by many indigenous people because it is very palatable, highly nutritious, cheap and available all year round. Worldwide there are over seventy (70) species of amaranthus, most of which are believed to have originated from the Americas.

Table 3.1: Selected Neglected and Underutilized Vegetables Species

Common Name	Origin	Scientific Name	Ecological adaptation	Uses
Moringa	Northwestern India	Moringa oleifera	It grows best in tropical and subtropical areas. Requires well-drained sandy, loamy, and sandy loam soils. Prefers a neutral to slightly acidic soil pH: 3.0 -7.0. It is drought resistant.	Serves as medicine in the treatment of anaemia, diabetes, diarrhoea, constipation, stomach and intestinal ulcers.
Leaf amaranth	Americas	*Amaranthus* sp	Resistant to drought and well-adapted to high environmental temperatures. Requires slightly acidic to slightly basic soil pH (6.5 – 7.5). Grows well in a well-drained loamy soil.	Used as a leafy vegetable, ornamental, dye and vegetable oil. Also used for medicinal purposes.
Locust bean	Africa	*Parkia biglobosa*	Grows well in drier lowland tropics. Prefers well-drained deep sandy to loamy cultivated soils of pH 4.5 – 5.5. Resistant to drought and grows best in sunny positions.	Pulp eaten fresh or made into sweetmeats and drinks. Seeds are fermented to make dawadawa. Used for medicinal purposes in treating fevers, diarrhoea and guinea worms. Serves as a wind break and provides shade.
Winged bean	New Guinea	*Phosphocarpus tetragonolobus*	Suitable in the tropical and subtropical regions with heavy rainfall but can thrive in dry climate. Prefers a loamy slightly acidic soil. Cannot withstand drought but can tolerate heavy soil.	Both leaves, flowers, roots and bean pods serve as food for humans. Used in making vegetable oil. Grows as a cover crop and also serves as an animal feed.
Chrysanthemum	East Africa	*Chrysanthemum* sp	Well adapted to the tropical and subtropical climatic conditions. Requires well-drained red loamy soil with slightly acidic soil pH ranging from 5.5 – 6.5.	Ornamental purposes, culinary uses and insecticidal uses.
Bitter gourd	India	*Momordica charantia*	Grows well in well-drained sandy loam soil rich in organic matter. Requires an alkaline soil of soil pH 8.0.	Culinary uses Medicinal purposes

			Suitable in areas with heavy rainfall. It is resistant to drought and extreme temperatures	
Snake gourd	South East Asia	*Trichosanthes cucumerina*	Grows best in tropical and subtropical areas. Suitable for sandy loam soils rich in organic matter. Grows well in alkaline soil of pH 8.0. Optimal temperature for growth (24 – 27 0C).	Medicinal uses (treating jaundice, diabetes and heart diseases). Serves as a vegetable for soups and stews.
Spider plant	South Africa	*Chlorophytum comosum*	Suitable under bright to moderate indirect light. Can be raised in-doors and in potting containers. Does not tolerate wet soil for longer periods. Highly adaptable to tropical and subtropical conditions. Prefers sandy loam soil for optimum growth.	Serves ornamental purposes, insecticidal uses (extract controls aphids and thrips attacks) and medicinal purposes.
(White jute, Tossa jute)	Southwest of Bangladesh India	*Corchorus capsularis* / *Corchorus olitorius*	Rich and fertile alluvium soil and warm moist climatic conditions. Requires temperature between 20 ^{0}C to 40 ^{0}C. Sandy loams and clay loams are ideal for cultivation.	Culinary and medicinal uses. Also used in paints and cosmetics. Making of rope and jute matting.
Black nightshade	Eurasia	Solanum nigrum	Very tolerant to dry conditions. Grows in acidic, neutral and basic soils.	Culinary uses, medicinal purposes.
Celosia	East Africa	*Celosia* sp	Prefers well-drained medium (loam), light (sandy) and heavy (clay) soils	Used for ornamental purposes, serves as food, treating diseases such as uterine bleeding, diarrhea and bloody stool. It is also a leafy vegetable.
Egusi	West Africa	*Citrullus colocynthis*	Grows well in lowland humid forest zone. Requires a well-drained sandy loam soil. It also grows well in marshy areas and prefers soil pH of between 6.0 and 6.5.	For culinary purposes, livestock fodder, medicinal properties (anti-inflammatory and anti-cancer properties).
Shea butter	West Africa	*Vitellaria paradoxa*	Grows well in sandy loams or slightly clayey soil rich in organic matter. Soil pH of 6.0 – 7.0 is ideal for optimum growth.	Used in the cosmetic industry for skin and hair related products. For making medicinal ointment.
Taro	Southern India and Southern Asia	*Colocasia esculentia*	Adapted to the drier lowland tropic. Grows best in sunny position and tolerates considerable amount of light shade. Grows well in clay, sandy-clay and stony soil. Prefers a soil pH range of 5.5 – 8.0.	Can serve as an ornamental, corms serve as food, and leaves are used for soups and stews. It can also be usedfor animal feed.

Golden thistle	Europe	*Scolymus hispanicus*	Best suited in tropical lowland areas with annual rainfall greater than 2000 mm. Grows well under semi-shade. Suitable for light to heavy (sandy, loamy, clay) soils; acidic, neutral and saline soils.	Medicinal and culinary uses
Bitter leaf	West Africa	Vernonia amuygdalina	Requires light to medium clay and sandy soils. Prefers well-drained fertile soils but can cope with acidic soils and moderate drought.	Medicinal usage (treatment of diarrhea, typhoid, malaria etc.) and. leaves are used for vegetable salads, stews, soups and beverages.
Purslane	North Africa	*Portulaca oleracea*	Suitable for the tropical growing conditions. Grows well in sandy loam soil with soil pH 6.0 – 7.5. Requires moderate amount of rainfall	Culinary and medicinal uses, livestock forage, leaves and stems serve as vegetables and green manure.
Ethiopian kale	North Africa (Ethiopia)	*Brassica carinata*	Suitable for tropical and subtropical growing conditions. Drought resistant. Wide adaptation from poor arid soils to rich garden soils with pH of 5.5 – 7.0.	Leafy vegetables, seed oil used to produce biofuel and can be used as a green manure.
Fluted gourd	West Africa	*Telfairia occidentalis*	Tolerant of a wide range of climatic conditions and can grow from temperate to tropical zones. It succeeds in a well-drained fertile alkaline soil with pH of 5.5 – 8.0. Does well with a mean rainfall of 800 – 1700 mm.	Mainly for food and medicinal purposes. Seed oil is used for cooking.
Roselle	West Africa	*Hibiscus sabdariffa*	Drought resistant. Grows well in the warm, humid tropics. Prefers a mean annual rainfall in the range of 1900 – 2200 mm. Suitable in soils with pH range of 6.5 – 7.0. Sandy loam soils preferred for cultivation.	Used as a leafy vegetables and beverage. Oily seeds used for soups and stews and it is a medicinal herb
Prickly pears	The Americas	*Opuntia fragilis*	Well adapted and cultivated in the tropical and subtropical zones. It also tolerates a warmer and more humid climate. Suits well-drained sandy loam with humus. Tolerates flooding, heavy winds or stagnant water. Soil pH of 4.5 to 8.0 is suitable.	Leaves serve as vegetables and are used as a thickener in soups and stews. Gum obtained from the stem is used in the production of candles and whitewash
Tomatillo	Mexico	*Physalis ixocarpa*	Suitable for light (sandy) and medium (loamy) soils. It prefers well-drained soils. Succeeds in both acidic, neutral	Key ingredients in soups and stews.

			and basic soils. It cannot grow under shade. It is drought tolerant.	
Water spinach	Pantropical	*Ipomoea aquatica*	Grows in well-drained sandy fertile soil condition with pH range of 5.5 - 7.3. It is cold sensitive and grows best at 25 - 32 ^{0}C.	Tender shoots and leaves used as a vegetable.
Waterleaf	North America	*Hydrophyllum occidentale*	Suitable for light (sandy), medium (loamy) and heavy (clay) soils. Can grow in acid, neutral and basic soils. It does not tolerate shade. It prefers moist or wet soil and can grow in water.	Leaves and roots serve as food
Baobab	Africa	*Adansonia digitata*	Suitable for light (sandy), medium (loamy) and heavy (clay) soils. It can grow in semishade (light woodland). It prefers moist soil.	Edible parts are used for vegetables and beverages and making of fiber dyes and fuel. It also serves medicinal purposes
Eru	West Africa	Guetum africanum	Succeeds in the lowland drier tropics with a mean annual temperature in the range 20 – 30 0C. Prefers a mean annual rainfall of 250 – 1000 mm. It is resistant to fire and grows well in sandy soils. It cannot grow in areas subject to frost but it is very tolerant to drought.	Leaves used as a vegetable and vines used as ropes or traps for catching game due to their durability and flexibility. Fruit, pulp and mature seeds are edible.
Crambe	West Asia	*Crambe cordifolia*	Shade-tolerant vine and prefers moist soils. Suitable for light (sandy), medium (loamy) and heavy (clay) soils. Grows well in acidic, neutral and basic soils.	Leaves used as vegetables herbs and cure for itching
Gourd	Africa	*Lagenaria siceraria*	Grows well in loamy soil and stony areas. Shade tolerant and prefers a slightly alkaline soil. Drought resistant.	Consumed as vegetable. Dried and used as utensils, containers and musical instruments
Chayote	Eastern Asia	*Citrus ichangensis*	Cultivated in tropical and subtropical areas. Suitable for sandy loamy and clay soils and prefers well-drained soils. Soil pH range of 5.5 to 7.5 suitable for growth. Requires moist soil and does not grow well under shade	It is used as a fruit and a lemon substitute.
Ivy gourd	Africa	*Coceinia grandis*	Does not grow under shade, requires moist soil conditions and prefers a moderately heavy loam soil for growth. Soil pH of 5.0 – 6.0 is preferred. Tolerates water-logging and grows well in pots.	Leaves and long slender stems cooked and eaten as a potherb or added to soups.

Indian poke	Eastern, Western and North America	*Veratrum viride*	Grows under tropical and subtropical climatic conditions. Succeeds in any soil but prefers shade in a humus-rich open soil	Dried and powdered root used as an insecticide and a parasiticide
Dika	Africa	Irvingia gabonensis	Suitable for moist or wet soils; sandy, loamy or clay soil with a pH range of 5.5 to 8.0. Grows well under semi-shade, not drought resistant. Prefers daytime temperatures of 20 - 38°C with a mean annual rainfall in the range of 1,200 - 3,300 mm.	Fruits and seeds used for soups and food flavouring. Kernel is an important source of vegetable oil. Used for agroforestry purposes.

Table 3.2: Underutilized NUS vegetable species in Ghana

Species	Common name	Location	Uses	Ecological adaptation	Community
Corchorus olitorius L.	Jew's mallow, Jute mallow, Bush okra	Asia and Africa	Leaves for soup, stem as raw material for paper pulp, leaves and roots also medicinal.	Grow in abandoned fields, often close to marshes rivers and lakes. Thrives best under hot and humid conditions	Ewe
Talinum triangulare	Waterleaf, talinum, Ceylon spinach	South America, West and Central Africa	Leaves for soups and stews, and leaves and roots also medicinal	It grows well under shade and in cloudy weather. Performs well in humid conditions at temperatures of about 30°C	Fante
Colocasia esculenta (L.) Schott	Taro	Tropical Asia and South west Pacific	Tuber used for food and animal feed. It is an ornamental plant and also serves medicinal purposes	Wet fields and near the banks of ponds and streams	Akan
Solanum macrocarpon L.	Gboma, gboma eggplant, African eggplant	Tropical Africa	Leaves and fruits are consumed as vegetables and incorporated into soups and stews Leaves and fruits are also medicinal	Adapted to humid coastal areas andrequires warm conditions for good growth.	Ewe, Fante

Solanum torvum SW.	Wild eggplant, prickly Solanum, Turkey berry, Komewu susua (Ashanti, Ghana)	Central and South America	Used in soups and sauces. Leaves, fruits and roots contain medicinal properties.	Establishes itself on open land in disturbed soil, along roads and on waste places	Ashanti
Solanum anguivi	Susua (Asante, Ghana)	Tropical Africa	Consumed as a leafy and/or fruit vegetable that are rich in essential minerals and vitamins	Grows well in humid localities	Akan
Amaranthus cruentus	Amaranth, African spinach, Indian spinach	Central America, Tropical Africa	Used as a leafy vegetable in soup and stews. Sometimes used as fodder, and contains medicinal properties	Grows well at day temperatures above 25°C and night temperatures not lower than 15°C Performs better in soils that are fertile, welldrained with loose structure. Adapted to humid and upland areas of Africa	Northern Ghana (tribes) mainly
Cleome gynandra	Spider plant, spider flower	Tropics and Subtropics; mainly found near human settlements	Tender leaves, young shoots and occasionally flowers are eaten boiled as potherb, relish or stew. Leaves and seeds are also medicinal	Requires warm conditions. Grows on a wide range of soils, mostly well drained sandy to clayey loam with PH 5.5–7.0.	Northern Ghana (tribes) mainly
Solanum aethiopicum	Ethiopian eggplant	Tropical Africa and South America (mainly Brazil)	Immature fruits are used as cooked vegetables in stews, soups or sometimes eaten raw. Fruits of bitter cultivars contain medicinal properties	Gilo Group thrives in full sun in woodland savanna. Kumba Group grows in hotter conditions (up to 45°C day temperature). Shum Group thrives under warm, humid conditions	Most tropical African countries

The most common species in Africa are Amaranthus *blitum* and *Amaranthus cruentus (Amaranthus hybridus)* (Schippers, 2000).

Ecology: The plant requires soils with high nutrient levels for optimum growth which invariably delay the onset of flowering and hence increase leaf yield. The plant also thrives well in disturbed, arid or saline habitats. Optimum soil pH for production ranges from 5.5-7.5. It, however, grows in a wide range of soils. The plant thrives within a temperature range of 22-30°C. Areas with elevations below 800 mm are most suitable for cultivation, but the crop also does well at higher altitudes (Rice et al., 1990).

Botany: Family: Amaranthaceae; Genus: Amaranthus; Chromosome number: 2n = 32. The crop is believed to have originated from Central America. It grows up to a height of 2 m. It is a short-lived annual with erect stems which are thick and fleshy without spines. The leaves are very long and are about two to three times the width. It has a large widely branched terminal inflorescence which is plume-like with a raceme diameter of 10 mm or more (Figure 3.1). Pollination of the plant is facilitated by wind and insects. Selfing and outcrossing may both occur as flowers are bisexual. Seeds are small and black with hard seed coats and are dispersed by wind and water. Seeds fall to the ground close to the parent plant but will only germinate when the site is disturbed (Schippers, 2000; Abbiw,1990).

Amaranthus roots

Amaranthus leaves and inflorescence

Figure 3.1: Amaranthus roots, flowers and inflorescence

Physiology and phenology: Amaranthus uses the C_4 photosynthetic pathway and hence it thrives well under high temperatures and bright light when water and nutrients are not lacking. High levels of nitrogen fertilizer delays flowering hence enhancing leaf yield. However, water stress induces early flowering (Schippers, 2000).

Germplasm: The taxonomy of amaranth is complex. It is a species found in tropical regions all over the world and contains species which are weeds, ornamentals, grains or pot herbs. Amaranthus germplasm collections are maintained in about 61 collection centers worldwide. Data from the National Bureau of Plant Genetic Resources, India include 2722 indigenous accessions, and 293 exotic accessions. In Africa there are about 6 known species but the most widely cultivated is the *A. cruentus/A.* hybridus (Schippers, 2000).

Propagation: Amaranthus may be direct seeded or nursed. The small seeds are often mixed with sand and drilled into soil to prevent overcrowding in direct seeding. For nursery planting, seeds are sown in nursery beds and transplanted to the field in rows of 20 cm - 30 cm by 10 cm - 15 cm. Plants to be harvested by uprooting may be planted at 10 cm by 10 cm spacing and those for ratoon crops should be planted using a spacing of 20 cm by 20 cm. Ratoon crops are cut back 15 cm from the soil surface to allow for lateral growths for successive harvests (Rice et al., 1990). Seeds are sown at a shallow depth and hence may be covered with grass mulch to protect them from washing off. Grass mulch should be removed soon after seedling emergence.

Amaranthus may be grown all year round where irrigation is possible during the dry season. Frequency of irrigation is dependent on the growth stage of the plant. Water stress causes early flowering. Amaranthus responds well to nitrogen fertilizer which delays flowering but promotes leaf yield. Plants may be fertilized using either organic or inorganic fertilizers, or a combination of both. Well decomposed chicken manure at a rate of 2 - 4 t/ha is usually sufficient (Sinnadurai, 1973; Rice et al., 1990; Schippers, 2000).

Protection: Common diseases and their causal organisms affecting amaranthus in Africa are damping off (*Pythium aphanidermatum*) and leaf spot (*Cercospora cacurbitarum*). The pests include leaf caterpillar (*Hymenia recarvalis*), stem borer (Hypo*lixus frunculatus*), aphid (*Aphis* spp.), *Cletus capensis*, and the sting bug (*Asparia armigera*). Common weeds associated with the cultivation of amaranthus are black spear grass (*Heteropogon contortus),* siam weed *(Chromolaena odorata), Schrankia leptocarpa,* Forest Burr (*Pupalia lappacea*), and *Cassia occidentalis* (Rice et al., 1990; Schippers, 2000))

Management of pests and diseases of amaranthus involves the use of preventive, cultural and chemical methods as well as integrated pest management. Use of raised beds and well decomposed manure will minimize the infestation of weeds. Handpicking of pests may suffice in small farms. The use of copper fungicides helps control damping off.

Harvesting and marketing: Amaranthus is ready for harvesting 20-45 days after planting depending on the variety and environmental conditions Plants may be harvested once or several times. Leaves may be picked for use as they mature, or plants may be pulled out whole. Topping retards flowering and promotes the vegetative growth phase, thereby allowing for extended formation of leaves and shoots. This facilitates multiple harvests using a 2 to 3-week interval, to enhance total leaf yield. Harvesting is recommended during the cooler part of the day to reduce water loss (Rice et al., 1990; Schippers, 2000). Amaranthus is sold fresh in bundles at the market. During periods of drought, the wild relative is collected for use at home.

Corchorus (Corchorus olitorius L.)

Importance: Corchorus (also known as Jew's mallow or Jute mallow) is an economically important crop cultivated for its fibre and leaves. The fibre obtained from the stem of the plant is used to produce bags, carpets, woven curtains, hessians cloth and backing for linoleum. It is also used in pulp and paper, automobile, furniture and bedding industries.

Cultivation of corchorus fibre contributes significantly to the income of countries such as India which contributes about 62% of the total world production (Rahman and Khan, 2010). However, in Africa corchorus fibre production is very low.

There are over 50 species under the genus. The varieties used as leafy vegetables (Figure 3.2) are distinct from the varieties for fibre production (Fondio and Grubben, 2011).

The fresh or dried, powdered leaves and immature fruits are cooked into slimy soup and consumed with starchy staples such as maize, cassava, yam and millet. Nutritionally, the leaves have been reported to contain appreciable levels of β-carotene, iron, calcium, vitamin C and antioxidants (Anil, 2015). Further, Samra et al. (2014) showed that, 100 g fresh edible portion of corchorus contains 80.4 g water, 243 kJ energy, 4.5 g protein, 0.3 g fat, 12.4 g carbohydrate, 2.0 g fibre, 360 mg calcium, 122 mg phosphorus, 7.2 mg iron, 6410 µg β-carotene, 0.15 mg thiamin, 0.53 mg riboflavin, 1.2 mg niacin and 80 mg ascorbic acid. Extracts from the plant are used in traditional medicine for treatment of various ailments (Ndlovu and Afolayan, 2008). Corchorus plants also purify the air by absorbing large quantities of carbon dioxide (CO_2) from the environment and emitting oxygen (O_2) to the atmosphere (IJSG, 2011). Islam and Ahmed (2012) reported that the corchorus plant can absorb an average value of 7302.38 thousand tonnes of CO_2 from the environment and emit 5309.91 tonnes of O_2 to the atmosphere per year. Its inclusion in crop rotation systems improves soil texture and pH (Alim et al., 2002).

Figure 3.2: Corchorus plant - leaves, flowers and pod

Ecology: Corchorus grows best between temperatures of 25–32°C with rainfall amounts of 1500 mm and relative humidity of around 85%; however, growth ceases below the temperature of 15°C. Wild types are usually found around marshy areas, rivers or lakes between the altitudes of 1250–1750 m and in grasslands and fallow fields. The crop grows on a wide range of soils but prefers sandy loam soils rich in organic matter with pH ranging from 6.5 to 7.0 (Anil, 2015). It is a short-day crop and hence variation in day length may influence leaf, fruit and seed production.

Botany: Family: Tiliaceae; Genus: *Corchorus*; *Chromosome* no. 2n= 14. Corchorus plants are annual or short-lived perennial herbs that can grow up to 2- 4 m tall. They branch profusely at the base with reddish, fibrous and tough stems. Leaves are alternate and simple with a characteristic prolongation of the last pair of marginal teeth at the base of the lamina. Margins are serrate or crenate, usually shiny dark green with 3 - 7-veined from the base (Fondio and Grubben, 2011). The flowers are solitary or in groups of 2 - 4 cymes opposite the leaf. Flowers are bisexual with short stalks and free yellow petals and sepals. The stamens are numerous with a superior ovary, usually 5-celled and short styles. Leaves exhibit a broad canopy with drooping lower leaves. It has a deep root system with few lateral roots that enhance adaptation to varying soil types.

There are over 50 species under the genus. The varieties used as leafy vegetables are distinct from the varieties for fibre production (Fondio and Grubben, 2011). Fruits are capsule dehiscent (with five valves) with a cylindrical shape measuring 7 - 10 cm long. Each capsule

contains many seeds. Seeds are angular, 1 - 3 mm long and dark grey in colour. Seed germination is epigeal with hypocotyl measuring 1 - 2 cm (Burkill, 2000).

Phenology: *C. olitorius* is a short-day species with optimum photoperiod of 12.5 hours (Mahapatra et al., 2009). Fondio and Grubben (2011) reported that day length of 12.5 hours resulted in high vegetative growth. However, flowering, fruiting and seed production are promoted at a photoperiod of 11.5 hours or lower.

Physiology: Corchorus is propagated by seed. Seeds show high degree of dormancy which can be broken by hot water treatment. Once seeds germinate, seedling development is fast although leaf development is generally slow at the initial growth stages. Flowering starts about a month after emergence and continues for 1–2 months under short day conditions. The flowers are usually self-pollinated; however, outcrossing of about 10% has been reported (Fondio and Grubben, 2011). A maturity period of 3–4 months after sowing is optimum (Fondio and Grubben, 2011).

Propagation: Corchorus is planted either on the flat land, ridged or raised beds, and is mostly broadcast. The seeds are mixed with sand to avoid wastage**.** Alternately, seeds may first be raised in a nursery and later transplanted onto nursery beds. Where this is the practice, seedlings about 15 cm in height are transplanted using a spacing of 10 cm x 30 cm or larger, depending on the variety. Alternate plants are pulled out during first harvest leaving a spacing of 20 cm within the rows. The seeds exhibit dormancy and hence seeds are best treated by soaking in hot water for a few minutes and drying out before sowing. As a cash crop it is normally cultivated as a monocrop. Production is mainly during the major rains or done under irrigation. It is compatible with many staple crops and hence may be intercropped as a form of early revenue generation. Plants may be topped to give a stronger side root. This practice, however, reduces fruit and seed yield. For effective vegetative growth adequate nutrient application is essential especially in poor soils. The crop thrives well on sandy loam soils rich in organic matter.

Protection: Major pests of Corchorus include grasshoppers (Acantharis), caterpillars (Lepidoptera), army worms (Spodoptera exempta), nematodes, flea bettles (Alticini), red spider mites (Tetranychidae). Diseases encountered include collar rot *(Sclerotium rolfsii)*, black leaf spot (*Cercospora*) and powdery mildew (*Oidium sp*) (Rice et al., 1990, Schippers, 2000). As a fresh vegetable, use of cultural methods of pest control is encouraged in the production of corchorus. Minimizing water use to reduce stem and root rot is ideal. Effective weed control results in judicious use of nutrients, prevents weed interference and leads to increased yields.

Harvesting and processing: Corchorus is harvested four to six weeks after seeding. Traditionally, farmers uproot whole plants but can also practice piecemeal harvesting. The leaves are highly perishable with a shelf life of about 6 days under indigenous storage structures such as clay pots for evaporative cooling. Leaves may be preserved first by steam blanching or by hot water blanching and drying in the sun. Leaves so treated can be stored for about 6 months. Alternatively, the leaves could be sundried directly before storage. Leaves processed first by steam blanching and drying in the sun can retain most of the Vitamin C content when stored for a period of about 6 months compared with hot water blanching alone. Sun dried leaves could be pulverized (Schippers, 2000).

Marketing: Corchorus leaves are highly perishable and hence marketed fresh for premium price. The crop attracts a high market price during the dry season and the first weeks of the rainy season. There is often a glut during the rainy season which results in a drop-in market prices. Off season planting

where irrigation is available substitutes for the absence of other fresh leafy vegetables on the market during this period. The leaves may also be dried and processed into powder and sold during the dry season.

Moringa (Moringa oleifera Lam)

Importance: Moringa is a fast-growing, deciduous perennial tree that is native to India but currently widely cultivated in Asia, Africa, and South America. It belongs to the monogeneric family Moringaceae to which also belong 13 other species. It is widely known by many other names, including Horseradish tree, and Ben oil tree. Moringa leaves and pods provide a great range and amount of essential proteins, vitamins, and minerals. They also contain vitamins such as vitamin A, vitamins B1 (thiamine), B2 (riboflavin), B3 (niacin), B6, folate, and ascorbic acid (vitamin C). Moringa mineral wealth includes calcium, potassium, iron, magnesium, phosphorus, and zinc. It has low fat content and no harmful cholesterol.

Moringa is a "miracle tree" as most parts, including the leaves, bark, pods, and roots, are used as food items (Figure 3.3). The leaves are an alternative to meat, because of the high protein content, especially for vegetarians. They can be added to salads and are also used in the preparation of sauces and soups. The immature pods, known as drumsticks in India, are used in various dishes. Moringa extracts possess anti-cyanobacterial qualities and are used in rural (natural) water filtration systems. The seeds are a coagulant and exert flocculating effects on clay particles and microorganisms present in water. Moringa seed oil has a low tendency to become rancid and is used as a lubricant for fine apparatus such as watches. Cold pressed drumstick oil is used for cooking (Fuglie (2001, Owusu-Ansah etal., 2011).

Moringa tree and pods | Moringa leaves and flowers | Moringa Powder

Figure 3.3: Moring tree, leaves and pods

Leaves of the moringa tree possess excellent nutritional qualities as fodder for livestock and enhance milk production as well as meat quality (Johnson, 2005). Extracts from moringa leaves contain growth-enhancing properties and improve the resistance of plants to pests and diseases thereby promoting better yield of crops.

Ecology: Moringa is suitable for cultivation in tropical, sub-tropical and semi-arid regions of Asia, Africa and America where it flowers and fruits freely and continuously. It, however, grows best in direct sunlight at altitudes below 500 m. It is usually found in areas with a temperature range of 25

°C to 40 °C but will tolerate temperatures of up to 48 °C and light frosts. Optimum leaf and pod production require mean daily temperatures of 25 – 30 °C and high solar radiation, with growth slowing significantly under temperatures below 20 °C. Moringa performs best under an annual rainfall within the range of 1000 - 2000 mm, well-distributed throughout the year. In waterlogged soil the roots tend to rot. The tree is able to withstand periods of drought due to its long taproot. It tolerates a wide range of soil conditions but prefers a slightly acidic to neutral (pH. 6.3 - 7.0), well-drained, sandy or loamy soil. It can tolerate clay soils provided that they do not become saturated for prolonged periods of time. Sandy soils are preferred for rooting branch cuttings directly in the ground.

Botany: Family: Moringaceae; Genus: *Moringa*; *Chromosome* number 2n= 28. *M. oleifera* is a fast-growing, deciduous, slender, softwood tree that branches freely, with sparse foliage, often resembling a leguminous species at a distance, especially when in flower. It can reach a height of 10 – 12 m and the trunk can reach 45 cm in diameter. The bark has a whitish - grey colour and is surrounded by thick cork. Young shoots have purplish or greenish - white, hairy bark. The tree has an open crown of drooping, fragile branches and the leaves build up feathery foliage of tripinnate compound leaves bearing several leaflets in opposite pairs, with a slightly larger terminal leaflet. The leaflets are dark green above and pale on the under surface; variable in size and shape, but often rounded-elliptic, seldom as much as 2.5 cm long.

Conspicuous, lightly fragrant flowers are borne on inflorescences 10 - 25 cm long, and are generally white to cream coloured, although they can be tinged with pink in some varieties. The flowers are bisexual, surrounded by five unequal, thinly veined, yellowish - white petals.

They grow on slender, hairy stalks in spreading or drooping manner. Trees start bearing pods 6 - 8 months after field planting but regular bearing commences after the second year. Within three years, a tree can yield 400 – 600 pods annually while a mature tree can produce up to 1,600 pods per year. The pods are large and distinctive, up to 90 cm long and 12 mm wide, slightly constricted at intervals, gradually tapering to a point, 3- (4-) angled, with 2 grooves on each face. Immature pods are green with a tinge of reddish colour in some varieties. Pods turn brown and dry at maturity containing 15-20 large seeds with apery wings (Amoatey et al., 2012).

Phenology: Flowering and fruiting in moringa vary widely among varieties and with location. These development stages appear to be influenced by rainfall (both distribution and amount), humidity, temperature, soil soil physico-chemical characteristics and topography of the habitat where the plant is growing. For example, in northern India characterized by cool climatic conditions, trees tend to flower once a year between the months of April and June, while in southern India, flowering typically spans 6 – 8 months per year or occurs two times a year. In other areas with more constant weather conditions, such as the Carribeans and some parts of Africa, flowering and fruiting occur throughout the year (Selvam, 2005).

Physiology: Moringa plant can tolerate a wide range of environmental stress factors including heat and salinity. The seeds have no dormancy requirements and can be planted as soon as they are mature, and they will retain the ability to germinate for up to one year. Viable seeds germinate within two weeks. Older seeds have spotty germination. During its first year, a moringa tree will grow up to five meters in height and produce flowers and fruits, reaching 12 m or more in height by the tenth year with a 30 cm wide trunk. The tree can be pruned to a height of 1 m from the ground but will quickly recover and produce leaves and pods.

Germplasm: The Moringaceae family consists of 14 species of moringa worldwide. The most widely cultivated species is *Moringa oleifera* (2*n* = 28), a multipurpose tree native to the foothills of the Himalayas in northwestern India and cultivated throughout the tropics. *M. stenopetala*, an African

species, is also widely grown, but to a much lesser extent than *M. oleifera*. Other species and their origins include the following : *Moringa arborea* Verdc. (Kenya), *Moringa borziana* Mattei (Somalia), *Moringa concanensis* (sv) Nimmo (northern India), *Moringa drouhardii* Jum. – bottle tree (southwestern Madagascar), *Moringa hildebrandtii* Engl. – Hildebrandt's moringa (southwestern Madagascar), *Moringa longituba* Engl. (Ethiopia and Somalia), *Moringa ovalifolia* Dinter & Berger (Namibia and Angola), *Moringa peregrina* (Forssk.) Fiori (Horn of Africa and in the Southern Sinai, Egypt), *Moringa pterygosperma* (syn. *M. oleifera* Lam.) – horseradish tree (northwestern India), *Moringa pygmaea* Verdc. (Somalia), *Moringa rivae* Chiov. (Kenya and Ethiopia), *Moringa ruspoliana* Engl. (Ethiopia). The International *Moringa* Germplasm Collection located on the coast of Jalisco, Mexico houses living material of 12 of the 14 *Moringa* species, as a resource for scientific research on the basic biology of *Moringa* and applied uses such as nutrition, cancer chemo-prevention, biofuel, and water clarification.
In India, several cutivars of *Moringa oleifera* Lam.are grown: 'Bombay' is considered one of the best, with curly pods. Others have pods which are 3-angled or about round in cross-section. 'Jaffna' is noted for pods 60 - 90 cm long while those of 'Chavakacheri murunga' are 90 - 120 cm in length (Selvam, 2005)

Propagation: Moringa trees can be grown from seed or stem cuttings using one of several techniques. The trees can be seeded directly and grown anytime during the year in a backyard garden if water is available. In a large field, however, trees can be seeded directly at the beginning of the wet season. The seeds have no dormancy requirements and can be planted as soon as they are mature. One or two seeds are sown per planting hill at a maximum depth of 2 cm. Alternately, the seeds may first be sown in seedling bags under nursery conditions and later transferred to the field. Each bag is filled with two to three seeds per bag, thinned to one per bag after germination. Another way is to sow the seeds in a nursery bed. Transfer to the field is done four to six months after germination when seedlings would have attained a height of 60 – 90 cm.

The other technique is to establish the field or plantation using hardwood stem cuttings of length 0.5 m - 1.5 m, planted directly in the field or raised in a nursery. Cuttings planted in a nursery can be out-planted after 2 or 3 months. The spacing to adopt during out-planting of moringa in the field varies depending on system of cultivation. Under intensive cultivation targeting leaf production, seeds, seedlings or stem cuttings may be closely spaced (45 cm x 5 cm, 30 cm x 20 cm, 30 cm x 10 cm, 20 cm x 10 cm, 15 cm x 15 cm) with alleys to facilitate field operations. For a semi-intensive system which targets both leaf and seed production, a spacing of 50 cm x 50 cm to 1 m x 1 m may be used. However, when moringa trees are grown in alleys in an agroforestry system a wider spacing of 2 m x 2 m to 4 m x 4 m is recommended.

Nutrient Management: Chemical fertilizers are unsuitable as sources of nutrients for trees in a moringa plantation as they are easily washed away with surface run-off or leached into the subsoil at depths inaccessible to the roots. Instead, the addition of biochar (is pyrolized wood that has been soaked in nitrogen-rich liquid) to the planting holes ensures slow release of nutrients to the trees over a long period of time to sustain their healthy growth.

Protection: Isolated trees in backyard gardens hardly face any incidences of pests or diseases. However, under plantation conditions in the field, moringa trees may be affected by several pests and diseases. Mature trees are parasitized by *Dendrophthoe flacata*, while pods are damaged by fruitflies belonging to the families Gitona and Myllocerus. Fungi which attack the horseradish-tree include: Leaf-spot (*Cercospora moringicola*), Spot anthracnose (*Sphaceloma morindae*) and rust (*Puccinia*

moringae). The use of preventive pest management methods and some cultural practices may help reduce the effect of pests and diseases.

Harvesting and storage: Moringa farmers grow the crop for its green leaves, fresh pods or dry seeds. Multi-purpose growers must know the appropriate time to harvest each product and the best post-harvest handling practices to ensure the highest quality. Leaves are picked manually off the trees directly or cut with an implement such as a pair of shears, a sickle or a sharp knife. For intensive leaf production on large plantations, the use of mechanical harvesters overcomes the drudgery associated with manual harvesting. Harvested leaves are packed into jute sacks or baskets for transportation to the processing unit. The presence of any form of moisture on the leaves during harvest can promote rotting during transport. For this reason, it is advisable to avoid harvesting early in the morning when there may be dew on the leaves or in damp weather. The use of implements or mechanical harvesters for harvesting the leaves provides additional advantage in leaving the trees well-pruned and hence primed for further branching and fresh vegetative growth.

If the purpose of cultivation is to produce fresh pods (popularly called drumsticks) for human consumption, these pods must be harvested while they are still young and immature and snap easily. Older pods develop a tough, fibrous and stringy exterior as in the case of over mature green beans, although seeds within may remain tender. As the moringa stem and branches break easily it is not recommended to climb up trees to harvest fresh pods. Any pods out of reach are best left to dry. For seed production, the pods should be harvested when dry, as they turn brown.

Processing and value addition: Although most parts of the plant are edible, moringa's value is in its leaves and pods, which are high in digestible protein, calcium, iron, vitamin C and antioxidants and have a nutritional profile that rivals milk and eggs. Moringa is known to contain 7 times the vitamin C content of orange, 10 times the vitamin A contenr of carrot, 17 times the calcium in milk, 15 times the potassium found in banana, and 25 times the iron of spinach. With a long history of traditional use, moringa has also been touted for some 300 medicinal benefits. Value addition means converting the fresh produce into products which could be utilized for immediate purpose or stored for future use by applying various indigenous and high techniques suitable for each crop. The processed products from moringa are moringa leaf powder, moringa fruit powder, moringa capsules, moringa dried leaves and moringa tea. The seeds can be processed to produce biodiesel or edible oil that is high in oleic acid while the seed cake yields a 61 percent protein meal (Anwar and Bhanger,2003).

Marketing: A Technavio market research report segments the global moringa products market into the following products: moringa seeds and oil, moringa leaves and leaf powder, and moringa fruits, tea, and pods. The key destinations for these products are the Americas, Asia-Pacific countries (APAC), and Europe, Middle East and Africa (EMEA). APAC was the leading region for the global moringa products market in 2017, accounting for a market share of 78%, followed by EMEA and the Americas. The key factor that is driving the sales of these products across all these regions is the growing consumer awareness of the health-promoting benefits of consuming moringa products.

The moringa seeds and oil segment held the largest market share in 2017, accounting for nearly 48% of the market. The market share for this product is expected to increase nearly 3% by 2022. The world food and nutritional supplements companies are predicting that the moringa products shall acquire more than 10% share of the industry in coming years. Present volume of trade of moringa products in international market is not enough to qualify it as a commodity, but it is nevertheless a growing market worldwide. Today, the global moringa market is estimated at more than US$ 4.5 Billion, which is expected to cross US$ 8.3 Billion by 2020, growing at a rate of more than nine per cent annually.

Roselle (Hibiscus sabdariffa)

Importance: The crop belonging to the family Malvaceae is native to the West Indies. It is commonly referred to as red sorrel, Jamaica sorrel or sour-sour. Roselle contains a wide range of secondary metabolites including phenolic compounds which have shown anti-carcinogenic, anti-hypertensive, anti-microbial, anti-mutagenic, anti-oxidative and anti-inflammatory properties. It is also a diuretic and antiscorbutic. The leaves are reported to contain higher levels of digestible protein than the calyces, but both contain vitamins and minerals. The green leaves are eaten as pot herb. The fresh swollen calyces are used in soups. Both leaves and calyces may be dried and stored for future use. The dried calyces may also be used for making jelly, jams and beverages. They are also used as food colourants and dyes. Roselle stem also has strong fibre, used in weaving sacks and the seed contains oil which can be used in industry and could also be ground and used in preparing a paste which may serve as a staple side dish (Rice et al., 1990, Schippers, 2000).

Ecology: The plant does well in a wide range of soil conditions. Sandy loam soil with a pH of 6.5 -7 is ideal. It does not do well in acid soils. Temperature range of 25-32°C is adequate although the plant can tolerate warm conditions. Rainfall of 600 - 800 mm is ideal for production of roselle.

Botany: Family: Malvaceae; Genus: *Hibiscus*; Chromosome number: 2n=72 (tetraploid). There are over 300 plant species under the family *Hibiscus* although only a few are used as a vegetable. The plant is an annual herb, erect and slightly branched growing to a height of 2 m. The stem is coloured red and smooth with a tap root system. There are other varieties with the stem coloured green. Leaves are ovate with 3 -5 lobes, 6 -15 cm long. The flowers are yellow with purple centres (Figure 3.4). However, roselle varieties differ in colour of calyces which range from green to red. The calyx is fleshy at maturity. Flowers are pollinated by insects, birds and bats. The fruit is ovoid (5-loculed capsule) containing small seeds dispersed by either wind or water. The crop is self - pollinated with a reported outcrossing of 0.3%. The pollen is only viable for a short period.

Roselle plant and flowers | Roselle inflorescence | Roselle leaves

Figure 3.4: Roselle plant with flower, Roeselle inflorescence and Roselle leaves

Phenology and physiology: Germination of seeds take place 7 days after emergence and first harvest follows 3-4 weeks later. Calyces mature about three weeks after flowering which is about 100-160

days after planting. Temperature range of 25°C-.32°C and rainfall of 600-800mm are optimum for production. The plant is day length sensitive and flowers only during short day periods. Ten hours of daylight is ideal while daylight of over 13 hours hampers flowering.

Germplasm: There are many different varieties of roselle, but these are still referred to as landraces since there is a high degree of mixtures in the plant population. However, since self-pollination in roselle is dominant, breeding should be relatively easy. The landraces are however easily distinguished by three different colour groups which are green, red and dark red. The petal colour which also ranges from cream to yellow to orange also helps to separate the varieties (Schippers, 2000).

Propagation: Seeds are sown directly in the field by broadcasting and later thinned to a spacing of 60 cm x 60 cm or nursed in seed boxes and transplanted to the field using a spacing of 60 cm x 60 cm. A reduced planting distance of 60 cm x 45 cm produces larger calyces. Usually a seeding rate of 5.5-7.5 kg/ha is required. Planting may also be done from stem cuttings. Irrigation is essential during the dry periods as plant growth and development ate adversely affected by water stress. Land should be deep ploughed to facilitate the development of the tap root system of the plant. Planting is done about 2.5 cm deep (Rice et al., 1990).

Nutrient Management: Roselle responds well to both organic and inorganic fertilizers fertilizers. Application of organic manure at a rate of 10-20 tons/ha is sufficient. Inorganic fertilizer (NPK) may be applied at an initial rate of 250 kg/ha after emergence and side dressed at 100 kg/ha when leaves are to be harvested after thinning. If calyces are to be harvested it is important to add a further boost of fertilizer (at the same rate) before the 6-week stage (Sinnadurai, 1973, Rice et al., 1990; Schippers, 2000).

Protection: Insect pests of roselle include the cotton stainer (*Dysdercus superstitiosus*)**,** flea beetle (*Podriga spp*). The plants are more susceptible to attack from flea beetles (*Nisotra breweri*) when the plant's growth is retarded especially under moisture stress. When roselle is cultivated with other Malvaceas, pest and disease infestation is more severe. Under hot dry conditions, leaf hoppers (*Aphis gossypii*) are also a major problem. Root knot nematodes (*Heterodera rudicicola*) have also been reported to affect plant development.

Common diseases include fruit rot (*Phytophthora parasitica*), especially during the rainy season and leaf blight (*Phyllostoca hibisci*). Damping off caused *by Pythium aphanidermatum* and mildew disease caused by *Oidium abelmoschi* are also common in poorly drained sites. Other diseases affecting roselle include charcoal rot caused by *Macrophomina phaseolina* and a viral disease which causes the leaf veins to thicken. The viral disease is transmitted by the white fly (Aleyrodidae). Plants with anthocyanin pigmentation are tolerant to drought and powdery mildew. The green ones, however, grow better under irrigation and produce higher amount of leaves but are also susceptible to powdery mildew.

Pests and diseases may be controlled using an integrated pest management approach but with less emphasis on chemical methods which may pose problems through persistence of residues in edible products. Careful site selection and judicious use of water in the nursery as well as in the field may minimize damping off and rot diseases. Diseases which attack the leaves but do not affect the calyces are not regarded as very troublesome RRice et al., 1990, Schippers, 2000).

Harvesting and storage: Leaves are harvested fresh and used as vegetables. The calyces may also be used fresh in stews as a substitute to okra. They can, however, be dried and used in beverages (especially the red varieties). Leaves are ready for harvest 3-4 weeks after germination. They are harvested whole with the roots, as a means of thinning out. Where ratoon cropping is practiced, harvesting is done 6 weeks after emergence. With this the tops are plucked to facilitate development of side shoots, which are then picked in the third harvest. There can be another harvest three weeks later after which only loose leaves can be collected for home use as these are very perishable. The leaves may however be sun-dried, which facilitates preservation for use later or sale. For calyces, harvesting is done about 100 days after sowing. They can also be dried and stored for use later.

Marketing: Generally, the fresh crop is sold in bunches comprising the stems and leaves. This method preserves the quality of the leaves in the short term. When dried, the leaves can be made into powder before marketing. It is especially important during the dry season. Calyces may be marketed fresh or dried. They are sometimes made into powder especially where they are used in beverages.

Garden egg (Solanum aetiopicum var Gilo)

Importance: Garden egg belongs to the family Solanaceae and is cultivated widely in West and Central Africa where it plays significant roles in both the diet and culture of the people. The immature fruits are used in stews but sometimes consumed raw. The fruit though low in vitamin C has a high iron content. The fruit also contains protein, carbohydrate and calcium and is noted to improve human nutrition. Its production is mainly rainfed and peasant farmers continue to dominate production in most countries in the sub-region (Blay, 1986, Arivalagan et al., 2013).

Ecology: Garden egg is native to Africa although it is found in Latin America. The crop is grown in Africa, Asia as well as in South America and in the Carribeans. It grows well in sandy, loamy and silty soils which are deep but well drained, with a pH of 5.5 - 6.8. It does not do well in clay soils. Day temperature range of 25 - 35°C and night temperature of 20 - 27°C are considered ideal for the crop. Garden egg grows best at altitudes below 800 m where temperatures are high. Medium rainfall of about 800 mm is most ideal when irrigation is not available (Blay, 1986; Schippers, 2000).

Botany: Family: Solanaceae; Genus: *Solanum*; Chromosome number: 2n=24. *Solanum aetiopicum* var Gilo is a herbaceous annual but may grow as a perennial when soil moisture is adequate throughout the year or under irrigation, reaching a height of about 2 m. It has a wide array of different forms depending on local selection criteria. The crop is single-stemmed at ground level with a strong taproot but branches out above ground (Figure 3.5). The large leaves are hairy and sometimes spiny and are not eaten. The fruits are elongated, ovoid or round with several graduations in shape among these forms. They may be smooth or lobed and range from 2 - 8 cm in diameter. Fruit colour varies widely ranging from green to off white when immature but turning yellow to orange upon ripening. Most fruits have 2-3 locules and contain a large amount of seed. The crop is mainly self-pollinated but may be cross pollinated by insects. The seed is usually flat and off white in colour (Blay, 1986; Danquah-Jones, 2000).

Garden eggplant, leaves and flowers

Garden egg plant fruits

Figure 3.5: Garden egg plant leaves, flowers and fruits

Physiology and phenology: The plant exhibits hypogeal germination. Germination of seeds takes 5-7 days but transplanted 5 weeks after germination. The plant matures in about 110-120 days after sowing. The plant is day neutral but unable to tolerate cold temperatures. Exposure to full sunlight is preferred for optimum growth of garden egg.

Germplasm: *Solanum aethiopicum* is a hypervariable species with many local varieties. It has four main groups namely Gilo, Kumba, Shum and Aculeatum. The Gilo group is found in medium rainfall areas and the fruits are eaten; the Kumba group is common in the savannah and semi-arid zones and both fruits and leaves are eaten. The Shum group is cultivated in high rainfall zones and only the leaves are eaten. The Aculeatum is found mostly in southern Africa and serves as an ornamental. The four groups are however interfertile (Schippers, 2000).

Propagation: The crop is propagated from seed. Seeds are first nursed in seed boxes and pricked out onto nursery beds soon after emergence or may be raised on nursery beds for 4-6 weeks after which they can be transplanted onto the field. Seedlings should be protected from fungal diseases by regulating irrigation at the nursery and with the use of fungicides, spacing of 75cm x 60cm is ideal. Where moisture is abundant, a wider spacing may be adopted. However closer spacing increases fruit number but results in reduction in fruit size and easy spread of diseases. When the crop is cultivated as a perennial, pruning is required to reduce branching which results in to the rejuvenation of the plant (Blay, 1986).

Nutrient management: A starter solution made up of 10g NPK 15-15-15 fertilizer may be applied to each seedling at transplanting and the rest of the fertilizer applied in 2-3 split doses 10 days later. The same fertilizer at a rate of 125 kg/ha is recommended 10 days after transplanting and a further application of 50 kg/ha at flowering. An additional dose may be required after a few harvests to boost fruit size (Blay, 1986).

Protection: *Solanum aetiopicum* var Gilo is tolerant to pests and diseases**.** In new fields, the plants can be grown without any significant pest management. Common diseases affecting the crop include Bacterial wilt (*Pseudomonas solanacearum*), southern blight/ scelrotium root rot, angular leaf spot (*Phaeoisaropsis griseola*), grey leaf spot and collar rot (*Sclerotium* rolfsii). Pests include fruit borers, stem borers (*Leucinodes orbonalis*), leaf miners, root knot nematodes, thrips (Thysanoptera), black aphids and spider mites. Pest and diseases may be managed using preventive, cultural and chemical control measures (Blay, 1986; Schippers, 2000)

Harvesting: Fruits are best harvested at marketable maturity, before the first sight of ripening. This is usually done during the cool part of the day, either in the morning or in the evening. Harvesting should be done regularly as ripe fruits left on the plant will stimulate senescence. Harvesting should be done using a knife to protect the stem. The average fruit weighs 24-45 g yielding 12-20 t/ha (Blay, 1986; Schippers, 2000).

Value addition and marketing: Garden eggs are not usually stored but when in transit, fruits should be stored under cool conditions, shaded from direct sunlight. In general, the fruits are harvested and consumed or marketed fresh mostly and hence there is (a premium price for garden eggs during the off season). However, the fruits may be diced or sliced, and sun dried for use later. This treatment, however, tends to discolour the fruits. Fruits for storage may also be ripened, boiled, cut, skewed and smoked. The skewed fruits may also be sun dried. Dried fruits may be ground into powder and used in thickening soups. Harvested fruits are packaged in jute sacks and transported to market centres within 2 days of harvesting to keep them fresh. Fruits are then sold locally in baskets or plastic buckets. Small scale retailers, however, pack in small plates or place in small heaps on the jute sacks on market racks.

Case studies

Feasibility analysis of leaf-based *Moringa oleifera* plantation in the Nigerian Guinea Savannah: Case study of University of Ilorin Moringa Plantation

Source: Animashaun and Toye, (2013)

This study examined the profitability and economic feasibility of a leaf-based Moringa production and processing under a plantation system in the Nigerian guinea savannah using the University of Ilorin Moringa Plantation as a case study. To achieve this objective, data on production and processing cost and revenue for the 2011/2012 planting season were collected and a simulated 10-year production and cost and revenue scenarios were scheduled based on the assumption of a constant cost and cash inflow over the same period. The cost-benefit was reported using the Return on Investment (ROI), Benefit Cost Ratio (BCR) and the Net Present Value (NPV) analyses.

Result indicated an estimated average net profit of N827, 109 (USD 5,137) ha/annum from a total production cost of N1, 371,360 (USD 8,580) ha/annum and a gross revenue of N2, 200,000.00 (USD 13,750) ha/annum derived from the sale of an average of 110 kg of processed dry leaf powder output. This indicates the relative profitability of the enterprise. Furthermore, at varying discount rates of 17.5%, 20%, 22.5%, and 25%, the BCR indicated that for every N1 invested in cost, the investor could realize N1.60 in returns, the ROI indicate a profit return turnover of 26.7% of the cost of investment and an NPV estimate at the end of the 10-year period considered the project to be financially worthwhile. Based on these findings, this study recommends Moringa production and value addition development due to the potential it portends for income generation.

Production and utilization of moringa by farmers in Limpopo Province, South Africa

Source: Mabapa, et al., (2017)

In the Limpopo province of South Africa, moringa is mainly grown by a limited number of farmers in the backyards and spaces around homesteads. This study was aimed at identifying moringa growers in the province and to collect information on their perspectives and knowledge on production and management of the tree as well as the commercial's production potential. The survey was conducted from November 2013-September 2014 in five districts of the Limpopo province. Focus group discussions, questionnaires and field observations were used for data collection. A total of 150 moringa growers formed part of the focus group and a questionnaire was administered to only 31 farmers producing moringa within an area of 0.25 ha or more. Collected data were analyzed using the SPSS version 22.

Results from the survey indicated that there are potential Moringa farmers in all the districts of the province, with the intension to commercialize the tree. Majority of growers were found in Vhembe district (38.7%) and the least in Waterberg and Sekhukhune districts with 9.7%. Male growers were dominant by 64.5% producing mainly in mixed farming systems. The highest percentage of farmers, who grow Moringa in 0.25-1.0 ha and have been producing the crop for the past 2 years, were found in Mopani and Vhembe districts. In general, most farmers grow Moringa for leaf processing into powder (96.8%) that is sold locally.

This study revealed that most farmers are willing to expand the Moringa production, however, the major challenge of effective market access need to be addressed. This is critical if the crop is to be incorporated in the smallholder farming systems for income generation and food security.

Environmental Sciences A case study on low cost water treatment using a natural coagulant.

Source**:** Prasad and Rao, (2013)

The purpose of this study was to provide information on household water treatment using seeds of the *Moringa oleifera* tree. Ground water is fresh water located in the core space of soil. Wells, springs and rivers constitute fresh water supplies. The present study dealt with the suitability of coagulation-flocculation process using *Moringa oleifera* seeds as natural coagulant for purification of water for drinking purpose. In the study various doses of *Moringa oleifera* seed powder like 50, 100 and 150 mg/litre were taken and checked for the efficient dose for various water samples. After treatment of water samples with *Moringa oleifera* seed powder, the mixtures were analysed for different parameters like turbidity, pH, conductivity and hardness. There was an appreciable change in most parameters. Application of this low cost *Moringa oleifera* seeds is recommended for eco-friendly, nontoxic, simplified water treatment where rural people living in extreme poverty are presently drinking highly turbid and contaminated water.

African traditional leafy vegetables and the urban and peri-urban poor

Source: Gockowski, et al., (2003

The importance of traditional leafy vegetables (TLVs) in nutrition and employment both in production and marketing among urban and peri-urban households was investigated. An expenditure model of demand using results from a 1998 survey (n = 150) in Yaounde, Cameroon, estimated that as a group TLVs were normal goods, which contribute a significant share of essential nutrients for the urban poor. Urban consumption of *Brassica* exotics, which have replaced TLVs in other parts of Africa, was minimal. Price analysis revealed a decline in supply during the dry season, which is a food security concern for the very poor. Field and market surveys conducted in 1998 and 1997 estimated that over 32,000 households were engaged in producing and marketing TLVs under readily accessible entry conditions. Three production styles were identified: an intensive system within the urban limits, a semi intensive style in the urban periphery and an extensive style also in the urban periphery. The largest number of producers were women employing an extensive mixed crop system. Successful in situ conservation will require research to improve the productivity of TLV cropping systems and media efforts to promote their use.

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Chapter 4

Neglected and Underutilized Cereals and Pseudocereals

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Overview

The world depends largely on a small range of crops for food and nutritional security, and income. However, there is a variety of alternative crops that could diversify diets and sources of income. Some of the neglected and underutilized species (NUS) of cereals and pseudocereals were important in diets and ceremonies of ancient communities but they are currently gaining popularity in the health food market. The growing demand for probiotic products and functional foods is driving the global health and wellness market. Most of the NUS are regarded as 'supergrains' and 'superfoods' due to their excellent nutritional composition and health benefits. This chapter looks at a selection of NUS cereals and pseudocereals that have potential to improve food and nutritional security and incomes. The contents of this chapter lay emphasis to the importance of these crops, ecological requirements, botany, phenology and physiology, the availability of germplasm and propagation, nutrient management and crop protection, harvesting and storage, processing, value addition and marketing. Case studies highlighting success stories are discussed.

Importance of cereals and pseudocereals

Cereals belong to the grass family (Gramineae) and they are grown for their edible, starchy sometimes high-protein grain. Cereal grain is composed of endosperm, germ and bran. Examples of cereals include maize (Zea mays), wheat (Triticum aestivum), rice (Oryza sativa), barley (Hordeum vulgare), sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), foxtail millet (Setaria italica), finger millet (Eleusine coracana), proso millet (Panicum miliaceum), tef (Agrostis tef), Fonio (Digitaria exilis), banyard grasses (Echinochloa spp.).

Pseudo-cereals are not members of the grass family, but they are used much in the same way as the true cereals. They are grouped based on use rather than the biology of the plant. Examples of pseudocereals are grain amaranth (Amaranthus spp.), quinoa (Chenopodium quinoa), buckwheat (Fagopyrum esculentum), breadnut or Maya nut (Brosimum alicastrum), chia

(Salvia hispanica), wattleseed (Acacia victoriae) and pitseed goosefoot (Chenopodium berlandieri).

The starchy seeds of cereals and pseudocereals are ground into floor and undergo other forms of processing and preparation to convert them to more edible and digestible formulae. Modern processing methods utilize the grains to produce flat and raised bread, macaroni, breakfast cereals and vegetable spreads. In some species, the seeds can be popped like popcorn or eaten whole without processing.

Despite limited cultivation, the neglected and underutilized species of cereals and pseudocereals have excellent nutritional and health benefits. These attributes are gaining global popularity as 'supergrains' and 'superfoods'.

Currently cultivated NUS cereals and pseudocereals

Some species of cereals and pseudocereals though listed as neglected and underutilized are in fact cultivated by certain communities. Due to their growing popularity among those communities and increasing global and especially African recognition of their nutritive importance and potential economic value, we discuss three cereals and three pseudo cereals. These are:

Cereals:

- Finger millet (Eleusine coracana)
- Proso millet (Panicum miliaceum)
- Tef (Eragrostis tef)

Pseudocereals:

- Grain amaranth (Amaranthus caudatus)
- Quinoa (Chenopodium quinoa)
- Buckwheat (Fagopyrum esculentum)

The production and marketing potential of these crop species is constrained by poor agronomic practices, weak post-harvest handling and processing and limited funding opportunities due to a negative perception that they are 'poor man's crops. As a consequence, they are not adequately supported by policies or agricultural institutions/regulations.

Value chains of neglected and underutilized cereals and pseudocereals

Analyses of value chains of the neglected and underutilized species have identified various challenges that could be addressed to improve productivity and utilization. Pertinent issues to be addressed include:

i. Better agronomy, harvest and post-harvest handling and value addition: There is insufficient knowledge on crop husbandry, agronomy and breeding aspects. There is limited research on the development of recommendations for fertilizer requirements,

seeding rates, varieties, diseases and pest management. Harvesting methods are typically traditional and there is inadequate knowledge on post-harvest handling practices while options for extending shelf life and value-addition are limited.

ii. Input supply: Certified seed for neglected and underutilized cereals and pseudocereals does not exist. Existing seed systems are largely informal. Despite the potential of these crop species to enhance food security and economic livelihoods breeding to improve nutritional quality and adoption is limited in Africa. Knowledge and information on the existing varieties is scarce.

iii. Market access, consumer demand and value chain: Intensive research is required in the development of global food products along with the popularization of these grains in the international health food industry. Marketing strategies could be fostered by good packaging, distribution and storage systems. Sensitization of local consumers on the health benefits of crops is required. Upgrading the value chains of these crops might fight hunger and malnutrition and increase household incomes through high-value niche markets.

iv. Farmer organization: Growers of NUS are poorly organised in cooperatives or societies. This makes it difficult to provide adequate and consistent supply of produce to the market. Individual farmers often have poor agribusiness skills and bargaining power which affects the commodity pricing. Extension and technology platforms on processing and value addition have little impact when farmers are not organised in groups. These crops have great potential to empower indigenous communities, farmers, women and youth.

v. Financial environment: Financial limitations constrain investment in the NUS of cereals and pseudocereals by farmers, traders and processors. Research, technology development and transfer are also constrained by poor funding.

vi. Policy and regulation: Policy makers have limited awareness of the potential of NUS of cereals and pseudo cereals to improve food security and nutrition. This hinders crop diversification. A few motivated individuals have led in the development of products and markets for these crops but the public-sector support for research and development is required.

Species diversity, inventory, ecological adaptation and communities associated with them

Table 4.1. Key characteristics of some neglected and underutilized cereals and pseudocereals.

Species	Geographical distribution	Ecological adaptation	Species diversity	Uses
Finger millet (Eleusine coracana)	-Native to Africa: Uganda and Ethiopia -Eastern and southern Africa, and west Africa -Asia: India, Nepal, China	-Highlands and lowlands	-Wild species -Cultivated species -African coracana Subpopulation – originate from Africa -Asian coracana	-Good for porridge for feeding infants and the sick -Bread and various baked products -When malted it's recommended for children

			Subpopulation – from Asia	and elderly -Popped products -Brewing
Proso millet (Panicum miliaceum)	-Native to South America: Bolivia, Peru, Colombia, Argentina and Chile -Cultivated in North America and Asia -Africa: eastern Kenya, Ethiopia, Malawi, Botswana, Zimbabwe and Madagascar	Hot and dry		-Whole grains are boiled, roasted, cooked into porridge, ground, baked into flat bread or chapati. -Grains are fermented for beer and brandy making
Tef (Eragrostis tef)	-Native to Ethiopia where it was domesticated around 4000-1000 BC	Drylands to highlands		Milled into flour to make injera, a flat bread in Ethiopia
Grain amaranth (Amaranthus caudatus)	-Native to tropical America: Mexico, Guatemala, Bolivia,	Grown in South and Central America, India and Africa	A. caudatus (Inca wheat, love-lies-bleeding): its seeds can be white, yellow or black	-Eaten as a cereal grain; milled into flour for porridge and vegetable spreads; popped like popcorn or
	Peru, Ecuador, Colombia -Africa: Kenya, Tanzania, Uganda, South Africa, Angola, Nigeria.	Mainly grown in South America	A. cruentus (purple amaranth): seeds are white, cream or gold	germinated into nutritious sprouts
		Mexico and Guatemala	A. hypochondriacus (Prince's feather): seeds are cream, white, gold or black	
Quinoa (Chenopodium quinoa)	-Native to Andean regions of South America: Chile, Peru, Columbia, Equador			-Primarily grown for edible seeds, and has been regarded as a 'superfood' or 'supergrain' -Can be eaten as a replacement for rice, breakfast cereal and infant cereal food -Can be milled into flour, popped or sprouted -An ingredient bread, pasta and biscuits

Buckwheat (Fagopyrum esculentum)	-Native to China -Asia: India, Nepal, Bhutan, Mongolia, North Korea and Japan -Europe, USA, Canada, Australia and South Africa - Leading producers are China, Russian Federation, Ukraine, and Kazakhstan	Arid hilly land and cool climates	F. esculentum (Common or sweet buckwheat) F. cymosum (wild buckwheat) F. tataricum (tartary or bitter buckwheat)	-Milled into flour to manufacture noodles - Natural and high nutritional quality food - Plant is used as animal feed, source of medicines, green manure, soil conservation and an ingredient in beer

Management of selected cereal and pseudo-cereal species

Finger millet (Eleusine coracana)

Fig. 4.1. Finger millet and some products. Mature panicle with seed (A). Threshed grain (B). Porridge made from milled flour (C). Breed (D) and cupcakes (E).

Importance: Finger millet (Figure 4.1) plays an important role in both the dietary needs and incomes of many rural households in sub-Saharan Africa and South Asia, and accounts for about 12% of the global millet area. The grain is rich in fibre, iron and contains 40 times more calcium than maize and rice, and 10 times more than wheat. It is the most important small millet in the tropics and is cultivated in more than 25 countries in Africa and Asia, predominantly as a staple food grain. The major producers are Uganda, Ethiopia, India, Nepal and China.

Ecology and physiology: Finger millet thrives under hot conditions, with temperatures as high as 35°C. In East Africa, the crop grows best where the mean maximum temperature exceeds 27°C and the average temperature does not fall below 18°C. However, it tolerates cooler climate than other millets. It adapts well at intermediate altitudes from 500-2400 m. The crop requires rainfall in the range of 500-1000mm that is well distributed during the growing season with the absence of prolonged droughts. Dry weather is required for drying the grain at harvest. Finger millet can be grown on a variety of soils but performs optimally on reddish-brown lateritic soils with good drainage and water holding capacity. The crop has reasonable tolerance to waterlogging and better utilizes rock phosphate compared with other cereals.

Finger millet has fine and long stems (0.5-2 m) that are covered with fuzzy-like short filaments. Leaves are light green, long and pointed. It produces open, branched or compact panicles. Finger millet is a short-day plant; 12-hour photoperiod is the optimum for most varieties. However, it has successfully been grown in the northern parts of the United States but with considerable problems of photoperiod sensitivity. Day-length-neutral types could be available.

Germplasm: The International Crops Research in Semi-Arid Tropics (ICRISAT) genebank conserves about 6000 finger millet germplasm accessions from 24 countries for use in research and development. Current breeding efforts seek the application of genetic male-sterility to hasten the production of F1 generations, backcrosses and other types of crosses. The intent is to facilitate recurrent selection for the development of broad variability as a background for breeding programs. Importantly, breeding aims at improving host-plant resistance to finger millet blast disease.

In Kenya, varieties P-224 and Gulu-E are preferred for early maturity, low susceptibility to blast and short-stature that makes harvesting easy, high yields and ease to thresh. Indigenous varieties are low yielding but less resistant to drought and diseases

Propagation: Finger millet is propagated from seed mainly by direct seeding in the field, although transplanting is also practised. The field is thoroughly ploughed to fine tilth and 12.5 t ha-1 of farm yard manure or compost is recommended. Depending on the soil nutrient status, compound fertilizer of NPK may be added as per soil test. A rate of 60:30:30 kg ha-1 is recommended. Four sowing methods are used in the propagation of finger millet:

Broadcasting: Seeds are directly sown in the field by random hand spraying. Broadcasting is easy and does not require special machinery. However, it presents weed management problems because it is difficult to distinguish between weed and crop.

Line sowing: Is an improved sowing method compared with broadcasting and offers better control of weeds. Crops are spaced at 0.20-0.30 m between lines and 0.08-0.10 m within lines.

Drilling in rows: This method is used in conservation agriculture, whereby seeds are sown directly into uncultivated soil using a direct-seed drill.

Transplanting seedlings: This method is common in India. Seedlings are raised in nursery beds and transplanted to the main field. Seedlings are established in nursery beds of 10 or 20 m with suitable irrigation channels. Seedlings should be transplanted 18-20 days after seeding. Two seedlings per sowing station at a depth of 3 cm and spacing of 0.15 m × 0.15 m is recommended. The roots of the transplants are dipped in 1000 g of Azospirillum® per 40 L water for 15-30 minutes to control fungal diseases such as damping off.

Nutrient management: Nitrogen is supplied when the crop is 15 cm tall or after the first weeding at the rate of 125 kg ha-1 of sulphate of ammonia or calcium ammonium nitrate (CAN). Integrated nutrient management modules for finger millet in India that combined 50% of the recommended dose of inorganic fertilizer, 2.5 t ha-1 of Gliricidia biomass, 2.5kg ha-1 of Azotobacter and phosphorus solubilizing bacteria as soil incoculants increased grain yield and gave the highest monetary gain (Dass et al., 2013).

Crop protection: Finger millet suffers a few diseases and insect damage but fungal infection by blast can devastate whole fields. Other diseases are seedling or leaf blight, wilt or foot rot, Cercospora leaf spot, downy mildew or green ear disease, smut and damping off.

Blast is caused by the fungus Pyricularia grisea. It is the most devastating finger millet disease and is mostly prevalent during continuous rains at heading. This fungal disease is ferocious, and the extent of damage depends on the severity and time of onset of disease. The average loss due to blast hovers around 28% but endemic areas can experience as high as 80-90% yield loss. Its incidence is shown to increase with high nitrogen rates (Nagaraja et al., 2007). The primary infection comes from seed-borne inoculum thus treating seeds with Tricyclazole (8 g/kg seed) is recommended. Later in the season, sprays of Carbendazim or tricyclazole (0.05%), first at ear emergence, then a second spray 10 days later with Mancozeb (0.2%) could be effective.

Seedling blight is caused by the fungus Drechslera nodulosum. It affects all plant parts from the root, base of the plant, culms, leaf sheath, leaf blade, neck of the panicle to the fingers. Infected seeds suffer pre-emergence seed rot which presents emergence problems and post-emergence seedling rot. Symptoms appear as brown to dark brown oval spots on the leaf lamina which later coalesce to give a blighting appearance on leaves and they dry prematurely. Drechslera nodulosum can survive in soil for over 18 months while on grain the spores can be viable up to a year. This disease occurs at temperatures from 10-37°C but the optimum temperature for infection 30-32 °C. Seed treatment with fungicides and spraying crops with Mancozeb (0.2%) controls blight.

Weeds are a major problem in finger millet production. In Africa, the dominant weed is Eleusine indica, which is a wild relative of finger millet. In early stages, the weed looks so much like finger millet that only skilled observers and scrutiny can distinguish them. The parasitic weed Striga (Striga hermonthica) causes significant losses in finger millet, especially in nitrogen deficient soils (Boukar et al., 1996). Other important weed species are the animal dispersed Xanthium strumarium, and the stolon-forming Cyperus rotondus and Cynodon dactylon.

Cultural methods for weed control could involve sowing in rows instead of broadcasting to ease the differentiation between finger millet seedlings and the wild species instead of broadcasting. Cover crops smother weeds while crop rotations disrupt their life cycle. Physical weed control by hand weeding or hoeing is practised. The use of herbicides is limited but an integrated approach that combines all weed control measures is recommended.

Harvesting and storage: Finger millet does not mature uniformly; hence multiple stage harvesting could be required after the ears turn brown. To minimise costs, two-stage harvesting is recommended. First harvest is done when the ear head of main shoot and 50% of ear heads turn brown while a week later the second harvest is done where rest of the heads are removed. The second harvest contains green heads; hence it is recommended to keep them under shade for a few days to hasten drying.

In most developing countries, the crop is harvested by hand. Individual heads are cut off with a knife, leaving a few centimetres of stalk attached. The heads are then piled in heaps for a few days to promote fermentation whose heat and hydrolysis makes the seeds easier to thresh. The heads are threshed using conventional beating with sticks and grain is winnowed. Machine threshing is not common in developing countries. Finger millet seeds are so small that weevils cannot squeeze inside. Unthreshed heads resist storage pests so well that they can be stored for 10 years or more without insect damage. It is said that if kept dry the seed can remain viable for up to 50 years.

Processing and value addition: Processing and value addition of finger involves milling the grain into flour to make various goods and malting processes that involve germinating the seed. The seeds are so small that it takes skill and much effort to mill the grain, particularly by hand. Similarly, hammer mills have difficulty and they should be fitted with fine screens and run at high speed. In addition to the seed being small, the bran is bound tightly to endosperm. As a result, the main product of finger millet is whole grain flour which has short shelf-life due to high oil content. In addition, the whole grain flour has limited industrial use.

An improved mini-millet mill that yields white flour has been developed in India. The milling process integrates the traditional knowledge of the farmers and moistens the seeds for half an hour before milling. Moistening the seeds helps to remove the bran mechanically without causing damage to the rest of the seed. The white flour is commercially used in making baked goods

Malting: This process is common in the production of brewed beverages such as beer. When the seed is germinated, enzymes are activated to transform starches into other carbohydrates such as sugars. The malted product can be used as a substrate to produce gluten-free beer or easily digestible food for infants.

Marketing: The Chagga people of Northern Tanzania use finger millet and ripe bananas to brew an alcoholic beverage known as 'mbege'. This local drink in becoming increasingly popular and is sold in modern bars. The challenge is that the quality degrades after 3-4 days if not refrigerated due to its high sugar content. Marketing organization and commercial utilization of finger millet is not as developed as for other cereals such as maize, rice and wheat. In Kenya, brewing companies have ventured into millets to produce beer, thus it is expected that contractual farming arrangements would improve the marketing channels. In Nepal, Adhikari (2012) found direct marketing channels of finger millet from producers to the consumers was common in rural areas while in urban areas middlemen dominated the value chain.

Proso millet (Panicum milaceum)

Fig. 4.2. Varieties of proso millet distinguished by panicle and grain colour

Importance: Proso millet seeds are tiny, pale yellow with a nutty flavour and can be eaten whole or cooked (Figure 4.2). It can also be added to a variety of dishes, tossed into salads, stir fried with vegetables and tofu or eaten for breakfast with some milk and honey. Proso millet has several nutritional and health benefits that include ant-aging antioxidants, high amounts of niacin that prevents pallegra, high amounts of calcium for strong bones, reduces cholesterol levels and cancer risks, is a rich source of phosphorus and prevents gallstones.

Ecology: Proso millet is a summer annual grass that is most frequently grown as a late-seeded summer crop. The crop is adapted to hot and dry high elevations, ranging from 1200-3500 m. Annual rainfall from 200-400 is enough, preferably if 35-40% falls during the growing period. The crop can be grown on a variety of soils except coarse sand.

Botany and physiology: Proso millet is an erect annual grass growing up to 0.3-1.2 m tall. It has a shallow adventitious root system and tillers freely at low plant density. The stems are cylindrical, simple or sparingly branched, with simple alternate and hairy leaves. The inflorescence is a slender panicle with solitary spikelets, and the panicle droops at the top. Grains are broadly ovoid, up to 3 mm x 2 mm, smooth, variously coloured and shed easily when mature (Changmei and Dorothy, 2014).

Proso millet is a warm-season grass with a short growing season that tolerates both water and heat stress. Given its C_4 photosynthetic pathway, the crop can efficiently fix carbon under drought, high temperatures and limited nitrogen and carbon dioxide supply. In addition, its rapid growth rate helps the crop to escape adverse conditions. It has one of the least water requirements among cereals. Proso millet completes life cycle within 60-100 days. The crop is sensitive to frost and requires warm temperatures for germination and development (Habiyaremye et al., 2017). Seedlings emerge in 4-8 days after sowing and the vegetative phase ends in about 15 days.

Propagation: Proso millet is propagated by seed through either broadcasting or row drilling at 0.20-0.25 m between rows and 0.075 within plants. For row drilling the seed rate is 8-12 kg ha-1. In Kenya, farmers sow in furrows with 0.30 m between plants and 0.10 m from plant to plant. At this spacing, seeding rate is approximately 4 kg ha-1. To maximise emergence, it is recommended to soak the seed for 24 hours prior to sowing and place it no deeper than 4 cm. The main breeding method employed is intraspecific hybridization.

A popular variety in Kenya is 'KAT/PRO-1' that was developed by the Kenya Agricultural and Livestock Research Organization (KALRO) using local lines and materials form ICRISAT. Fertilizer management research and recommendations are not available in Africa. In India, the standard recommendation is 20-40 kg N ha-1 and 20 kg P ha-1.

Crop protection: The major diseases of proso millet are head smut, grain smut and leaf spot.

i. Head smut: Head smut disease is caused by Sporisorium destruens and Sphacelotheca destruens. It is widely distributed in Europe and Asia. The smut sori first become evident as the panicles emerge. Subsequently, the entire inflorescence is covered with sori enclosed by a grayish-white false membrane. The membrane ruptures as the plants mature, exposing the darkbrown spore mass and the vascular tissues of the smutted panicle. Head smut is treated with fungicides such as Carboxin and Benomyl (Sharma and Sugha, 1991).
ii. Grain smut: Grain smut is caused by Sphacelotheca sorghi or Ustilago crameri. The disease is also known as covered or kernel smut. Most of the grains are transformed into white grayish sacs (smut sori). The sori are slightly pointed to oval and filled with black powder (chlaymydospores). The pathogen perpetuates through contaminated seeds and can be managed through seed treatment, early collection and burning of diseased ears on appearance and crop rotation for 2-3 years.

iii. Leaf spot: Leaf spot is caused by Bipolaris panici-miliacei or Helminthosporium panicimiliacei. It is transmitted in seed. Seed infection causes seed rotting, coleoptile spot and seedling blight. Resistant varieties are recommended.

Harvesting, storage and value addition: Proso-millet should be harvested when the seed moisture content reduces to 14-15%. Delayed harvesting leads to seed shattering while premature harvesting reduces yield and quality. Whole plants are uprooted and threshed immediately to minimise grain loss. If the crop is harvested during the rainy season when relative humidity is high, the grain should be dried to a moisture content of below 14% before storage.

In dry and warm storage conditions, proso-millet can be stored for 5 years without losing viability or quality. The seeds are hardly susceptible to insect attack due to their small size. In India, granaries with clay walls or clay jars are used for storage, and the grain is mixed with ash. Despite many health benefits, proso-millet is not satisfactorily consumed. This is partly due to limited knowledge on processing and value addition techniques.

Tef (Eragrostis tef)

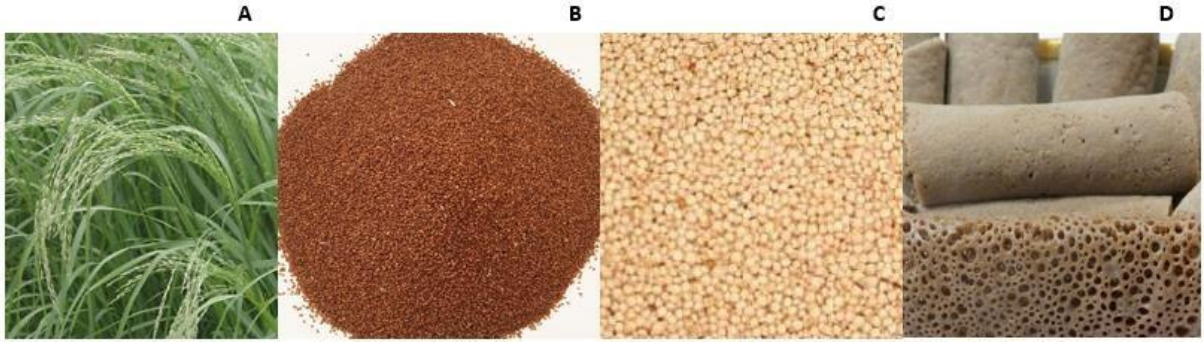

Fig 4.3. A crop of tef at grain filling stage (A). Brown (B) and white (C) tef grain. Injera, the Ethiopian flat breed made of teff (D)

Importance: Tef (*Eragrostis tef)* is a species of love grass that originated and was domesticated in Ethiopia and Eritrea. The grain is predominantly used to make injera, a flatbread or flat pancake-like fermented bread (Fekadu et al., 2015) (Figure 4.3). It is also eaten as porridge or used as an ingredient of home-brewed alcoholic drinks. The straw is used as livestock feed and thatching. Tef flour has excellent nutritional and health benefits because it does not contain gluten (Spaenij-Dekking et al., 2005). The grain has high dietary fibre and nutrients, most of which are easily absorbed by human body, such as calcium, thiamin, iron, copper, zinc, aluminium, molybdenum, barium and silicon oxide. It is rich in amino acids such as phenylalanine, tyrosine, threonine, histidine and methionine (Jansen et al., 1962; Spaenij-Dekking et al., 2005; Fekadu et al., 2015).

Tef is mainly grown for food in Ethiopia, either as a staple or as a standby. The crop is normally sown late and harvested in the dry season. When there are signs of maize, sorghum and wheat crop failure, fast-maturity varieties are sown as back-up for food. In the producing areas of Gojam (Amhara) and Shoa (Oromiya) tef is largely grown for market mainly because of its high price and absence of alternative cash crops such as coffee, tea or cotton. Tef is popularly

grown in USA, Canada, Australia, South Africa and northern Kenya both for food and animal feed due to its high nutritional and fodder quality attributes.

Ecology: Tef is adapted to a wide range of environments, from drylands to waterlogged conditions. The most conducive altitude for maximum yield is 1800-2100 m above sea level, with growing season rainfall of 450-550 mm and temperatures ranging from 10-27°C. Early maturing varieties (60-75 days) can do with less than 300 mm of rainfall.

Botany: Tef belongs to the family Poaceae and genus Eragrostis. It is a tetraploid plant, with 40 chromosomes (2n = 4X = 40). It has large crown, many tillers and a shallow diverse root system (Assefa et al., 2015). Tef has a wide variation in morphological and agronomic traits. Plant height varies from 25-135 cm, panicle length is 11-63 cm while spikelets vary from 190-1410 in a panicle. Panicle types vary from loose, lax, compact, multiple branching multi-lateral and unilateral loose to compact forms (Fig. 4.4).

Tef grain colour ranges from pale white to ivory white and from very light tan to deep brown to reddish brown purple. Grain is very small, from 1.0-1.7 mm long and 0.6-1.0 mm diameter while l000 seed weight is 0.3-0.4 grams (Ketema, 1997). The florets consist of a lemma, palea, 3 stamens, two stigma and two lodicules. Floret colours vary from white to dark brown. Panicle spikelets consist of 2-12 florets.

Fig. 4.4. Diversity in the form of tef panicles. Very compact (A), semi-compact (B),) loose (C), very loose (D). Adapted from Assefa et al. (2015)

Physiology and phenology: Tef is a warm season C4 annual grass plant having Kranz anatomical characteristics and classified intermediate between tropical and temperate grasses. It is day length sensitive and flowers best during 12 hours of daylight. Tef is a short-day cereal. Thus, due to photoperiod sensitivity, growing it in the temperate and Mediterranean-type climates during summer when the daylight is longer is a challenge (Assefa et al., 2015). Tef matures in 45-160 days after sowing depending on the variety. Very earlymaturing types are ready to harvest in 45-60 days; early types in 60-120 days; and late types in 120-160 days.

Germplasm: Tef is a self-pollinating chasmogamous plant. Tef germplasm accessions have wide genetic variability in key agronomic and nutritional traits. Around 3842 accessions are preserved at the Plant Genetic Resources Centre of Ethiopia. Diversity in the panicles is a key distinguishing feature (Fig. 4.4). The tef grown in Ethiopia comprises landraces and varieties

that are adapted to specific climatic conditions (Ketema, 1997). Common varieties in Ethiopia include Kora, Dessie, Sirgynia, Kaye Murri, Quncho and Duken (Assefa et al., 2017).

Generally, tef has benefited little from genetic improvement (Assefa et al., 2015). Breeders have employed direct selection from the landraces, interspecific and intraspecific hybridization and mutation breeding. However, mutation and interspecific hybridization have not yet contributed to the development of improved cultivars. There is potential in the use of genomics, transcriptomics and proteomics to develop better varieties (Assefa et al., 2015).

Propagation: Tef is propagated from seed. Seedbed preparation is like that of maize, wheat, millets and other cereals. Seeding rate is 4.5-9.0 kg ha-1, either broadcast or in narrow rows. The seed is sown 12-15 mm deep.

Nutrient management: Moderate rates of nitrogen and phosphorus fertilization reduce the risks of plant lodging (displacement of stems or roots from their vertical and proper orientation). The nitrogen use efficiency, defined as the ratio of grain yield to soil available nitrogen, is low in tef compared with other cereals. It ranges from 16-34% (Tulema et al., 2005). Breeding for improved nitrogen use efficiency might reduce fertilizer requirements without significant decline in yield (Assefa et al., 2015).

Crop protection: The rapid growth of tef smothers most weeds while few diseases and pests are known to cause economic losses. African armyworm (Spodoptera exempta) is an occasional pest that causes serious damage during outbreaks. Young plants are the most susceptible to caterpillars that feed on the leaves. Outbreaks start in May in the southern provinces of Ethiopia while during the main growing season the pest moves northwards. Regular monitoring of field margins, inspection of lodged plants and the underneath of leaves for caterpillars is recommended. Daily monitoring for the pest is necessary when conditions become favourable for the pest. Spraying with either botanicals or inorganic insecticides is only effective when the caterpillars are young.

Mature caterpillars cause serious damage and it is uneconomical to spray insecticides at this stage. Tef rust (*Uromyces eragrostidis*) is the most common disease affecting this crop. It's a fungal disease whose symptoms appear as brownish-red pustules on leaves. Broadleaf weeds, particularly redroot pigweed *(Amaranthus retroflexus)* is important. The weed produces seeds that cannot be separated from tef.

Harvesting and storage: Yields range from 0.3-3.0 t ha^{-1}. The national average in Ethiopia is 0.9 t ha^{-1} but a potential yield of up to 2 t ha^{-1} is achievable with good agronomic practices. The grain threshes well with standard methods and equipment. The grain is easy to store and will survive for many years in traditional storehouses without damage by insects. This makes it a valuable safeguard against famine.

When tef is harvested for grain, due to its small seed size, the seed delivery systems of the combine must be checked for gaps and areas through which the seed can be lost. Separating the seed from fine soil particles is nearly impossible, thus soil particles must be prevented from going through the combine and into the grain hopper. Tef has desirable storage properties when the grain has less than 12% moisture content. Storing tef for one year does not affect the malting quality of the grain (Gebremariam et al., 2013).
Farmers pack their produce in a variety of packaging materials, which are either the traditional types such as Akomada or the modern packing materials such as sisal or plastic sacks and

plastic bags. The traditional packaging materials are less preferred because they produce odour and can permit water entry which affects the quality of the grain.

Processing and value addition: Processing tef grain into flour and injera is limited to a small-scale miller who use hammer mills and individual bakers who use the traditional clay pan. The millers sell tef flour or provide milling services to customers. Making and selling injera is a major source of livelihood in major towns and cities in Ethiopia (Demeke and Di Marcantonio, 2013). Injera making largely relies on traditional mode of production technology (Fig. 4.5). Injera is made by mixing tef flour or blends of sorghum, barely flour with water to make a dough, and then triggering a fermentation process by inoculating the dough with ersho, a starter culture, left over from a previous fermentation. The starter culture is typically added at a ratio of 1:1.6 w/v (Baye et al., 2013). Depending on weather conditions, fermentation takes 2–3 days after which the dough is thinned into a batter before baking on an open platter. Tef is used to blend the flours of other cereals such as maize, sorghum, wheat and barley to improve nutritional quality. This is particularly important in baked goods.

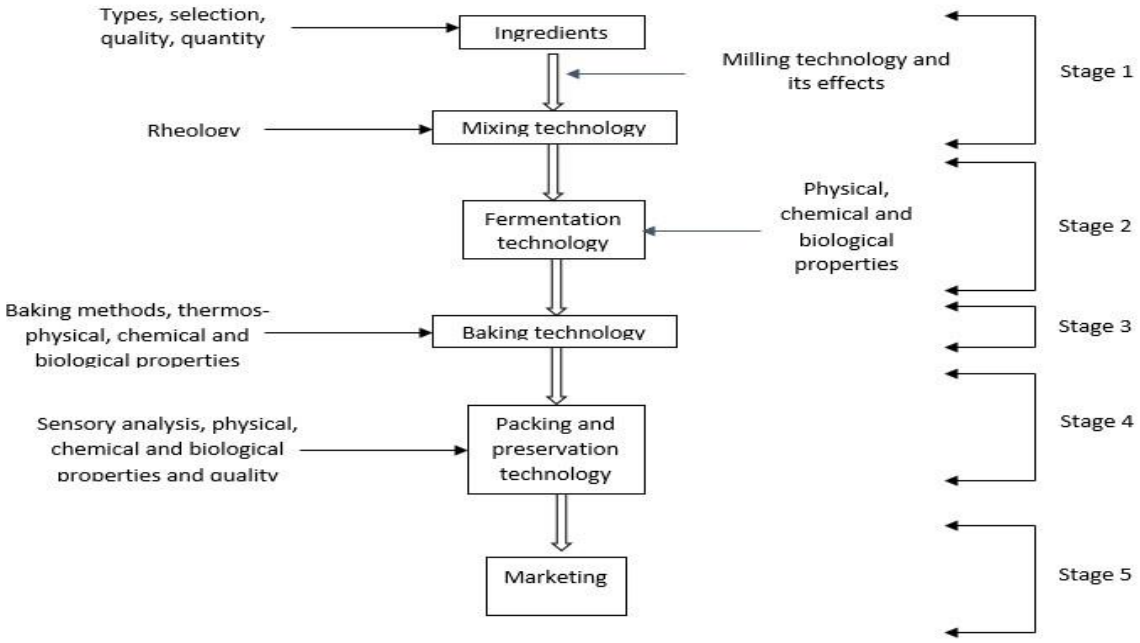

Fig. 4.5. Model of injera (Ethiopian bread) preparation process

Marketing: In Ethiopia, marketing of tef is done by assemblers in village markets and wholesalers in regional markets. These actors play a significant role in the quality of tef. There are three general colour-based grades of tef; the white, mixed and red. The white fetches the highest and red the lowest price. There are also important sub-grades within each grade such as magna (very white) which is grown in East Shoa and is sold at a premium price (Demeke and Di Marcantonio, 2013). The central market in Addis plays an important role in determining prices in the major production areas. While the bulk of the grain moves to Addis Ababa, some urban consumption centers such as Mekele and Dessie get their supplies directly from the production areas. Other urban centers such as Harar and Dire Dawa are supplied from Nazeret/Adama town in East Shoa (Demeke and Di Marcantonio, 2013).

There is increasing demand for tef in the export market (Abraham, 2015). It is exported mainly to the Arab world, North America and numerous European countries primarily for Ethiopian Diasporas. Out of its original cultivation area many countries are involved in the production and marketing of tef, especially South Africa, Cameroon, Canada, Netherlands, British, India, USA, china and Uganda (Abraham, 2015). Knowledge of the physical and nutritional properties of tef seed could be useful for fine-tuning agronomy, storage, marketing, and other socio-cultural purposes of tef (Assefa et al., 2015). The increasing global demand for gluten-free foods and attractive nutritional profile is fundamental in the marketing of tef (Gebremariam et al., 2014).

Case studies

A case study of Ethiopia's value chains on tef showed increased adoption of better agronomy in the use of inorganic fertilizers, pesticides, improved seed and herbicides in tef production (Minten et al., 2013). Increasing demand for quality tef products has led to investment in better varieties. Farmers are shifting from low quality red varieties to high quality white ones. These improvements are matched by improved marketing efficiency, with one-stop retail outlets that provide transport, cleaning, milling, packaging and sales. Other case studies in Bacho and Dawo districts of South West Shewa in Ethiopia showed that injera sellers were the most important in the value addition of tef (Tura et al., 2016).

The sellers determined the value and standard of the grain. Lack of adequate inputs and credit facilities and price setting by traders is a major constraint to farmers while traders face poor infrastructure, capital shortage and limited access to credit, farmers' unwillingness to sell their produce, absence of storage facilities and government support (Tura et al., 2016). Tura et al. (2016) proposes the creation of trust among value chain actors and the development of extension services to upgrading tef value chains

Grain amaranth (Amaranthus caudatus)

Fig. 4.6. Amaranth plant, different types of panicles and assorted colours of seed

Importance: Grain amaranth has significant economic, nutritional and cultural importance (Figure 4.6). The grain can be cooked, milled into flour, popped as popcorn, germinated for sprouts and malted for beer production. The flour can be used as an ingredient in making bread, macaroni, biscuits, crackers, vegetable spreads and breakfast cereals. Milled amaranth can be

mixed with flour of cereals such as millet, sorghum, maize or ground fish to make a nutritious thin porridge. Grain amaranth is gaining popularity in the international health food market and is gluten-free (Mlakar et al., 2009).

During the pre-Columbian era in central Mexico, the Aztecs cultivated grain amaranth as staple to make tamales, tortillas and atole, a hot cereal meal (Sebastia, 2016). They used amaranth, agave and maize to make idols of their gods during the sacred month of Huitzilopochtli and the statues would be eaten at the end of the month. In current Mexican culture, amaranth seeds are offered as a snack for 'spirits' on the Memorial Day for the Dead (Sebastia, 2016).

Ecology: Grain amaranth grows from sea level to 2400 m altitude depending on the species. Normally, amaranth grows rapidly in hot and high light intensity environments, with temperature ranging from 22-30oC, and low to medium humidity. The ideal temperature for seed germination is 15-17oC. Rainfall is supplemented with irrigation for frequent water supply in dry conditions. Amaranth can grow in a wide range of soils but grows best in loam to silty-loam with good water holding capacity and soil pH of 4.5-8.

Botany: Amaranth is an annual or perennial herbaceous plant that at maturity reaches a maximum height of 3m, although there are dwarf varieties (<0.5m). The stem is robust, erect, cylindrical, succulent and fibrous, and becomes hollow when mature. The stem has stripes on the outside and shades of green, purple, pink, red or brown depending on variety. Leaves are stalked and compound, alternate, rhomboid-shaped, elliptical or oval, with glabrous on both surfaces and large veins. Leaf colour ranges from green-yellow to deep red, and length ranges from 6-15cm.

Inflorescences are large and form a panicle, either terminal or axillary. The panicle is about 0.5-1.0m, whose colour varies with variety. Pollination is predominantly autogamous and the flowers are unisexual and small, with stamens at the apex of glomerulus and pistils. Seeds are small, spherical or lenticular, and the colour varies with variety. Seed diameter is 1-1.5mm and 1000-3000 seeds could weigh a gram.

Physiology and phenology: Grain amaranth has a C4-photosynthetic pathway that contributes to its broad adaptation to diverse and sometimes adverse environments. Light conditions influence seedling growth depending on species. For example, red light seems to promote the growth of A. caudatus and A. tricolor seedlings while far-red light favours the growth of A. viridis seedlings (Singhal et al., 1983).

Germination occurs within 3-4 days after sowing but low soil temperature delays emergence. Time to flowering varies with species and variety and often has a logarithmic correlation with the inflorescence axis. The flowering window for A. caudatus varies from 15-25 days while A. maim has a shorter flowering duration of 4-7 days (Cavers and Steel, 1984). Seed ripening begins 30-35 days after flowering, irrespective of species and inflorescence morphology (Cavers and Steel, 1984).

Germplasm: Amaranth species are self-pollinated and have a wide diversity of landraces and varieties due to outcrossing and hybridization (Akin-Idowu et al., 2016). In Kenya, varieties are broadly classified as short for low rainfall areas and tall varieties for high rainfall environments. Seed is supplied by KALRO-Mtwapa as well as private businesses such as Amaranth International, Amaranth Incas and African Amaranth Limited.

Breeding objectives for amaranth range from improved yield, better harvestability, lodging (permanent displacement of the plant from its upright position) reduced seed shattering,

uniform maturity, reduced leafiness in the green head region, short stature, seedling vigour, pest and disease tolerance, and nutritional quality (Mlakar et al., 2009; Adeniji and Aloyce, 2013; Espitia-Rangel, 2018)

Propagation: Amaranth is propagated through seed by either direct sowing or transplanting to the seedbed. Direct seeding is preferred when plenty of seed is available and labour is limited as well as during the dry season when chances of flooding are low. Transplanting is appropriate when seed is limited but adequate labour is available. Transplanting is preferred in wet conditions when heavy rains and flooding are most likely to wash out seeds. Amaranth requires thorough land ploughing and raised beds about 20cm in dry conditions but 30cm in rainy seasons. The distance between centres of adjacent furrows should be about 150cm. For direct seeding, seeds are either broadcast or sown in rows. It is advisable to broadcast seeds uniformly at the rate of 0.5 to 1.0gm-2. The seeds are mixed with sand at the ratio of 1g seed to 100g sand to make sowing easier and achieve uniform distribution. When sowing in rows, make furrows 0.5 to 1.0cm deep, with 10cm between rows.

Nutrient management: Although grain amaranth is well adapted to poor soils, addition of organic and inorganic fertilizer improves yields. In Central India, studies showed that in addition to the application of 50kg N ha-1 and 50kg P ha-1, the integrated supply of 10t ha-1 farm yard manure, 5t ha^{-1} vermicompost and 5kg ha^{-1} Azotobacter increased grain yield and improved soil quality (Tayade et al., 2012).

Crop Protection: Important insect pests of amaranth include aphids, cutworms, leaf miners, spider mites and weevils.

i. Aphids (Aphis spp): Aphids suck the plant sap which leads to wrinkled leaves, stunted growth and deformed seeds. Aphids can be managed by monitoring the crops regularly and performing spot spraying on only the affected plants when infestations are sighted. The use of biopesticides that are less harmful to the environment such as neem products is recommended.
ii. Cutworms: Cutworms attack young seedlings. First instars are 7-12mm while mature caterpillars are 3.5-5cm long. The caterpillars emerge from the soil at night and cut through the stem of young plants just above ground level. Systemic and contact insecticides which a long residual effect in the soil are recommended.
iii. Leafminers (Liriomyza spp.): Leafminers are small flies, 1.3-1.6mm long. The maggot makes long, slender, white tunnels in leaves. Severely mined leaves turn yellow and drop while seedlings are stunted and may eventually die. Spray crops with biopesticides such as neem extracts and destroy the damaged leaves.
iv. Spider mites (Tetranychus spp.): Spider mites attack reduces plant growth, flowering and seed set. Damage is more severe during dry seasons, and particularly devastating on young plants. Avoid planting next to infested fields and minimise the use of broad spectrum insecticides such aspyrethroids. It is recommended to use overhead irrigation to knock-off mites and their webs.
v. Weevils: Adult weevils feed on leaves, but the larvae (grubs) are more damaging because they bore into roots and stems. This causes rotting, lodging and predisposes the crop to fungal diseases.

Economically important diseases of amaranthus include:

Damping-off (Pythium spp.; Rhizoctonia solani): This disease is caused by Pythium aphanidermatum, Rhizoctonia solani and Aphanomyces spp. Seeds may rot in the soil before

emergence (pre-emergence damping-off) or seedlings may exhibit stem canker above the soil line and root necrosis. Affected seedlings eventually wilt (post-emergence damping-off). The disease is favoured by high soil water content and low soil temperature. Dense planting without sufficient aeration favours disease development. Control include the use of disease-free seed, spaced sowing, clean field and avoidance of over-watering.

Choanephora rot: Choanephora blight (also called Choanephora rot) is caused by the fungus Choanephora cucurbitarium. It causes wet rot of stems and leaves. Affected plant parts show silk-like threads that contain fungal spores. Infection is predisposed by injuries. During rainy season it can cause heavy defoliation. The disease is spread by air and infected seeds. Warm, moist conditions favour disease development. Use disease-free seeds, resistant varieties and avoid dense planting to allow for sufficient ventilation. Copper spray is recommended on affected plants.

Weeds significantly reduce amaranth yields, by competing for light, water and nutrients. Thorough land preparation is the first step to effective weed control. Amaranth is small-seeded and slow to germinate, thus weed control is essential early in the season. A seedbed free of weeds gives amaranth seedlings a head-start to establish a canopy that shades emerging weed seedlings. Mulching is recommended to smother weeds, in addition to moisture conservation and the reduction of soil compaction and erosion. However, organic mulch should be free of weed seeds. Mulching is easier to apply if the amaranth crop is transplanted but can also be applied on row-seeded crops after the seedlings are 10-15cm tall.

Harvesting and storage: Panicles mature in 45-60 days for early maturity short varieties while the late maturing (tall) ones take 70-120 days. Maturity indicators appear when the crop turns brown or pale green or yellowish; yellow flowers drop, and seeds are visible in the panicles; seeds do not produce a milky substance when squeezed. Mature heads are cut at the end of the stem with a knife and spread on canvas or polythene paper to dry. Delayed harvesting leads to sprouting if the conditions are wet and humid. Harvested bunches/heads are beaten with a stick to thresh the seeds. Seeds are winnowed and dried under the sun for two to three days or until 13% moisture content.

Value addition and marketing: Grain amaranth is utilized in several ways: cooked as a cereal or in combination with other whole grains, ground into flour, popped like pop corns, sprouted, toasted, added into stir fry or soups and stews as a nutrient dense thickening agent. The flour is used to prepare porridge, pizza, pasta, pancake and flat bread. As part of value addition, grain amaranth flour is blended with nutritionally poor cereal flours. In Kenya, processing and marketing of grain amaranth, both locally and internationally is conducted by Amaranth International Ltd, Incas Health International Ltd, African Amarantha Ltd, Amaranth Grain Ltd, All Grain Company Kenya Ltd in Nairobi and MAP international. In Kenya, poor marketing infrastructure discouraged farmers from growing amaranth for commercial purposes (Waithera, 2012).

Case studies

In Kenya, there are some success stories on grain amaranth initiatives. KALRO conducts seed multiplication activities at Katumani, Kiboko and Mtwapa stations (Kiarie et al., 2014), and

promotes the dissemination of agronomic practices, processing and value addition technology (Omari et al., 2014).

Quinoa (Chenopodium quinoa)

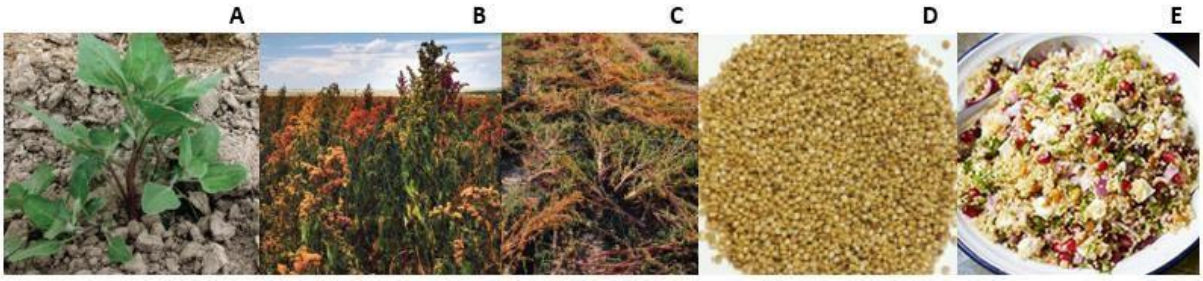

Fig. 4.7. Quinoa plant (A), mixed quinoa varieties growing in the field (B), swathed quinoa crop left in the field to dry (C), threshed quinoa seed (D) and quinoa, feta and pomegranate salad (E). Adopted from Liang et al. (2016)

Importance: Quinoa (Figure 4.7) is native to the Andean highlands of South America and is one of the oldest crops in that continent. It is grown for edible seeds and is considered a "supergrain" due to its high concentration of essential amino acids, fibre, vitamins A, B2 and E, and minerals such as calcium, magnesium, copper, zinc and iron (Liang et al., 2016). This crop can do well in Africa highlands where the conditions are similar to South America.

Ecology: Quinoa is grown in the coastal regions (sea level) to over 4000m in the Andes highlands. Most varieties are grown from 2500m to 4000m. Depending on the variety, optimal growing conditions are in cool climates with temperatures that vary between -4°C during the night to near 35°C during the day but can tolerate higher temperatures. Quinoa tolerates frost when the frost occurs before flowering but causes significant damage after flowering. Quinoa is drought resistant and can grow well with annual rainfall of 200-400 mm (Valencia-Chamorro, 2003).

Botany: Prior to the use of morphological characteristics, quinoa species were initially classified based on the colour of the plant and fruits. Quinoa is one single species, and 17 races have been identified from collections in Ecuador, Peru, and Bolivia while more races could be available. Two morphologically distinct inflorescences have been described: the glomerulates which have small groups of flowers (glomeruli) originating from tertiary axes; and the amaranthiformes, that have glomeruli originating mainly from secondary axes (Valencia-Chamorro, 2003). Quinoa grows to 0.5-2.0m tall. In the initial vegetative stage, the crop resembles lambsquarters. However, the base of the quinoa stem is pink to red while that of lambsquarters is green to grey.

Phenology: Depending on variety, quinoa takes about 90-150 days to mature. Flowering and grain filling stages occur 40-80 days after sowing. Water and heat stress, and poor soil fertility during flowering and grain filling significantly reduce yield (Geerts et al., 2008). Planting date should be set in a way that flowering does not coincide with peak summer temperatures (Liang et al. 2016).

Germplasm: Breeding of quinoa through genetic engineering has modified the crop for higher yield, improved tolerance to heat stress, pests and diseases, and greater sweetness through

saponin inhibition. Genetic engineering of quinoa follows the success in the sequencing of its genome (Jarvis et al., 2017).

Propagation: Quinoa is propagated from direct seeding or by transplanting. Direct seeding is at a rate of 0.40.6 gm-2 with 0.30-0.60m between rows and thinned to 0.10m between plants. When transplanting, plant the transplants 0.30m apart and 0.30-0.60m between rows. The recommended spacing is good for plants that have large panicles. Closely spaced crops have restricted branching and mature early (Risi and Galwey, 1991).

The seed bed is tilled to 0.15-0.20m for direct seeding or transplanting. Quinoa seeds are small and susceptible to desiccation, waterlogging, and failure to emerge through crusted soil (Murphy and Kellogg, 2017). Ideal germination (nearly 100%) occurs at soil temperatures from 2-20 °C. Low temperatures delay and reduce germination. Young plants at two-leaf stage can withstand temperatures up to -4°C but the flowering stage is susceptible to frost (Jacobsen et al., 2003).

Nutrient management: Inorganic fertilizers, green manures or aged compost amend soil fertility requirements in quinoa. However, fertilizer requirements for this crop have not been developed (Liang et al., 2016). Excessive application of nitrogen can decrease yield due to delayed maturity, overproduction of vegetative biomass and lodging. Close placement of seed and fertilizer inhibits germination (Peterson and Murphy, 2015).

Protection: Plant bugs (Melanotrichus coagulates; Atomoscelis modestus; Lygus spp) and seed bugs (Nysius raphanus) damage seedlings, mature plants and seeds using their piercing and sucking mouthparts to feed on plant sap.

Flea beetles are small, dark, shiny beetles that have chewing mouthparts. They leave small holes on damaged leaves. Beet armyworm (Spodoptera exigua) larva (caterpillar) is the destructive stage. Armyworms are soft bodied and green with dark longitudinal stripes. They feed on leaves and seed heads. Leaf miners damage the tissue between the lower and upper sides of the leaf. Visible tunnels characterize their feeding damage. Aphids (Macrosiphum euphorbiae, Hayhurstia atriplicis and Pemphigus populivenae) feed on foliar tissue by piercing and sucking plant sap.

In the USA, cultural and biological management options are commonly used because insecticides registered for use in quinoa are not available. Planting date should be set so that crops escape pest infestation. Use of recommended seeding rates, better irrigation and nutrient management practices increases plant vigour hence increased tolerance to pest attack.

There is limited information on the epidemiology and impact of diseases of quinoa, and the most damaging disease is **downy mildew** (*Peronospora variabilis*). The fungus oospores can adhere to the grain, thus certified and treated seed is a key step to the control of downy mildew, in addition to the use of resistant cultivars. Symptoms appear as chlorotic or yellow lesions on the leaves and gray fungal bodies develop on the lower surface of the leaf. The lesions become necrotic leading to stunted crops, premature defoliation, hence reduced yields. The germination and spread of *P. variabilis* are favoured by cool rainy conditions with moderate temperatures of 18-22 ^{o}C and more than 85% relative humidity. Wide spacing and orienting the field to increase air circulation and minimising the use of overhead irrigation can control downy mildew.

Harvesting, storage and value addition: The crop is harvested when the seeds reach the hard-dough stage, and the plants will dry down and leaves will drop. The plants with the seed heads

should be dry enough (10% moisture content) to allow easy separation of the seeds from the hulls by hand (Liang et al., 2016). Combine is used for harvesting, and often, crops are swathed and left to dry for approximately one week before the machines are used. Due to the light weight and small size of quinoa seed, the harvester's cyclinder speed and air flow should be reduced below that of other grains, while a fanning mill and gravity separator are used to separate seeds from chaff.

Quinoa seed should be kept in dry storage (Liang et al., 2016). The shelf life of quinoa depends on different factors; on whether it is totally cooked or not and whether it is milled to flour or not. It is difficult to know when quinoa has gone rotten or not because it does not become sour or smell. Raw quinoa lasts for two to three years when stored in the pantry or the refrigerator. The cooked quinoa lasts for six to seven days in the refrigerator and eight to twelve months in the freezer. The pericarp of quinoa seeds contains saponins, phytic acid and polyphenols (tannins) that give a bitter taste and are poisonous. Therefore, before the grain is processed for food, the toxins are removed by soaking the seeds in water or by mechanical abrasion (Liang et al., 2016).

Buckwheat (Fagopyrum esculentum)

Fig. 4.8. The crop cycle of buckwheat plant in New York. 21 days after sowing; the beginning of rapid growth (A). 28 days after sowing; flower buds just visible (B). 52 days after planting; peak flowering (C). 73 days after sowing; ready to harvest (D). Harvested seeds (E).

Source: http://www.hort.cornell.edu/bjorkman/lab/buck/guide/buckgrowthphotos.php

Importance: Buckwheat (Figure 4.8) is primarily used for human food through the consumption of the dehulled seed, or the groat. It is used either in breakfast cereals or milled into grits (Li and Zhang., 2001). Roasted groats (kasha) are sold in whole and granulated forms. Both kasha and groats can be baked, steamed or boiled.

Buckwheat flowers provide both pollen and nectar for bees and can be used as a honey crop. The plants improve conditions for the cultivation of other crops by smothering weeds, harbours beneficial insects and provides green manure when the crop ploughed under. The crop fits well in rotations with lettuce, peas, rye straw, barley or wheat.

Ecology and Botany: Buckwheat is adapted to a wide range of soil types and performs optimally in medium texture soils. However, it is particularly adapted to arid hilly land and cool climates. Compared with other cereals, buckwheat performs well in poor soils where other crops cannot grow. Crusted soils lead to emergence problems. Buckwheat grows up to 0.6-1.3m tall and is characterized by large heart-shaped leaves, reddish stems and flowers ranging

in colour from white to pink. It has a shallow tap root system, with numerous laterals extending up to 1-1.2m in diameter. Its flowers are perfect but incomplete and can be white or white tinged with pink. They have no petals, but the calyx is composed of five petal-like sepals that are usually white, pink or dark pink. The flowers are densely clustered in racemes at the end of branches or on short pedicles that arise from the axils of the leaves (Woo et al., 2016). The kernels of buckwheat are triangular-shaped seeds that are enclosed by a tough, dark brown or gray rind.

Physiology and phenology: The emergence buckwheat seedlings occur in four days after sowing and the plant takes 7590 days to mature. This does not tolerate waterlogging and is sensitive to drought. The crop thrives best in cool moist climates. Temperatures over 25°C reduce seed set and yield (Obendorf, 1991).

All growth stages of buckwheat are sensitive to frost. In North Dakota (USA), planting is done from May 25 to June 15 to minimise the impact of frost on crop growth and yield. Extending sowing to July significantly reduces yields (Edwardson, 1996). The crop is heat sensitive from the beginning of flower budding through to grain set. Table 4.2 illustrates buckwheat crop growth by week and associated challenges.

Table 4.2. Buckwheat crop growth stages and special concerns.

Week	Growth stage	Special concerns
1	Germination	Crusting
2	Emergence	Puddling
3	Early vegetative growth	
4	Main vegetative growth	
5	Buds show	Heat stress
6	Bloom and seed set	Heat stress
7	Peak flowering	
8	Seed fill	
9	Seeds start to brown	
10	Leaf yellowing	Monitor maturity
11	Maturing	Windrowing
12	Mature	Harvest, frost
13	Drying straw	Frost, shattering

Adapted: http://www.hort.cornell.edu/bjorkman/lab/buck/guide/growth&development.php

Germplasm: Limitted breeding efforts have been done to improve buckwheat yields in the past century (Edwardson, 1996). Essentially, the extreme plant to plant variability of buckwheat is a major impediment to cultivar improvement. Interspecific hybridization between F. homotropicum and F. esculentum is underway (Campbell, 1995) in the development of cultivars with greater uniformity in yield (Ohnishi, 1995). Two types of buckwheat cultivars are grown in North America; thesmall seeded and the large seeded. The small seeded varieties include Tokyo, Tempest and Common whereas Manor, Mancan, Manisoba and Giant American are large seeded (Campbell, 1995).

Propagation: Buckwheat is propagated from seed at the rate of 50-70 kg seed ha-1. The seeds are sown in rows spaced 0.15-0.17m apart and 2-5cm deep. Buckwheat is rotated with small grains such as wheat and barley.

Nutrient management: High levels of nitrogen fertilization results in excessive vegetative growth, lodging and reduced grain set. The crop requires high amounts of phosphorous during set seed and filling. Management guides that provide recommendations for micronutrients are not available.

Crop protection: Most insect pests do not cause major economic losses in buckwheat production, but aphids and grasshoppers frequent the crop. Grasshoppers cause defoliation on field borders when their population is high and other food sources are scarce (Marshall and Pomeranz, 1982).

Diseases in buckwheat are rarely reported. Rhizoctonia root rot, Alternaria and downy mildew cause some problems but typically minimal.

Buckwheat is competitive against weeds and no serious weed problems are reported. The crop is sensitive to carryover of trifluralin, atrazine, and sulfonylurea herbicides.

Harvesting and storage: Buckwheat should be windrowed when 75% of the seeds in upper ⅓ of the plant are ripe (Gubbels and Campbell, 1985). Windrowing is recommended when field is damp, usually after frost to reduce shatter loss. The estimation of the optimal time to windrow the crop is complicated by plant to plant variability. Improving the uniformity of seed set and yield through breeding can improve buckwheat harvest and yields (Gubbels and Campbell, 1985).

Typical yield ranges from 1100 -1700 kg ha-1 but yields over 2200 kg ha-1 have been reported (Edwardson, 1996). Buckwheat will store safely at 14 to 16% moisture content. To increase marketability, it is important for the groat to maintain a green colour. Over time, oxidation will cause the groat to turn red, which reduces milling quality. Research on the maintenance of the green colour of the groat will reduce quality deterioration during storage.

Value addition and marketing: The grain is milled into flour for making pancake mixes and bread. It is also blended with wheat flour for use in bread, pasta products and breakfast cereals. The Japanese mill buckwheat groats into flour for use in the production of soba noodles. In Eastern Europe, buckwheat flour is used in cooking like wheat flour. Buckwheat flour is used alone in some dishes, such as polenta and could be mixed with wheat flour to make bread, cakes and dumplings.

The nutritionally superior characteristics of buckwheat place it in an excellent position for expanded utilization. However, increasing the utilization of buckwheat as a food ingredient will require targeted market research (Edwardson, 1996). Since the cost of introducing new food products into the market is substantial, buckwheat processors will need to focus on the health benefits of the crop. Present market expansion research indicates that buckwheat is well positioned to be included in specialty breads, pasta, snack foods and ready to eat cereals (Edwardson, 1996). The main market for buckwheat is Japan.

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Chapter 5

Neglected and Underutilized Rodents

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Overview

Rodents are the most numerous and diverse group of mammals. They are distributed worldwide and often become very abundant in their habitats. The majority are generalists in food habits. Size differs widely ranging from a few grams to several kilograms in some species. Worldwide rodents are utilized as food in diverse societies and cultures. Rodents are hunted or reared in captivity for meat supply to consumers in rural and urban areas. In Africa, rodent species commonly utilized for meat include the cane rats (*Thryonomys swinderianus*), African giant pouched rats (*Cricetomys* spp.), porcupines and some species of rats and mice (*Mastomys natalensis*, *Arvicanthis niloticus* and *Gerbilliscus* spp.). Guinea pigs (*Cavia procellus*) are reared in cages for food in both urban and rural areas. However, much as utilization of rodent meat is widespread, this is an underutilized or neglected source of protein in the continent. To harness rodents as a major source of meat, there is need to encourage people to rear them in captivity, process and package the meat for wider distribution to consumers. This chapter describes the potential of rearing and marketing of rodent meat from three main species, *T. swinderianus*, *Cricetomys* spp. and *C. procellus*.

General characteristics of rodents

Rodents are ubiquitous animals that are distributed worldwide (Happold 2013). Some follow man wherever he settles and in so doing, they interact with him in many ways, often beneficially and occasionally causing him health related problems associated with disease harbourage and transmission, economic problems mainly due to crop and property damages. In general rodents have short life spans, but they maximize breeding, growth and development when conditions are favourable, even if for short periods, which ensures that they can survive in harsh conditions. They have highly developed senses that allow them to integrate themselves in social groups, secure food, mates and even enable them to avoid predators. Their shape and general morphology (small size for the majority) enables them to hide in small spaces, away from potential predators. Most rodents are generalists in their food habits, a characteristic that enables them to colonize all possible habitats, while they can adapt very fast to changing environments ensuring that survival is not sacrificed. Many species can occur together in the same habitat and therefore niche partitioning in suitable habitats ensures that available resources for co-existing species do not lead to extreme competition between them, which will have adverse effects on survival. Being prey to many species of animals, they have developed behavioural avoidance of other animals, strange objects and other substances in their surrounding environment, which enables them to keep away from predators, traps and poisons. The reproductive strategies of rodents differ, but when conditions are suitable, a large litter

size, fast maturation and development can ensure large turnovers over a short period, making some species major pests (Leirs et al., 2010). Rodents are highly adaptable to changes in their surroundings and respond to environmental changes in a manner unparalleled by any other group of mammals. These characteristics enable them to survive in a changing landscape, but also to use available resources to reproduce and multiply.

Diversity and geographical distribution

Rodents belong to the Order Rodentia. They are grouped as small mammals based on body mass. Although most species of rodents are small weighing less than 200 g when they are adults, there is however a great variation in their body size; some being very small, small, medium and large size. The African pigmy mouse, *Mus minutoides*, is approximately 57 g in weight, *Rhabdomys* sp. is about 15 g, squirrels range from 400 g to 1 kg, the African giant pouched rats, *Cricetomys gambianus*, are approximately 3 kg, porcupines (*Hystrix critata)* could attain a weight of about 20 kg (Happold, 2013) while the Capybara (*Hydrochaeris hydrochaeris*) of South America can reach 50-65 kg in weight (Vaughan et al., 2000). Rodents show a very high genetic diversity, which is attributed to high rate of chromosomal mutation (Corti, 2005). Rodents comprise the largest order of mammals, comprising 2,277 out of the 5,422 living mammal species or approximately 42% of worldwide mammalian biodiversity (Happold, 2013). The genetic diversity among the rodents plays a huge role in their survival and adaptability of species. Rodents are some of the most important small mammals contributing to ecosystem species diversity. They interact extensively with their environment (physical, chemical and biotic) with complex effects on other organisms (plants and animals) on spatial and temporal scales (Dickman, 1999). Their community structure and species richness are related to variables such as habitat structure, rainfall and primary productivity (Avenant, 2000; 2003). Rapid changes in natural ecosystems are not only a major threat to rodent species diversity but lead to increasing dominancy of some opportunistic species in agricultural land (Makundi et al., 1999; Makundi et al., 2005).

Rodents are of considerable biological and economic importance because of their abundance, diversity and proliferation on almost all continents. Their harmfulness on one hand and their potential benefits as food for humans and other useful exploitation such as experimental animals make them of considerable importance to human livelihood. Rodents are widely distributed in every continent except Antarctica (Happold, 2013). This is because of their ability to exploit a wide range of suitable habitats and environments throughout the world (Vaughan et al., 2000). Their ability to exploit every conceivable habitat is based largely on their ecological requirements (shelter, food diversity, etc), behaviour, physiology, morphology, life history strategies, etc. Since many species are generalists in their food requirements, several species can inhabit even a small area, but are able to partition niches in their resource requirements to avoid competition between them.

Breeding and population dynamics

Populations of all living organisms change in numbers temporally and spatially. These changes are related to inherent characteristics of the organism, the environment surrounding them and their interactions with other organisms of the same or different species. Rodents are no

exception to these population changes. In fact, among the mammals, rodent population fluctuations are more dramatic and violent than any other mammal species (Makundi et al., 2005). Rodents show amazing characteristics related to their reproduction and breeding patterns, recruitment and development. They also exhibit certain behaviours related to mating, with some being highly promiscuous (Borremans et al., 2014). The population dynamics of rodents in the tropics is strongly influenced by climatic conditions. They show remarkable reproductive capacities. For example, under ideal conditions, a single pregnant rat could theoretically breed several hundred rats in a year, were all of her progeny to survive and breed normally.

Food plays an important role in the breeding, development and survival of rodents. The importance of food on demographic parameters of rodents cannot be overemphasized, in particular its influence on reproduction and population dynamics. Rodents switch diets in response to seasonal changes, which may lead to population regulation. Some studies show that *Mastomys natalensis* feeds more on seeds, arthropods and grasses during the wet seasons (Odhiambo et al., 2008). In agricultural land, cereal seeds become the most preferred showing a seasonal switch in food selection, being a survival strategy in this species determined by seasonality. In the tropics, rainfall seasonality appears to be of prime importance for breeding, recruitment and survival of many species of rodents.

Currently domesticated rodents in Africa

Rodents are some of the vertebrates used by many communities as a meat source. About 89 species have been reported to be utilised (Fiedler, 1990) some of which are domesticated while others are hunted in the wild. Consuming rodent meat is not new in human history. Rodents were a principal source of protein back in 2500 B.C, for example, the guinea pigs in Peru, the domestication of Capybara in Brazil since A.D. 1565, *Rattus norvegicus* or *R. flavipectus* and bamboo rats (*Rhizomys* spp.) during the Tang dynasty (A.D. 618-907) in China (Fiedler, 1990), while meat from the African giant pouched rat is widely consumed in west Africa (Fiedler, 1990; Ajayi, 1974). Among the small mammals which are closest to rodents which have been used for human food are rabbits and hares. These are grouped under the order Lagomorpha which were grouped together with Order Rodentia, but are now regarded as separate, but still they are closely related. Many communities worldwide continue to rear rabbits on commercial basis for sale in food stores, but similar ventures with rodents on a world scale are yet to be realized.

Although many communities in Africa consume rodent meat, attempts to domesticate and rear them in captivity has only been for a few species. These are cane rats (*Thryonomys swiderianus*), African giant pouched rats (*Cricetomys gambianus, C. ansorge*i) and guinea pigs (*Cavia procellus*). Meat from these rodent species is highly valued by local people and is a source of income for farmers. Other species with potential for domestication which have not been fully exploited include the brush tailed porcupine (*Atherurus africanus*) and multimammate rats (*Mastomys natalensis*). These two species are hunted by many communities in Africa as a source of meat for the household. There are many challenges in domestication or rearing rodents in captivity. They include:

i. Problems associated with current practices of rearing in captivity (e.g. design of pens for rearing, lack of extension services, optimum diet for growth and development)
ii. Low survival rate and mating success in captivity.
iii. Lack of knowledge on the breeding behaviour to optimize reproduction in captivity
iv. Diseases affecting animals in captivity
v. Little understanding of the biology of each individual species being considered for domestication.
vi. Lack of knowledge of the ecological adaptations of individual species which make them to occur in large numbers in the wild but fail to equally multiply in captivity (e.g. multimammate rats).

Underutilized rodents

A variety of species have been reported as an alternative source of bush meat in Africa (Fiedler, 1990) and elsewhere. However, only a few species are routinely reared in households as a source of protein in the daily diet and for sale to other consumers.
Some of the more obvious cases of underutilized rodent species are shown in Table 5.1. Currently, under utilization of rodents as a source of meat is due to three main factors, namely taboos, availability of meat from other bigger vertebrates and challenges of rearing animals in captivity. Taboos that restrict eating of rat meat are diverse but not very common (Fiedler, 1990). Religion plays a major role in restrictions on eating certain kinds of foods, with some prohibitions among believers in Christianity, Buddhism, Islam and Judaism. Supernatural beliefs also influence people's attitudes towards eating rodent meat. Commensal species (the black/roof rat, *Rattus rattus*; the house mouse, *Mus musculus*; the Norway rat, *Rattus norvergicus*) are less targeted for meat because they are considered "dirty" and are associated with disease outbreaks in many societies.

In some societies, people have tended to eat rodent meat when the larger vertebrates have become scarce or are unavailable (Fiedler, 1990). Rodents are easy to capture and are not, in most cases, protected by game laws. Therefore, they are often a cheaper source of meat than the larger vertebrates. Rodents could also be abundant in places where large vertebrates are not readily available due to excessive hunting. In sub-Saharan Africa, 37 countries are infested with tsetse flies making some areas unsuitable for producing meat from goats, sheep and cattle (Hursey and Slingenbergh, 1995). Therefore, people in these countries often utilize rodents as an alternative source of protein.

Table 5.1: Common rodents underutilized for meat in the world

	Species	**Distribution**	**Remarks**
1.	African giant pouched rats (*Cricetomys gambianus; C. ansorgei, C. eminii*)	West, Central, East and Southern Africa (Cooper, 2008)	Highly favoured as a source of meat in West Africa (Ajayi and Tewe, 1978). It weighs up to 3 Kg.
2.	Cane rats/grass cutter (*Thryonomys swinderianus)*	Sub-Saharan Africa	Greater cane rats: 3-5 Kg (Skinner and Smithers 1990). Reared by many families for meat in Ghana and Benin (Opara, 2010)

3	Multimammate rats (*Mastomys natalensis)*.	Sub-Saharan Africa	Outbreak species in the savannas and crop fields (Leirs et al. 2010). Abundant and cheap source of meat (Adults: 30-42 g). Harvested in Malawi, Zambia, Tanzania and Mozambique)
4	Nile rat (*Arvicanthis niloticus)*, Porcupines *(Hystrix africaeaustralis*) Yellow footed squirrels *(Paraxerus cepapi) Springhares (Pedetes caponsis)*	Eastern and Southern Africa	Utilized for meat in various countries in Africa including Sudan, Zambia, South Africa, Zimbabwe, and Botswana (Fiedler, 1990)
5	Muskrats (*Ondatra zibethicus);* Beaver (*Castor* spp).	Europe	Eaten as a supplement in the diet in Netherlands and Belgium
6	Asian rice field rats (*Rattus argentiventer*), Philippine rice field rats (*R. mindanensis*), Marmots (*M. babok*) (Fiedler, 1990)	Asia	Utilized for meat in countries including India, Cambodia, Philippines, Indonesia, Thailand, China and Vietnam (Belmain and Singleton in BBC, 2015)
7	Muskrats (*Ondatra zibethicus*), Porcupine (*Erethizon dorsatum*), Ground hog (*Marmota monax*), Grey squirrels *(Sciurus carolinensis)*	United States of America Canada	Eaten by people across several states (Fiedler, 1990).

Selected species and their importance

There are several economic benefits associated with rearing rodents for meat compared to the large ungulates. Rearing them in small scale enterprises can generate employment. Secondly, they are efficient converters of feed to protein while the costs of feed are also low. Thirdly, they do not require high capital investment to house them (Wilson, 2011). A rising demand for meat from certain rodent species ensures availability of markets for producers.

Cane rats (Thryonomys swinderianus)

The cane rat (Figure 5.1) is a very valuable resource in West and Central Africa, where its meat is consumed in large quantities (Jori et al., 1995). Cane rat meat fetches the highest prices in local markets in West Africa, at US$ 8-10 per kg (Assogbagjo et al., 2003). Cane rats are commercially farmed in Benin, where about 16,000 rodents are reported in 500 farms (Granjon & Duplantier 2009). An estimated 40,000 tonnes per year of rat meat is consumed in West Africa, of which only 0.2% is produced in captivity (Mensah and Okeyo, 2005).

Figure 5.1: Cane rats (grass cutter) in captive raring for meat supply and sale in Benin, West Africa. Photo by Makundi R.H

African giant pouched rats (C. gambianus)

Figure. 5.2: African giant pouched rats, *C. gambianus* (Picture by R.H. Makundi)

Cricetomys spp (Family Thryonomidae) are widespread in Africa in all except the driest areas (Figure 5.2). They are mostly used for as a source of meat in West (C. gambianus), Eastern (C. ansorgei) and Southern Africa (Wilson, 2011). Cricetomys emini is a forest dwelling giant rat which is also hunted for meat but not as much as C. gambianus because of its more restricted distribution. In West Africa the meat fetches US $2-10 per kg (Assogbagjo et al., 2003).)

Guinea pigs (Cavia procellus)

Figure 3: Guinea pigs, *Cavia procellus*

Guinea pigs (Figure 5.3) belong to the genus *Cavia,* family Cavidae and order Rodentia. The domestic species *Cavia procellus (*commonly known as cavies) is native to the South American Andes. Guinea pigs rarely weigh more than 1 kg at maturity. Several domesticated types are reared in small numbers for meat supply in households in Africa. According to a report by ILRI (2012), guinea pigs could provide a great source of cheap protein in DRC, which has some of the highest rates of malnutrition in the world. The lean white meat has around 20 percent protein, more than beef or lamb, and the skin is more than 30 percent protein. They reproduce quickly, with females giving birth to 10–15 offspring a year (Macmillan, 2012).

Nutritional importance

Consuming rodent meat has no known physiological ill effect on people. The reason why people should eat rats is to make full potential of available and nutritious food resources in their peculiar surroundings, and as an alternative to other resources which are scarce. Farming and eating rodents could be one solution for alleviating the world's hunger and malnutrition problems (Meyer-Rostow, 2015; Gruber, 2016). Rodent meat has more protein, essential amino acids and less fat compared with conventional meat. The meat, like all meat, is generally easily digestible and contains essential minerals (especially iron and zinc) and vitamin B (Wilson, 2011).

Environmental importance

Rearing rodents under captivity has a major advantage compared to the large vertebrates. Cattle, goats and sheep farming generate a lot of waste, require large areas to graze or to produce feed and are associated with polluting gases such as methane. Rodents, on the other hand, require a small space for rearing, in form of cages, and are often fed on waste products of human food. They do not require large areas for the production of feed. Therefore, for small scale farmers, keeping rodents for meat production has a lower negative environmental impact than keeping livestock.

Management of selected species

Physiology

Domestication of rodents requires a good understanding of their physiology, particularly the ideal conditions which will maximize breeding, survival and growth of offspring. Some rodent species limit their reproductive activity to certain seasons of the year, while others breed throughout the year. Seasonal reproductive activity is often associated with rains which increase the abundance of feed. Savannah species, including *M. natalensis,* are seasonal breeders (Leirs et al., 2010; Makundi et al., 2005, Makundi et al., 2007, Makundi et al., 2009). Physiological changes in rodents particularly those related to breeding are hormone controlled. Changes in oestrogen concentration and many other environmental factors like availability of food, water, housing, space and climate also influence the onset of breeding (Vasantha, 2016).

Breeding

Germplasm: Some populations of rodents, especially those which have been subjected to "forced" inbreeding in cages, usually exhibit low levels of genetic diversity that could be a major threat to their existence. However, most wild populations of rodents are genetically very diverse. Several species often co-exist and interact in the same habitat. Physical barriers such as mountains separated by low land have also been found to prevent gene flow between populations leading to speciation.

Genetic research on the common rodent species has long been of interest in Africa. However, the number of taxa that require genetic characterization and sequencing is still high. A limited number of studies have generated a compelling picture of the evolutionary relationships among rodent species in natural habitats (Corti et al., 2005, Castiglia et al., 2006, Lalis et al., 2006).
An evaluation of the genetic diversity of rodents is important to establish their potential as a biological resource in any given natural habitat. It enables determination of of species which require efforts for conservation, and which species are not threatened by continued harvesting. Loss of diversity in rodent populations in the wild could result from habitat fragmentation. Small population size, inbreeding, lack of gene flow and founder effects are more pronounced in populations in fragmented habitats compared with populations in intact landscapes that are not geographically isolated. For isolated rodent populations such as those being reared for meat under captivity for a long-time, diversification would be low and, therefore, the genetic diversity needs to be maintained. Genetic resource or germplasm collection from the wild (males introduce semen while female introduce ova) is necessary for sustainable domestication of rodents for food. It could help to maintain a healthy and more productive population of domesticated rodents. Other benefits of introducing diverse germplasm into the population include increase of tolerance or resistance to diseases, resilience to unfavourable environmental conditions (e.g. excessive heat in rearing cages) and an increase in the quality of the meat.
A management strategy must be established such as translocation of germplasm from the wild into the captive population and establiment of captive-breeding programs for supplementation of animals to overcome the negative consequences of their isolation and inbreeding.

Breeding behavior: Rodents are prolific breeders and can breed throughout the year if the conditions are favourable. However, this applies to some of the mice and rat species, but for

the bigger species such as the African giant rats and the cane rats, they produce much smaller litter sizes and may have extended gestation periods allowing two or three litters per annum. In some species such as *M. natalensis* reproduction follows rainfall patterns while in other species, such as the cane rats, there is no definite seasonality in breeding.

In most rodents such as those in the family Muridae (the murids) the life cycle is short. They exhibit certain biological characteristics most often not found in other mammals. Most species are polyoestrus whereby they undergo 4 days sexual cycles until they are pregnant. The gestation period is short, being 19 – 21 days when the young are born at a very early stage of development. The young are born naked and helpless, eyes and ears are not open, legs are small and undeveloped, but usually they will grow very fast. Sexual maturity duration ranges among species but is usually reached when they are about 6 – 16 weeks old.

The litter size per birth varies among species. For example, the commensal species have an average of 5-6 for the roof rat (*Rattus rattus*), 7-8 for the sewer rat, *R. norvegicus*, and the field mouse or multimammate rats, M. *natalensis*, has an average of 11-13, but with a maximum of 22 young in a single litter. Females can become pregnant in the post-partum period within 24 hours of giving birth. The cane rat, which is commonly utilized species for meat, is a seasonal breeder, with a very low fecundity rate with an average litter size of 2.9 (range 1-5). Studies in South Africa have shown that they produce a maximum of two litters per annum being a result of the extended gestation period which exceeds 150 days in duration (van der Merwe, 1999).

Parental care in mammals is often critical for survival and development of the offspring. The reproductive strategy of many mammalian species including rodents that give birth to altricial (helpless when young and dependent on their parents for food) young involves intense and prolonged care of their offspring. In most cases, the mother provides all nurturee, but in some cases, fathers also participate in parental care. The display of these parental behaviors in rodents other than mothers is affected by numerous factors, including their sex. Dewsbury (1985) described the following parental behaviour among females and males in different species of rodents: *huddling*-sleeping with, crouching over, or adopting the nursing position with the young; *grooming* - cleaning, licking, or otherwise grooming the young; *retrieving* - carrying or transporting the young from place to place, generally returning to the nest; *play*-engaging in play behavior with the young; *tutoring* -behavioral patterns that facilitate learning by the young; *providing food*- bringing food to the young; *greeting*-engaging in species typical greeting displays; *manipulation in nest* - manipulating the young while in the nest. It has been reported that in many species of rodents the female actively excludes the male from the nest and pups for the first few days after birth, but the male gradually comes back into the nest after some days (Dewsbury, 1985). However, many species of rodents display biparental behavior in the care of the offspring in the nest. Paternal care, though rare among mammals, is routinely displayed by several species of rodents and is probably influenced by hormonal activity). Young rodents remain in the nest until they can venture out as sub-adults. Differences in species parental behavior are common and are probably genetically determined.

Breeding methods: To be successful domestication of rodents for meat will require a breeding programme that involves a combination of methods, similar to other livestock breeding methods. The breeding programme must start with high quality rodents using inbreeding, line breeding and occasional outcrosses to maintain a stock which has been improved for better productivity.

Line breeding: Line breeding involves selection of inbred rodents in pairs which are considered to be foundation family. These usually are closely related or are from the same lineage. Farmers can select the foundation pairs based on certain characteristics which they consider favouarable.
Inbreeding: This is used extensively in the breeding of many species and can be used either to set a positive trait or identify a potentially negative trait depending upon the choices made. Inbreeding of rodents involves animals from different known lineages (e.g. exchange or purchase from different farmers) which are crossed together to produce offspring that have the desired traits or do not carry certain unwanted genetic traits.

Outcrossing: Outcrossing is done to introduce new traits that are missing from inbreeding or linebreeding of animals in captivity. Outcrossing can be used to improve vigor in a line that has been inbred or linebred for many generations if the litters appear to become consistently smaller or the pups no longer have the strong health (vigor) or size that is normally seen in that line. Outcrossing can also be introduced to "breed out" an unwanted trait, such as susceptibility to diseases and genetic defects.

Selection of breeds: Selection of breeding stock of rodents is necessary to improve the quality of the animals being reared for meat. A breeding stock usually consists of a group of males and females which act as parents for future generations. Animals which do not perform to the desired level are removed from the stock. The selected parental stock passes the heritable traits to their offspring. Farmers should be very selective and strict in ensuring that only rodents with good characteristics are allowed to pair and reproduce. These characteristics should not be those influenced by the environment, but heritable ones controlled by genes. Some factors may be considered in the selection of the breeding stock. They include age (the young have a longer productive life while the older are poor breeders and low producers), performance (keeping records of each animal), quality of meat from progeny, body form (size and weight of animals), health (avoid selecting sick and unhealthy individuals for breeding) and good adaptability to prevailing conditions.

Housing

Proper housing for rodents must consider the appropriate dimensions and shapes that are usually used for the species. The cages must be secure enough that they do not allow the animals to escape and are not easily accessible by other animals and thieves. Expert advice may be needed in planning, building and setting up the cages. The cages must be designed with enough space. Dimensions for the cages should be 180 cm in length, 60 cm in width and 45 cm in height for big species such as cane rats and African giant pouched rats (Figure 5.3).

Figure. 5.3 Rodent rearing cages

If a walled pen or house is being used, it must be built in such way that the place they eat must be separate from where they sleep. Also, the production building must be designed to protect the animals from excess temperature and humidity. The floor should be covered with dry soft grasses to provide warmth, nesting materials for the young and comfortable conditions for playing.

Structure and construction of breeding cages: Rodents show a wide range of social organisations which often depend on population density, territoriality and reproductive activity. Some species such as African giant pouched rats (*C. gambianus*) live in groups, with one male among several females while in some other species the pregnant and lactating females may aggressively defend their nests. All these behaviours will determine the structure and construction of breeding cages for rodents. However, they all need enough space for exercise, normal social behaviour (e.g. grooming and play) and the provision of environmental enrichment to help reduce the risk of social stress and aggression and allow the animals to fulfil some of their species-specific behaviours. Solid floors are necessary for hygiene, comfort and to permit foraging and digging behaviour. The incisor teeth of rodents are continuously growing and therefore all rodents require materials to prevent the teeth from overgrowing, thus preventing chewing of the food stuff. Domesticated rodents are commonly housed in cages which can be constructed with brick and mortar with doors made of wire mesh. For comfort, any rodent cage must be provided with nesting material (e.g. dry grass, soft wood dust, and soft paper.). The nesting material is also required for females which have given birth to a litter to help them provide cover and warmth for the offspring. A typical cage for *C. gambianus* will be a box structure measuring 1.0 m by length x 0.5 m height and about 0.75 m width constructed with bricks.

Caging types, methods and placing: Basic cage requirements for the African giant pouched rats and cane rats are:

i. A multi-level cage providing room to move

ii. A solid floor instead of wire
iii. An all metal cage but not wood or plastic which the animals are able to quickly chew through.

iv. Wood ash or shaving or pulp-based bedding material in the bottom of the cage provide lots of hay for nesting
v. Thorough cleaning of the cage on weekly basis.
vi. A corner box for the litter in case of the African giant pouched rats

Caging types, methods and placing for Guinea pigs: These animals do not burrow but they need to be raised in an environment with enough room for them to explore. Therefore, it is recommended to:

i. Construct multi-level cage in a room to ensure you maximize space use
ii. Use a rectangular wood frame to make the cage
iii. Make a cage with dimensions of about 150 cm length x 75 cm width x 45 cm height.
iv. Make the floor out of wood and not wire mesh
v. Make the sides using a small size wire mesh such as chicken mesh
vi. Introduce deep layer of bedding material such as saw dust
vii. Introduce a pair of guinea pigs in the cage

Feeding and watering: Rodents may be herbivorous (feeding on grasses), graminivorous (feeding on roots and leaves), or frugivorous (feeding on seeds or fruits) and can also be carnivorous (Hugo and Bozinovic, 1997), particularly on insects and chicks. The diurnal species will normally search for food from morning hours but will tend to avoid the heat during mid day, but again become active before sunset. The nocturnal species start searching for food after sunset and probably continue feeding until midnight. Some species such as the African giant pouched rats carry food to hiding places in the burrow before consuming it. This hoarding behaviour can lead to serious losses or damage of crops by only a few individuals. This species will only eat in the open if starved or if the pieces are too big to move.

Watering devices, such as drinking bottles and automated water delivery systems, can be fitted in cages for rearing rodents. These should be checked frequently to ensure appropriate maintenance, cleanliness, and operation. Water bottles must be refilled regularly but care should be taken to return each bottle to the cage from which it was removed.

The African giant pouched rats (*C. gambianus*) need more protein than their smaller rat counterparts. They are omnivores in the wild, eating everything from vegetation to insects and even some smaller mammals, although their diet is more vegetarian than carnivorous. In the wild they prefer various kinds of fruits and root vegetables. They should be fed a mixture of food items from the following list, including a variety of fruits and vegetables daily:

i. Grain (commonly maize)
ii. Good variety of fresh vegetables and fruits (e.g. ripe banana, tomatoes, carrots, apples and pawpaw)
iii. Dried fruits
iv. Insects (e.g. crickets and meal worms)
v. Nuts and pumpkin seeds

vi. Whole grain bread

Cane rats prefer to feed on a variety of gramineous plant stems that grow in the wild. These include the elephant grass (*Pennisetum purpureum*), succulent plants such as sugar cane (*Saccharium* spp.), Guinea grass (*Panicum maximum*), Gambia grass (*Andropogon gayanus*), and Congo grass (*Bracharia ruziziensis*). They also can feed on herbaceous legumes. The roots and pitch of oil and coconut palms, barks of Anacardium and fruits such as half ripened pawpaw, plantain, pineapple and mango. Maize supplied on the cob is devoured by cane rats. In captivity they can be provided also with groundnut, rice, maize, legumes, tubers such as fresh cassava and sweet potato chips. Like most other rodents, they need to be supplied with adequate drinking water.

Diseases and pest control

Health management: The health of rodents reared for meat depends on three main factors: the environment, housing, and management. There are no guidelines for health management of rodents reared for meat that are applicable across species and therefore additional information should be sought about how to apply them to meet the specific needs of any species. Animals being reared for meat are subjected to micro and macro environments.

The micro-environment of the species being reared is the physical environment immediately surrounding it; that is, the primary enclosure such as the cage or pen. It contains all the resources with which the animals come directly in contact and provides the limits of the animals' immediate environment. The microenvironment is characterized by many factors, including illumination, noise, vibration, temperature, humidity, and gaseous and particulate composition of the air. The physical environment of the secondary enclosure such as a room in which the cages are installed or an outdoor enclosure, constitutes the macro-environment. Micro-environmental conditions can directly affect physiological processes and behavior and may alter disease susceptibility (Memarzadeh et al., 2004).

Temperature and humidity are key factors that affect the physiology and behaviour of captive animals. Rodents being reared for meat should be housed within temperature and humidity ranges appropriate for the species, to which they can adapt with minimal stress and physiological alteration. The ambient temperature range in which thermoregulation occurs without the need to increase metabolic heat production or activate evaporative heat loss mechanisms is called the thermoneutral zone (TNZ) and is bounded by the lower and upper critical temperatures (Gordon, 2005). The TNZ of most rodent's ranges between 26°C and 34°C; at lower temperatures, building nests and huddling for resting and sleeping allow them to thermoregulate by behaviorally controlling their microclimate (Gordon, 1993).

Exposure to wide temperature and humidity fluctuations or extremes may result in behavioral, physiological, and morphologic changes, which might negatively affect animal well-being and production performance (Garrard et al., 1974). Depending on the specific caging system employed, the selection of appropriate macro- and micro-environmental temperatures will differ based on a variety of factors, including but not limited to the species or strain, age, numbers of animals in an enclosure, size and type of the primary enclosure, and husbandry conditions (e.g., provision of contact bedding, nesting material and/or shelter, and individually ventilated cages). Relative humidity should also be controlled, but not nearly as narrowly as

temperature for many mammals; the acceptable range of relative humidity is considered to be 30% to 70% for most mammalian species. Good ventilation is necessary in animal enclosures and cages. The primary purpose of ventilation is to provide appropriate air quality and a stable environment. Specifically, ventilation: provides an adequate oxygen supply; removes heat caused by the animals, personnel, lights, and equipment; dilutes gaseous and particulate contaminants including allergens and airborne pathogens; adjusts the moisture content and temperature of room air; and, where appropriate, creates air pressure differentials (directional air flow) between adjoining spaces (National Research Council, 2011).

Most rats and mice are nocturnal. These include the cane rats and African giant pouched rats. Therefore, they generally prefer cages with low light intensity (Blom et al., 1996). Young rats prefer much lower illumination than adults (Wax, 1977). Animals should have adequate bedding substrate and/or structures for resting and sleeping. For rodents, contact bedding expands the opportunities for species-typical behavior such as foraging, digging, burrowing, and nest building (Armstrong et al., 1998; Ivy et al., 2008). Moreover, it absorbs urine and feces to facilitate cleaning and sanitation. If provided in sufficient quantity to allow nest building or burrowing, bedding also facilitates heat regulation (Gordon, 2004). Breeding animals should have adequate nesting materials and/or substitute structures based on species-specific requirements (Lawlor, 2002).

The animals being reared for meat must be maintained under environmental conditions conducive to health and well-being. This should involve bedding change (as appropriate), cleaning, and disinfection. Cleaning removes excessive amounts of excrement, dirt, and debris, and disinfection reduces or eliminates unacceptable concentrations of microorganisms. The goal of any sanitation program is to maintain sufficiently clean and dry bedding, adequate air quality, and clean cage surfaces and accessories.

Diseases and treatment: Rodents often suffer from some diseases which may require veterinary attention while in captivity. These include respiratory diseases, anorexia (persistent lack of appetite; not eating), lethargy (lack of energy, weariness or exhaustion), tumours and overgrowth of teeth due to little or lack of gnawing. Respiratory infections are common, and signs include discharges from the nose and eyes. With more severe infections coughing may occur and open-mouthed breathing can be a result of sickness due to pneumonia. Sick animals often stop eating and become lethargic. Infection with mycoplasma (a bacterium) can also cause respiratory disease in rats. Respiratory infections in rodents are very common and the most common and routine methods for their prevention are to keep the rearing pens or cages in a clean, dry and warm environment and to avoid overcrowding of the animals.

Animals usually show signs of anorexia and lethargy when they are sick due to one or more types of diseases that afflict rodents, including pneumonia, cancer, kidney or liver failure. The correct treatment for anorexia and lethargy will depend on the diagnosis of the disease causing these conditions. Full recovery occurs once treatment is prescribed by a vet. Rodents have teeth which grow continuously throughout their lives. When the teeth become too long, the animals are unable to feed and chew the food. This can cause them to stop eating. Rodents must have a surface to gnaw to prevent the teeth from overgrowing. Tumours are common ailments in rodents and tend to occur as lumps that can develop anywhere on the body. Common cancers in rodents include those which occur in mammary glands; a form of breast cancer.

Respiratory diseases are treated with antibiotics, but because antibiotics can cause un-expected complications such as diarrhoea, they must be administered after prescription by a veterinary officer. The overgrown teeth are better prevented by supplying the animals with a surface to gnaw, such as a block of wood.

Tumours are difficult to treat and in extreme cases they can be removed surgically under anaesthesia, which is best done while the tumour is still small. However, much as this is a common practice by people keeping rats as pets, it is questionable whether resource poor farmers rearing rodents as a source of protein in their diet will engage in a costly treatment involving surgery.

Overall, maintaining good hygiene, a proper diet and a stress-free environment are important factors in preventing most diseases of rodents being reared for meat supply.

Pest control: Rats reared for meat are most likely to be infested by pests such as fleas, mites and ticks which, other than sucking blood from the animals, could also transmit zoonotic diseases. Therefore, there must be a management strategy designed to prevent, control, or eliminate the presence of infestations by pests in the animal's environment. A regularly scheduled programme of pest control and monitoring should be implemented. The ideal program prevents the infestation by pest rats (such as roof rat, *R. rattus* and house mice, *M. musculus*) in the rearing facility. For animals in outdoor facilities, consideration should be given to eliminating or minimizing the potential risk associated with pests and predators. Other than maintaining clean and hygienic conditions, pesticides may be necessary, but should be applied with care so that they do not induce toxic effects on the reared animals (Anadon et al., 2009). They should be used in animal areas only when necessary. Traps can be used, instead of poisons, to capture pest rat species such as *R. rattus*.

Stocking rate: The size of the cage and number of animals per cage will depend on the size of the species being reared and the behaviour of the species, with emphasis on reduction of stress of the individuals and aggressive behaviour which may be a result of overcrowding. Cane rats, *T. swinderianus*, are usually found in groups composed of one male, several females, and young ones from more than one generation (National Research Council, 1991). They are nocturnal and feeding on selected fleshy grass. Nests are made of grass and make shallow burrows for shelter. Occasionally, they show aggressive behaviour especially among the males by fighting by having a nose to nose pushing duel, which is not observed with females or the young ones (Fitzinger, 1995). This behaviour is important for stocking animals in cages. Not more than one male can be introduced in a cage.

In the case of the African giant pouched rats and cane rats, individual caging of pairs of male and female is often practiced. The African giant pouched rats are social animals and are largely nocturnal, although they may show some activity in their cages during daylight. *Cricetomys gambianus* makes elaborate burrows in the wild or in enclosed pens. The giant rats therefore require more space than other rodents to allow them to build and use burrows of sufficient size if they are enclosed in pens.

Human and rodent interactions: Zoonotic diseases

Common rodent-borne zoonotic diseases: In Africa, human infections with rodent reservoirs account for great deal in morbidity and mortality. A little more than 64 diseases afflicting humans worldwide for which rodents are involved as reservoirs have been recorded (Gratz, 1997). These diseases include rodent-borne haemorrhagic fevers, rodent borne viruses, rodent-borne rickettsial diseases, rodent-borne bacterial diseases and rodent-borne protozoal diseases. Table 5.2 summarises the more common rodent-borne diseases. Human infections occur due to the close contact with rodents, both wild and commensal, and the vectors, which include fleas, ticks, sandflies and *Culex* mosquitoes (Gratz, 1997).

Table 5.2: Major rodent-borne diseases affecting humans in the world

Disease	**Agent**	**Where the disease occurs**	**Rodent Species Involved**	**How the Disease Spreads**
Haemoharrgic fever with renal syndrome	Virus	Primarily in eastern Asia, Russia, Korea, Scandinavia, western Europe, and the Balkans	Striped field mouse (*Apodemus agrarius*), brown or Norway rat (*Rattus norvegicus*), bank vole (*Clethrionomys glareolus*), and yellownecked field mouse (*Apodemus flavicollis*)	➢ Breathing in dust that is contaminated with rodent urine or droppings ➢ Direct contact with rodents or their urine and droppings. ➢ Bite wounds, although this is rare ➢ The disease may spread through direct contact from person to person, but it is extremely rare
Hantavirus Pulmonary Syndrome	Virus	Throughout most of north and South America	Deer mouse (*Peromyscus maniculatus*), Cotton rat (*Sigmodon Hispidus*), Rice rat (*Oryzomys palustris*) and White-footed mouse (*Peromyscus leucopus*)	➢ Breathing in dust that is contaminated with rodent urine or droppings ➢ Direct contact with rodents or their urine and droppings ➢ Bite wounds, although this is rare
Lassa fever	Virus	West Africa	Multi-mammate rats (*Mastomys natalensis* species complex)	➢ Breathing in dust that is contaminated with rodent urine or droppings ➢ Direct contact with rodents or their

				urine and droppings ➢ Eating food that is contaminated with rodent urine or droppings ➢ Bite wounds, although this does not happen frequently ➢ The disease may spread through direct contact from person to person
Leptospirosis	Bacteria	Worldwide	Rodents and other animals	➢ Eating food or drinking water contaminated with urine from infected animals ➢ Contact, through the skin or mucous membranes (such as inside the nose), with water or soil that is contaminated with the urine from infected animals
Lymphocytic Chorio Meningitis	Virus		House mouse (*Mus musculus*)	➢ Breathing in dust that is contaminated with rodent urine or droppings ➢ Direct contact with rodents or their urine and droppings ➢ Bite wounds, although this is rare
Omsk Haemorrhagic fever	Virus	Western Siberia	Muskrats and possibly narrow-skulled voles	➢ Direct contact with infected animal ➢ Bite from an infected tick
Plague	Bacteria	Western US, South America, Africa, Asia	Wild rodents, including rock squirrels, prairie dogs, wood rats, fox squirrels and other species of ground squirrels and chipmunks	➢ Bite of an infected flea ➢ Direct contact with infected animal

Rat bite fever	Bacteria	Worldwide; *Streptobacillus moniliformis* inNorth America	Rats and mice	➢ Bite or scratch wound from an infected rodent, or contact with a dead rodent
Salmonellosis	Bacteria	Worldwide	Rats and mice	➢ Eating or drinking food or water that is contaminated by rat faeces
South American Arenaviruses (Argentine Haemorrhagic fever, Bolivian Haemorrhagic fevers, Venezuelan Haemorrhagic fever)	Virus	South America: parts of Argentina, Bolivia, Venezuela and Brazil	Cane rat (*Zygodontomys brevicauda*), dry lands vesper mouse, (*Calomys musculinus*), large vesper mouse (*Calomys callosus*)	➢ Breathing in dust that is contaminated with rodent urine or droppings ➢ Direct contact with rodents or their urine and droppings ➢ Bite wounds, although this is rare ➢ The disease may rarely spread through direct contact from person to person
Tularemia	Bacteria	Worldwide	Wild rodents, including muskrats, ground squirrels and beavers	➢ Handling infected animal carcasses ➢ Being bitten by an infected tick, deerfly or other insect ➢ Eating or drinking ➢ contaminated food or water ➢ Breathing in the bacteria *(F. Tularensis*)
Others				
West Nile fever	Virus	Some are specific to Africa, but others infect humans in countries outside Africa	Wild rodents	➢ Vectors and contacts with rodents, faeces, urine
Crimean Congo fever	Virus			
Rift Valley Fever	Virus			
	Virus			
Murine Typhus	Virus			

African tick bite fever	Virus			
Brucellosis	Bacteria			
Lyme disease	Bacteria			
Leishmaniasis	-			
Toxoplasmosis	Protozoa			

Transmission systems for zoonotic diseases: There are some important risk factors associated with infections of rodent borne diseases, as listed below:

i. Living in close contact with rodents: Commensal rodents infest residential areas in both rural and urban environments and any direct contact with humans can lead to infection with diseases such as toxoplasmosis (e.g. by *R. rattus*), Salmonellosis, Leptospirosis, Brucellosis and African bite fever.
ii. Living in close contact with vectors of rodent borne zoonotic diseases: Vectors include fleas, ticks, *Culex* mosquitoes, and sandflies. Among the zoonotic diseases, plague is the most dangerous bacterial infection transmitted through the bite of fleas. Fleas implicated include *Xenopsylla cheopis.* The fleas are found in wild rodent nests and on the body fur of the rodent host when feeding on blood. The plague bacteria, *Y. pestis,* multiplies in the gut of the flea vector and is transmitted to humans either within the house or within the habitat of the wild rodent species through flea bites. Commensal rodents can act as intermediary in the transmission of plague from the wild rodent host.
iii. Handling rodent carcases for food or other purposes: Direct contact with rodent carcases or waste/excretory products can lead to infections with diseases such as toxoplasmosis, leptospirosis and some of the rodent-borne haemorrhagic fevers. Contamination of water and foodstuffs by rodent urine and excreta could lead to infection with Lassa fever (Gratz, 1997).

Control measures, prevention and treatment: Many of the health problems in African communities involve zoonotic diseases, which are infections circulating in wildlife or domesticated 'reservoir' hosts that can be transmitted to humans, where they can cause serious illness or mortality. To control rodent-borne infectious diseases, a good understanding of the epidemiology, clinical manifestations and how they spread from the reservoir host to humans and between humans is necessary. This knowledge is required to facilitate prophylactic therapies and effective control and prevention strategies during disease outbreaks. One of the most effective strategies for controlling rodent-borne zoonoses is to provide public health education with practical approaches to limit human contact with all wild and peridomestic rats and mice, avoiding all contact with rodent excreta, safely disposing of all rodent excreta, and modifying the built environment to deter rodents from colonizing households and workplaces (Diaz, 2014). Learning to control the spread of infection from rodent reservoirs to humans in urban and rural areas is a challenge that must be addressed in any disease control programmes.

Risk management: The risk of infection with rodent-borne zoonoses intensifies with increasing contact of people and rodents particularly in areas with proven high rodent infestations and where certain diseases are endemic. Rodent infestations in houses should be controlled using

traps and poison bait. Recent studies in Southern Africa have also shown that keeping dogs also deter infestation by rodents by creating a landscape of fear (Mahlaba-Themb'alilahlwa et al., 2017). As much as possible, buildings can be rodent-proofed to prevent entry. Sanitation practices are essential in deterring rodents from entering buildings. As much as possible, all sources of food and water available to rodents should be eliminated. Regular rodent surveillance is important within residential areas to ensure infestations are detected early enough before the transmission of zoonoses to humans. As many of the rodent-borne zoonoses infections occur due to direct contact between people and rodents or with rodent infestations in enclosed buildings it is important to ensure that rodent-human contacts in houses and in the fields are minimized.

To minimize the risk of rodent-borne virus infection, personal protective equipment should be worn by those exposed to field rodents or their droppings/urine. People attending to rodents being domesticated for meat production also need to put on protective gears such as gloves when cleaning the pens or cages to minimize contact with the urine and faeces.

Infestation with vectors such as fleas which spread plague increases the risk of plague infection. Rodent urine and faeces pose the greatest health risk to people. Risk is increased when rodent droppings or urine are aerosolized in enclosed spaces such as buildings, food stores, warehouses and rooms constructed for rearing rodents for meat. Persons who are not adequately protected are mainly at risk of infection. Areas with evidence of rodent infestations should be thoroughly disinfected and cleaned to reduce the likelihood of exposure to virus-infected materials. Direct contact with rodent droppings may also be a means of transmitting the infectious rodent-borne viruses.

Cleanup procedures should be performed in a manner that limits the potential for aerosolization of rodent-contaminated material (droppings, urine, or nests). Anyone involved in cleaning rodent-infested buildings or handling dead rodents should use proper procedures for disposal of carcasses, urine and excreta.

Capture and utilization

There are no known attempts to domesticate the smaller species of rats and mice for meat supply. Some of these species (e.g. multimammate rats and grass rats) have seasonal population explosions (Makundi et al., 2005; Leirs et al., 2010). Many communities in Africa take advantage of these regular abundances to harvest them for food. Cane rats, porcupines, squirrels and African giant pouched rats are hunted or captured in locally made traps to supply meat to the family in many parts of Africa. These methods of utilization are not sustainable since these species are disappearing in many areas where there is overexploitation of wild populations. In such areas, conservation initiatives for the species are necessary but could also involve introduction of domestication programmes.

Processing and value addition

Processing of rodent meat is one of the primary value addition strategies, enabling storage and transportation to markets far away from the area of production. Processing also creates differentiated products, moving them from being a mere commodity to the higher standard of

a product (Wilson, 2011). Proper storage can also enable the producer to sell the rodent meat when prices are more favourable, without having to keep live animals that are costly to feed and care. One of the feasible value addition strategies is the canning of meat of freshly slaughtered rats. Canned meat is more likely to fetch higher prices among urban high-income consumers. Adherence to strict hygienic practices and thorough inspection of the health of animals for slaughter could promote export of the canned rat meat.

Storage and transportation

Rodent meat that has been processed for future use must be stored safely in a refrigerator or freezer. When the meat is being transported over a long distance for several hours proper packing and storage in cool containers is necessary to ensure that it doesn't get contaminated or undergo deterioration in quality. There are generally no specific guidelines for storage and transport of rodent meat. When there is need to store and transport rodent meat it must take place in accordance with the existing requirements for other types of meat. These include:

i Inspection of the meat for potential infections with diseases.
ii Chilling the meat to ensure that the temperature during transportation is not too high to lead to meat decomposition.
iii There must be adequate ventilation in the transportation van to prevent heat build-up that will facilitate decomposition.
iv Transport does not take many hours if the meat is not refrigerated.
v For transportation over a long duration, the meat is frozen without delay.

Exposed meat must be stored and transported separately from packaged meat, unless stored or transported at different times or in such a way that the packaging material and the manner of storage or transport cannot be a source of contamination for the meat.

Waste management

Animals being reared in captivity must be maintained in a clean and hygienic environment. Manure and urine are the two most important wastes which could affect the health of the animals. The manure must be removed at least once a week to prevent flies from laying eggs in it. Flies have a life cycle of about 8 days from egg to adult and therefore unattended manure will produce many flies in the cages. It is also important to keep the animal houses clean to keep ammonia levels down. Ammonia can build up and cause respiratory problems in rodents besides being unpleasant to the animal house attendants. Therefore, there is a need for regular cleaning to remove the urine and manure to reduce ammonia levels.

Cages may be constructed to allow the manure to drop on the floor. These types of cages require enough clearance underneath to allow the cleaner to remove the wastes by cleaning with a broom. Animal cages which are stacked on top of each other require removable trays underneath of each cage for collection of manure and urine. Occasionally, the floor and the trays must be properly scraped and washed with soap in order to remove traces of urine mixed with manure which often stick on the surface.

Waste disposal is an important undertaking in a rodent rearing facility. There are two practical options for effective waste disposal. The first is to spread the manure in a garden or in the crop

farms. The second applies in situations where there is no farm or garden for waste disposal. Instead, there should be a dedicated waste storage area that can be kept free of insects and other vermins. The manure can be incinerated alongside carcasses of animals which may have died naturally or due to infections.

Marketing

The demand for rodent meat in many African countries is higher than the supply and the only feasible solution is to domesticate the species hunted in the wild. In the West African region, demand for cane rats and African pouched rats' meat is high and accounts for the greater proportion of bushmeat sold in markets. Previous estimates show that 80 million cane rats are hunted in west Africa annually, yielding the equivalent of 300,000 metric tons of meat (Jori et al., 1995). Studies in West Africa (Benin, Nigeria and Ghana) have also indicated that cane rat farmers fetch more per kg of cane rat meat than those involved in cattle, goat and pig production (Baptist and Mensah, 1986). In Nigeria it was observed that the price of cane rat meat was rising faster than that of other bush meat or domestic animals (Martin, 1985). Supplies of cane rat meat in West Africa, particularly in urban areas, seem to be lower than the demand and therefore resulting to increased prices, which could be offset by involving more farmers in cane rat meat production. Baptist and Mensah (1986) suggested that if the cost of cane rat meat could be reduced to lower or the same as that of poultry, the market would be practically unlimited. In the rest of African countries, particularly in east and southern Africa, the demand for rodent meat, particularly cane rats, at all levels of society is also high, but supplies are from hunting animals in the wild.

Safety

Many types of bacteria can grow on animal products**,** including meat from rodents, and therefore it is important to safely handle it. While it is perfectly safe to eat rodent meat that has been properly prepared, undercooked meat can lead to infections due to viruses, bacteria and protozoa. The most serious rodent meat safety issues relate to consumer health risksof potential contamination associated with microbial pathogens, especially bacteria and viruses. The list of potentially infectious pathogens in rodents is high (Gratz, 1997) and therefore rodent meat safety is a major concern for consumers. Enteric bacteria such as Salmonella can easily infect people consuming undercooked meat. Other concerns involve the presence of viral agents of diseases during handling and preparation of rodent meat for human consumption. Some of the viruses are spread directly by contact with rodent meat by the consumer or people handling the meat. Safety considerations include sanitation of the cages for rearing, wearing gloves while skinning, handling and preparing the meat for cooking and ensuring the meat is properly cooked. As much as possible, undercooked rodent meat should be avoided. Efforts to control pathogens associated with rodent meat should be a major goal in promoting its consumption. Some important considerations should include pathogen control and rodent meat safety enhancement. The health of the animals in captivity and interventions at the rearing facilities, including treatment of sick animals, should be given priority.

Standards and certification

To realize the development of the genetic potential of cane rats, foraging in its natural environment has been described as a critical factor (El-Hassan et al., 2009). However, for all

rodents species being domesticated, conditions, particularly of feed comparable to the wild environment must be maintained so as to ensure high standard and good quality meat production. Therefore, quality assurance measures are necessary in the production of rodent meat. The major consideration in quality assurance is to ensure adequate protein in the composition of the diet supplied to animals in captivity. To satisfy the growing demand for rodent meat, as well as ensure quality control and sustainable supply, it is desirable that the production of rodents for meat supply is properly planned (Opara, 2010). Balanced feeds can be produced using available inexpensive products. According to Yi and Tewe (1980) balanced feeds for cane rats may be formulated from maize, rice bran or wheat bran, palm kernel cake meal or groundnut cake, oyster or periwinkle shells, bone meal, common salt and vitamin/mineral premix. To produce high quality meat from rodents, it is suggested that they would require the same 41 nutrients ordinarily required by other monogastric animals, which include 13 essential amino acids (Olomu et al., 2003). Feeds containing 12-20% crude protein (CP) have been reported to be suitable for cane rats (Meduna, 2002).

Each country has its own provisions and policies to regulate packaging, import and sale of different types of foods. Consumption of rodent meat, however, is a new venture in many countries in Africa where rodent meat is not officially acclaimed. Most common provisions that may apply in the registration of rodent meat for human consumption include:

i. Registration of the food product by a recognized authority.
ii. Packaging regulations
iii. Compliance of food products being marketed with country's regulations and policies
iv. Prescribed standards to be complied with by manufacturers/producers about the composition of food or its microbiological, chemical and physical standards.
v. Prescribed standards and the manufacturing/production operations for such food in compliance with the "Prescribed Current Good Manufacturing Practice" requirements.
vi. Require, prohibit or regulate the addition to food or extraction from it of any specified substance or any substance of any specified category, or the use of any substance as an ingredient in the manufacture or preservation of that food;
vii. Prescribe or provide for methods of analysis for ascertaining the presence in any food, or the absence from it, of any specified substance, or the quantity of any substance present in any food.

For meat and meat products the following provisions also will apply:

(i) Inspections for zoonotic diseases.
(ii) Restrictions on use of premises for slaughter of animals.
(iii) Transportation requirements for meat.
(iv) Hygiene standards for staff who process the meat.

Local practices in domestication and use of rodents

The most widely domesticated rodent for meat in Africa is the cane rat, followed by the African giant pouched rats. In West Africa (Ghana, Nigeria, Benin, Côte d'Ivoire) governments have encouraged and supported the domestication of cane rats for meat supply and to develop

commercial ventures capable of meeting both local and foreign demands without depending on hunting from the wild (Opara, 2010). Rearing doesn't need much space and is particularly easy in rural and urban settings. People with adequate space keep animals in boxes, empty drums and enclosures, cages in rooms and on the floor (Adu, 1999) (pers. observations in Benin). Domestication of rats provide opportunities to increase rodent meat supplies, maintain quality and control of potential infectious diseases found in wild hunted animals. The high demand for rodent meat, particularly cane rats, in west African countries can only be met by large scale domestication and household rearing for family consumption and local market supply.

Establishing a Colony: The ideal starting point is to establish a colony composed of a male and three to four females. Adult males usually fight when mixed together in the same cage and therefore, two males should not be kept in a cage. Depending on the ability of farmers, several cages can be established.

Feeding: Animals must be fed with the right feed. Depending on the species being reared, an ideal diet should be identified. This should be balanced in order to ensure that the animals grow healthy, fast and produce quality meat. For most herbivorous species, supply of the appropriate plants for forage is important. Additionally, formulated feeds can be supplied either as supplements or as entire feed. Hygiene and good feeding are the most important factors for successful rearing of rats for meat.

Weaning and harvesting It is important to know the right time to wean and to harvest the animals for slaughtering to supply meat to the market. If the harvest time is extended, it will reduce the profitability of the animals.

Risk analysis: Two main risks are associated with the rearing of rodents for meat. The first and most important is outbreaks of diseases in the animal stock leading to high mortality and loss of revenue for the farmers. Unhygienic rearing conditions and overcrowding of the animals are the two factors that can easily promote diseases outbreaks. These two conditions can easily be controlled by farmers by observing cleanliness in cages and ensuring that cages do not carry more animals than the space allows. The second main risk is market unpredictability. Most farmers rear rodents for home consumption and for sale in the local market. As more farmers get into rodent rearing businesses, prices are most likely to fall making it unprofitable or reducing the profit margin. This risk can be mitigated by a search for external markets and value addition through packaging of the meat. However, farmers should be encouraged to form cooperatives to handle processing and marketing.

Rodent enterprise development strategies: Investment in rodent rearing can initially be small and then incremental. It can also be spread over several units and thus contribute considerably to reduced risk. Rodents reach sexual maturity fast and can reproduce quickly which further expands the investment (Wilson, 2011). The most successful rodent enterprise development has been with cane rats in Wet Africa. These are raised in backyards or inside the home and do not require large areas of land per unit of output. Production for home use and/or market is distributed more evenly throughout the year and can contribute to a steady income that can be more easily controlled in response to market conditions (Spore, 2008). Almost anyone can start a small household rodent production activity based on a few rodents then scale up to the next level of a viable and regular output with a view to achieve regular sales (Wilson, 2011). Success depends largely on developing clear production strategies based on sound veterinary and animal husbandry practices and the diffusion of affordable production methods that are suited

to small-scale producers. Rearing cane rats has proved successful in West Africa because of research on all aspects of this type of farming including buildings and equipment, feeding, reproduction, health and behavior (Spore, 2008).

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Chapter 6

Neglected and Underutilized Insects

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Overview

There has been dramatic upsurge of interest in insects for food and feed over the last few years. However, while substantial information has been generated on edible insects in the last decade, relatively little has been done to consolidate and disseminate the information. This chapter provides a general overview of the importance of edible insects, focusing on nutritional, environmental and socioeconomic aspects, and highlights currently reared and underutilized edible insects. The management of the African edible bush-cricket (*Ruspolia differens*), African palm weevil (*Rhynchophorus phoenicis*), crickets, termites and mopane worms (*Imbrasia belina*) for food or feed is discussed with attention to their importance, physiology, breeding, rearing, human interaction, capture/harvesting, utilization, processing and marketing. Overall, the information presented indicates a remarkable potential of these insects to improve the livelihoods, especially of resource limited households in Africa, through provision of cheap and nutritious foods and feeds with low environmental impact.

Importance of edible insects

The use of insects as food and feed has recently gained global recognition as a key driver to underpin developmental efforts for addressing the interrelated challenges of food security, poverty, nutrition and climate change. There are several strong health, environmental, economic and social benefits of using insects as food and feed as discussed below.

Nutrition: The nutritional value of edible insects is highly variable, depending on the species, metamorphic stage, habitat and diet. The protein content, on a dry weight basis, of 78 insect species has been reported to range from 15 to 81%, with protein digestibility varying from 76 to 98% and fat content ranging from 2 to 50% of dry matter (Ramos-Elorduy et al., 1997). Many insects are nutritionally comparable to mainstream staples such as chicken, pork, beef and fish (Payne et al., 2016; Finke and Oonincx, 2017). Energetic values for livestock are 165-705 kcal/100 g, and vegetables 308-352 k cal/100g, while edible insects provide 217-777 kcal/100 g, and insects raised on organic wastes provide 288-575 kcal/100 g (Ramos-Elorduy, 2008). Carbohydrates in insects are represented mainly by chitin, whose content ranges between 2.7 mg and 49.8 mg per kg of fresh matter. Total polyunsaturated fatty acids' content may be up to 70% of total fatty acids (Kouřimská and Adámková, 2016). A number of insect species are high in several minerals as well as vitamins such as B group vitamins, vitamins A,

D, E, K, and C. For example, 100 g of cooked caterpillars provide 100% of daily requirements for copper, zinc, iron, thiamin and riboflavin (DeFoliart, 1992). The nutritional content of insects is, however, dependent on feed and some insects may produce or contain toxic bioactive compounds and residues of pesticides and heavy metals from the ecosystem (Kouřimská and Adámková, 2016).

Environmental: Insects produce less ammonia and greenhouse gases, such as methane, carbondioxide, and nitrous oxide, than most conventional livestock. In a life cycle assessment of mealworms, Tenebrio molitor and Zophobas morio production, Oonincx and de Boer (2012) concluded that mealworms are a more sustainable source of protein than main stream staples because the production of 1 kg of edible protein from milk, chicken, pork or beef result in higher greenhouse gas emissions, requires similar amount of energy and requires much more land. Insects have more efficient feed conversion rates. For example, crickets require 12 times less feed than cattle, four times less feed than sheep, and half as much feed as pigs and broiler chickens to produce the same amount of protein (van Huis et al., 2013). Insects can be fed on organic waste streams such as food and human waste, compost and animal slurry, thus reducing environmental contamination. They also pose low risk of transmitting zoonotic infections to humans, livestock and wildlife (van Huis et al., 2013).

Socio-economic: Insect harvesting from the wild is not capital intensive and insect rearing can use low-level technology, thus offering important livelihood opportunity to the poor and disadvantaged in society such as women, youth and the landless in rural and urban areas. These activities can directly improve diets and provide cash income through the selling of excess production. Edible insects are generating hard currency for countries involved in their trade locally or internationally. For example, there is a significant trans-border trade in edible insects within Central African Region, as well as with the Sudan and Nigeria, and with France and Belgium (Vantomme et al., 2004). France and Belgium annually import about 5 tons and 3 tons, respectively, of dried Imbrasia species from the Democratic Republic of Congo valued at US$41,500, at an average price of US $13.8 per kg (Vantomme et al., 2004). The edible insect import market in Thailand is valued at 1.14 million USD/year (Hanboonsong et al., 2013). In South Korea, the market for insects as food, feed and medicine was valued at 109 million GBP in 2017 and predicted to quadruple to 348 million GBP by 2020 (Halloran et al., 2017). It has been estimated that the value of insects as food and feed for the combined market in the US, Belgium, France, UK, The Netherlands, China, Thailand, Vietnam, Brazil and Mexico in 2015 was 25.1 million GBP, with a predicted growth to 398 million GBP by 2023 (Dobemann et al., 2017).

Currently reared insects

Until recently, domestication of insects has largely focused on species that produce commercially valuable products and services such as silk worm (*Bombyx mori*) in sericulture, bees for honey production and pollination, cochineal insect (*Dactylopius coccus*) for carminic acid used in food, pharmaceutical and cosmetic industries, and several insect species used as biological control agents (Van Huis et al. 2013). Rearing insects for food and feed is a relatively recent development. Examples of currently reared edible insects are presented in Table 6.1.

Table 6.1: Reared insect species for food and/or feed

Scientific name	Common name	Main use	References
Acheta domesticus L.	Crickets	Food	Hanboonsong et al., 2013; Megido et al., 2017; Mott, 2017
Alphitobius diaperinus Panzer	Lesser mealworm	Food, feed	Calis, 2016; Berezina, 2017
Brachytrupes membraneceus Drury	Tobacco cricket	Food	Megido et al., 2017
Gryllodes sigillatus F. Walker	Banded or decorated cricket	Food	Mott, 2017
Gryllus bimaculatus DeGeer	Two-spotted cricket	Food	Megido et al., 2017
Hermetia illucens L.	Black soldier fly	Feed	Sheppard et al., 2002; Tomberlin and Cammack, 2017
Locusta migratoria L.	Migratory locust	Food, feed	Haldar and Malakar, 2017
Musca domestica L.	House fly	Feed	Tomberlin et al., 2017
Rhynchophorus ferrugineus Olivier	Red palm weevil	Food	
Rhynchophorus phoenicis Fabricius	African palm weevil	Food	Muafor et al., 2015; Muafor et al., 2017
Rhynchophorus quadrangulus Quedenfeldt	-	Food	Muafor et al., 2017
Schistocerca gregaria Forskål	Desert locust	Food	Haldar and Malakar, 2017
Teleogryllus mitratus Walker	Oriental ground cricket	Food	Megido et al., 2017
Tenebrio molitor L.	Yellow mealworm	Food, feed	Miglietta et al., 2015; Berezina, 2017
Zophobas morio L.	Superworm	Food, feed	Miglietta et al., 2015
Imbrasia belina L.	Mopane worms	Food	Gazhoul, 2006

Underutilized edible insect species

The exact number of edible insects is difficult to know mainly because of inconsistencies in vernacular and Latin names of some species reported (van Huis et al., 2013) and estimates of the number of species may reflect research intensities rather than actual figures (van Huis and Tomberlin, 2017). A recent worldwide inventory of edible insects by Jongema (2017) through literature search produced a global list of 2111 edible insect species, including spiders which are arthropods but not really insects. The inventory found that the highest number of insect species consumed (31%) belong to beetles (Coleoptera) followed by caterpillars (Lepidoptera) (17%); bees, wasps and ants (Hymenoptera) (15%); grasshoppers and locusts (Orthoptera) (13%); true bugs (Hemiptera) (11%), termites (Isoptera) (3%); dragonflies (Odonata) (3%), flies (Diptera) (2%), cockroaches (Blattodea) (2%), spiders (Araneae) (1%) and others (2%).

The diversity of insects consumed by humans varies among continents, regions and countries (Figure 6.1). Entomophagy has a long history in Asia, Latin America and Africa. It is therefore not surprising that higher numbers of edible insect species have been recorded in these regions than, for example, in Europe. In Asia, 170 species have been reported in China (Chen et al. 2009) and 164 species in the Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam (Young-Aree and Viwatpanich, 2005). In the Americas, Ramos Elorduy et al. (2008) listed 549 species in Mexico while Paoletti and Dufour (2005) estimated that 428 species were consumed as food in the Amazon. In Africa, a recent survey by Kelemu et al. (2015) revealed the existence of 470 species of edible insects with the highest diversity of edible insect species found in Lepidoptera followed by Orthoptera and Coleoptera (Table 6.2). The Central African region alone was found to host about 256 edible species making it the most important biodiversity hotspot in Africa, followed by southern Africa (164 species) and eastern Africa (100 species). A total of 91 species were found in western Africa and only 8 species were recorded from northern Africa. The study identified 41 most consumed species in Africa, belonging to six Orders: Lepidoptera (34%), Orthoptera (14%), Isoptera (12), Hymenoptera (10%), Coleoptera 97%) and Hemiptera (2%).

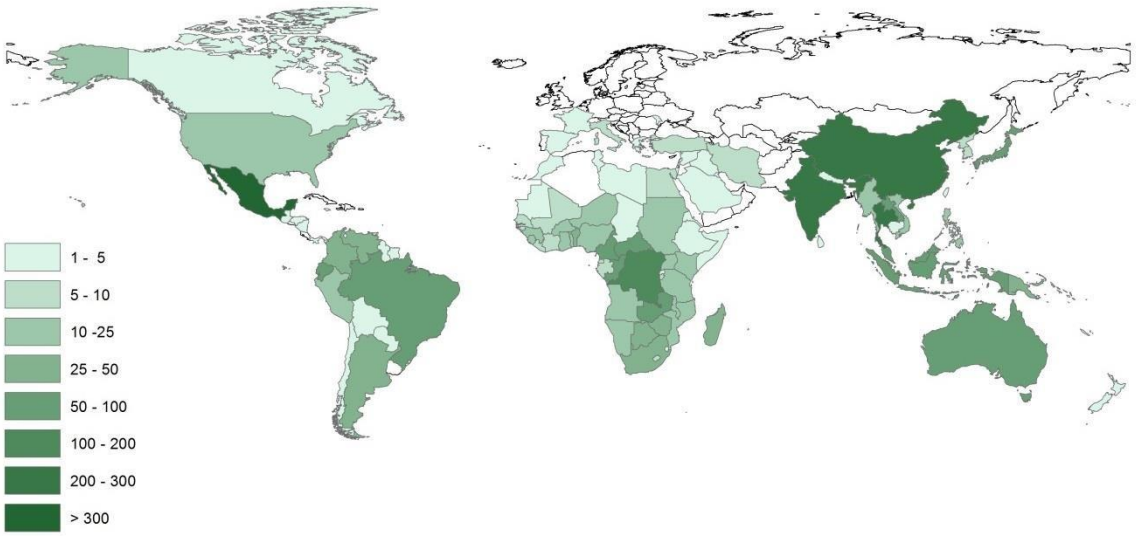

Figure 6.1: Recorded edible insect species by country

Source: Centre of Geo information, Wageningen University, based on data by Jongema (2017)

Table 6.2. List of the most consumed insect species in Africa

Order	Species	Countries reported
Lepidoptera	*Bunaea alcinoë* (Stoll)	Democratic Republic of Congo (DRC), Zambia, South Africa, Cameroon, Congo, Central African Republic (CA Republic), Zimbabwe, Nigeria, Tanzania
	Anaphe panda (Boisduval)	DRC, Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Nigeria, Tanzania

	Cirina forda (Westwood)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	Dactyloceras lucina (Drury)	DRC, Zambia, South Africa, Cameroon, Congo, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea
	Platysphinx stigmatica Mabille	DRC, Zambia, Congo, CA Republic, Sierra Leone, Sao Tomé, Equatorial Guinea, Rwanda, Burundi
	Cirina butyrospermi Vuillot	DRC, Zambia, South Africa, Zimbabwe, Burkina Faso, Nigeria, Mali, Ghana
	Epanaphe carteri Walsingham	DRC, Zambia, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea
	Imbrasia belina (Westwood)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi
	Gynanisa ata Strand	DRC, Zambia, Malawi, South Sudan
	Eumeta cervina Druce	DRC, Cameroon, Congo, CA Republic, Angola, Gabon, Sierra Leone, Sao Tomé, Equatorial Guinea, Rwanda, Burundi, Liberia
	Imbrasia ertli Rebel	Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Botswana, Angola
	Anaphe venata Butler	Zambia, Nigeria, Côte d'Ivoire, Sierra Leone, Guinea, Liberia, Guinea Bissau
	Imbrasia epimethea (Drury)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe
	Urota sinope (Westwood)	DRC, South Africa, Zimbabwe, Botswana, Gabon, Mozambique, Namibia
Orthoptera	*Schistocerca gregaria* (Forskål)	Zambia, South Africa, Cameroon, Congo, Botswana, Tanzania, Sudan, Uganda, Ethiopia, Kenya, Sierra Leone, Morocco, Guinea, Lesotho, Mauritania, Somalia, Eritrea, Guinea Bissau
	Acanthacris ruficornis (Fabricius)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Malawi, Mali, Niger, Togo, Benin
	Brachytrupes membranaceus (Drury)	Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Nigeria, Tanzania, Angola, Togo, Benin
	Nomadacris septemfasciata (Serville)	Zambia, South Africa, Congo, Zimbabwe, Botswana, Nigeria, Tanzania, Malawi, Uganda, Mozambique
	Ruspolia differens (Serville)	DRC, Zambia, South Africa, Cameroon, Zimbabwe, Kenya, Uganda, Tanzania, Malawi
	Zonocerus variegatus (Linnaeus)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, Sao Tomé, Guinea, Ghana, Liberia, Guinea Bissau
	Locusta migratoria migratorioides (Reich & Fairmaire)	Zambia, Cameroon, Congo, Zimbabwe, Sudan, South Sudan

	Locustana pardalina Walker	Zambia, South Africa, Zimbabwe, Botswana, Malawi, Libya
	Gastrimargus africanus (Saussure)	Cameroon, Congo, Niger, Lesotho, Liberia
	Phymateus viridipes brunneri Bolivar	Zambia, South Africa, Congo, Zimbabwe, Botswana, Mozambique, Namibia
	Gryllus bimaculatus De Geer	Guinea Bissau, Sierra Leone, Guinea, Liberia, Benin, Togo, Nigeria, DRC, Kenya, South Sudan, Zambia
	Anacridium melanorhodon melanorhodon (Walker)	Cameroon, Sudan, Niger
	Paracinema tricolor (Thunberg)	Cameroon, Malawi, Lesotho
	Acheta spp.	Zambia, Zimbabwe, Kenya
Coleoptera	*Oryctes owariensis* Palisot de Beauvois	DRC, South Africa, Congo, Ivory Coast, Sierra Leone, Guinea, Ghana, Equatorial Guinea, Guinea Bissau
	Rhynchophorus phoenicis (Fabricius)	DRC, Cameroon, Congo, CA Republic, Nigeria, Angola, Ivory Coast, Niger, Sao Tomé, Guinea, Togo, Liberia, Benin, Guinea Bissau
	Oryctes boas (Fabricius)	Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau DRC, Congo, South Africa, Botswana, Namibia
Isoptera	*Macrotermes* spp.	DRC, Zambia, Zimbabwe, Nigeria, Tanzania, Malawi, Senegal, Uganda, Côte d'Ivoire, Guinea, Ghana, Togo, Burundi, Benin
	Macrotermes bellicosus (Smeathman)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, Kenya, Sao Tomé, Guinea, Togo, Liberia, Guinea Bissau, Burundi
	Macrotermes subhyalinus (Rambur)	Zambia, Angola, Kenya, Togo, Burundi
	Macrotermes falciger (Gerstäcker)	Zambia, Zimbabwe, Burkina Faso, Burundi, Benin
	Macrotermes natalensis (Haviland)	DRC, Cameroon, Congo, CA Republic, Nigeria, Burundi, South Africa, Zimbabwe, Nigeria, Malawi
Hymenoptera	*Apis mellifera mellifera* Linnaeus	DRC, Zambia, Botswana, Nigeria, Tanzania, Senegal, Sierra Leone, Ghana, South Sudan, Togo, Lesotho, Benin
	Apis mellifera adansoni Latreille	DRC, Zambia, CA Republic, Nigeria, Tanzania, Sierra Leone, Ghana, Benin
	Carebara vidua Smith	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi, Sudan, Kenya, South Sudan
	Carebara lignata Westwood	Zambia, South Africa, Zimbabwe, Botswana, Sudan, Mozambique, Namibia, South Sudan
Hemiptera	*Encosternum delegorguei* Spinola	South Africa, Swaziland, Mozambique, Malawi Zimbabwe, Botswana, Namibia

Source: Kelemu et al. (2015).

Management of selected species for food or feed

African edible bush-cricket (Ruspolia differens Serville)

Importance: The African edible bush-cricket, *Ruspolia differens* (Orthoptera: Tettigoniidae), is a highly valued insect with a widespread distribution throughout several countries in the Afrotropical region (Bailey and McCrae, 1978; Massa, 2015). In Eastern Africa, *R. differens* is among the most consumed species of insects (Kinyuru et al., 2010; Okia et al., 2017; van Huis, 2003) with potential to contribute to both rural and urban livelihood and employment opportunities (Agea et al., 2008). For example, Kinyuru et al. (2011) found high levels of protein content (up to 48%), fat content (48%), polyunsaturated fatty acids (89% of lipids) and several minerals, including K (371 mg/100g), P (141 mg/100g), Ca (27 mg/100g), Fe (17 mg/100g) and Zn (17 mg/100g) in *R. differens*. Consumption of 100 g of the insects contributes significantly to the recommended daily requirements of retinol, á-tocopherol, niacin, riboflavin and folic acid (Kinyuru et al., 2011).

A marketing survey by Agea et al. (2008) in 2008 estimated the average retail cost of the insect in Kampala city at US$ 2.8/kg, which compared favourably to goat meat that was sold at US$ 2.3/kg in the city. A study conducted by Odongo et al. (in press) in rural and urban markets in central Uganda in 2012 found gross margins of US$ 2,633 and US$ 690 per swarming season for wholesalers and retailers of *R. differens*, respectively.

Physiology: *Ruspolia differens* occurs in swarming and nonswarming phases. Swarming usually occurs during peaks of rainy seasons following dry seasons (Bailey and McCrae, 1978). The insect has colour polymorphism and sex-ratio biasness, but the variations in these traits are not very clearly understood. The commonest colour morphs are bright green predominating in females and straw-brown more frequent among males than females (McCrae, 1982). Other colourmophs which are less frequent and not sex-linked are brown stripped purple, light green, pale green, purple light green, green stripped purple and light brown (Bailey and McCrae, 1978; Nyeko et al., 2014). The feeding ecology of *R. differens* is not well understood owing to its nocturnal habit. In the field, nymphs and swarming adults have been observed feeding mainly on flowers and young grains (Swaine, 1964). The nymphs and adults also readily accept artificial foods and flowers and grains of some grasses and cultivated cereals under laboratory rearing (Hartley,1967; Malinga et al., 2018a). According to Hartley (1967), *R. differens* eggs (Figure 6.2a) hatch after 17-18 days when kept under at 30^{o}C, 50% relative humidity and 12-hour photoperiod. The first-instar nymphs (Figure 6.2b) are green and there are six nymphal instars, which last 4-5 weeks. Adults (Figure 6.2c) mature for about four weeks before egg-laying starts, and the adult life span is around two months.

(a) Eggs (b) Newly hatched nymph (c) Green adult

Figure 6.2: Developmental stages of *Ruspolia differens*

Breeding: Breeding refers to genetically improving the stock by selecting specimens in a population with certain desired characteristics. However, keeping insects under confined conditions can also have a genetic effect on populations through inbreeding depression, founder effect, genetic drift and laboratory adaptation, such that they often no longer much resemble wild populations (Van Huis et al., 2013). There is apparently no published information on breeding *Ruspolia differens*.

Rearing: Currently, there is a great need to develop mass rearing methods for *Ruspolia differens* because of concerns of overharvesting wild populations, and the need to enhance food security (Okia et al., 2017). Laboratory studies conducted in jars and cages showed that *R. differens* can be reared on grass as well as some artificial diets (Hartley, 1967; Brits and Thornton, 1981; Nyeko et al., 2014; Malinga et al., 2018b), but they may be cannibalistic if starved (Hartley, 1967). They eat a wide range of feeds, such as flowers, seeds, cereal flours, wheat bran, germinated finger millet, ground dog biscuits, dried blood, lucerne meal and a high protein and fatty acid meal.

Several cage designs have been used to experimentally rear *R. differens*. For example, Hartley (1967) found 15 in. high and 8 in. across cylindrical cages made of celluloid apart from a metal bottom and a perforated metal lid to be convenient for holding 50 first- and second instar nymphs. As the nymphs grow they must be transferred to larger cages. For example, a 30 in. high and with an 18-in.-square base cage made from wood and perforated zinc and have glass fronts will hold 50-60 of the later instars, including adults (Hartley, 1967). Nyeko et al. 2014 used wooden cages (45 cm x 35 cm base and 60 cm height) with wire mesh at the bottom, top and all sides, except the front, that comprised of a transparent plastic cover (Figure 6.3). In such cages, adult *R. differens* laid eggs, which hatched and developed into adults. Adult females normally lay their eggs in the leaf sheaths of various grasses, sand or cotton wool (Hartley, 1967; Nyeko et al., 2014). Eggs laid in these media are, however, difficult to collect, indicating the need to find satisfactory substitutes.

Figure 6.3: A cage used for rearing *Ruspolia differens*

The development of *R. differens* eggs from laying to hatching is known to be strongly temperature dependent with the lower and higher temperatures being 17 and 33 ^{o}C, respectively (Hartley and Ando 1988). Hartley (1967) reared generations of *R. differens* in an insectary with controlled environmental conditions at 30°C, 50% relative humidity and with a daily photoperiod of 12 hours. Studies conducted at Makerere University, Uganda demonstrated the potential of mass rearing *R. differens* under naturally prevailing room temperature (22 – 28 ^{o}C) and relative humidity (51-73%) conditions (Nyeko et al., 2014; Malinga et al., 2018a; Valtonen, 2018). At a constant temperature of 30 ^{o}C and 50% relative humidity with a daily photophase of 13 hours, Brits and Thornton (1981) observed that the oviposition period for *R. differens* extended over 32 days, with disparity in the number of eggs laid by the green (148 eggs/female) and brown (46 eggs/female) polymorphs. Hartley (1967) found that nymphs hatch in 11–12 days, reaching adult maturity in 2–3 months under similar temperature and humidity conditions. In a study to examine the effects of artificial diet mixtures on the developmental and reproductive performance of *R. differens*, Malinga et al. (2018b) found that more diversified diets resulted in shorter development time and greater adult fresh weight and female fecundity than the single diet or less diversified diets. Overall, results of these studies have indicated the importance of temperature, humidity and diet in *R. differens* rearing programs to maximize the survival, development, growth and reproduction performance of this edible grasshopper.

Very little is known about the pests and diseases of *Ruspolia* species. Bailey and McCrae (1978) observed moderately high infection of the Tachinid fly parasite (*Glaurocara flava*) on swarms of *R. differens* in Uganda and Tanzania, and heavy infection of *R. flavovirens* by the tracheal mite (*Berlesia* species) around Kampala, Uganda way back in 1962 to 1963. Hartley (1967) reported that moulds may develop on egg cultures of *Homorocoryphus* (=*Ruspolia*) *nitidulus*, and if eggs are heavily infected it may affect hatching. There has apparently been no recent study examining the pests and pathogens of *R. differens* in the wild and/or under rearing conditions. Similarly, there are no reports of zoonotic diseases emanating from *R. differens*.

Human and insects' interaction: Specific information on biological and chemical hazards or allergy in humans, which can be associated with *R. differens* is lacking in the scientific literature.

Capture/harvesting and utilization: Wild populations of *R. differens* are harvested during natural swarming periods, which are seasonal and unpredictable. Two main methods are used in capturing wild *R. differens*, namely hand-picking and light trapping. *Ruspolia differens* are hand-picked in early mornings during swarming periods. In this method, *R. differens* individuals are either caught from parts of any vegetation where they are resting, or they are beaten with tree branches, hand-picked from the ground, and put in containers with lids, e.g. Jerry-cans and bottles, so that they cannot escape. Sometimes clothes are used as hand gloves to avoid being bitten/harmed by the insects.

Light trapping of *R. differens* is done at night, usually at a commercial scale. Equipment required for light trapping include: drums (1,000 L), white iron sheet (to reflect light), raised platform for placing drums (wooden or flat building top), high voltage electric wires, and electric bulbs (400-1,000 W), capacitors for power stabilization and sacs for bulking insects. Drums are placed on a platform in a row and one iron sheet is placed in each drum with the upper part being supported by a wooden structure (Figure 6.4). High voltage bulbs are placed near the iron sheets. The iron sheet is always placed against the direction of the wind to trap more *R. differens*. Lights are switched on at 7 pm so that swarming *R. differens* are attracted by the bright light. Flying *R. differens* attracted by the strong light will hit the iron sheet placed in the drum in a slanting position and eventually fall inside the drum whose inside is coated with moistened cassava floor and/or cooking oil making it slippery for trapped insects to climb out. *Ruspolia differens* are emptied from the drums when ¾ full.

Smoke from herbaceous plants is also applied in the collection site to attract more *R. differens* and apparently induce docility through intoxication, thus facilitating more catch. *Ruspolia differens* is predominantly used as human food. In addition to the main value as food, some communities in East Africa also consider the insect as important for medicine, income, gifts, feed for poultry or baits for birds and fish (Nyeko et al. 2014).

Figure 6.4: Light trap set to collect *R. differens* in Masaka district, Uganda.

Processing for food and feed: *Ruspolia differens* is highly perishable. After capturing, the insect is normally transported alive in perforated containers such as baskets and sacks to facilitate aeration and reduce the risk of decomposition in transit. Processing *R. differens* for food is manually done. Traditionally, the activities conducted during processing include sorting of debris and removal of wings, ovipositors and legs. These activities are followed by frying the insect in its own oil with or without onions (Figure 6.5a). The fried insect can be consumed

immediately or stored for later consumption. Some traders in Uganda have reported storing of fresh or fried *R. differens* in deep freezers for later sales in periods of scarcity. Recent studies have shown that products such as cakes, cookies and bread can be prepared from *R. differens* flour (Figure 6.5b, c and d).

(a) Fried *Ruspolia* (b) *Ruspolia* cookies *(c) Ruspolia* cake (d) *Ruspolia* bread

Figure 6.5: Rupolia processed into different products for human consumption

Marketing: *Ruspolia differens* is one of the most marketed edible insects in East Africa (Agea et al., 2008; Nyeko et al., 2014). In Uganda, the key players in marketing *R. differens* are wholesalers, retailers and consumers. The characteristics of the market players have been described by Nyeko et al. (2014). Most wholesalers are edible collectors who own light traps from which they can collect and sell up to 70 bags (approximately 700 kg) of *R. differens* daily during the peak of the swarming season. Wholesalers usually package and transport the insects from points of collection to points of sales, mostly in the urban areas. Retailers for *R. differens* comprise road side and market venders.

The road side venders market the insects through staging at busy street junctions especially during the rush hours (early morning and late evening). Road side venders also move with their insects to residential areas and offices selling their produce.
Most road side venders process their insects by frying ready to eat. Market venders are usually stationed at markets and market positions where they sell their insects. Market venders also sell other food or non-food items alongside theinsects. There is a lack of standards in the measurement of the edible insects by the venders. Often, a table spoon, a ladle or a cup is used with varying prices depending on the vender, and the location of sales. The retailers add value to the edible insects by frying and packaging them before selling. Consumers are mainly individuals who buy the insects to eat as snacks in their homes or when travelling. In rural areas, the insect is a delicacy served on special occasions.

Case studies: A market survey of *R. differens* business in Kampala, Uganda indicates that the average price increased from collectors to wholesale traders and to retailers (Table 6.3). Collectors charged the lowest price, but their profit margins were higher than those of wholesalers and retailers.

Table 6.3: Average prices and margins for *Ruspolia* traders in Kampala city, Uganda

Variable	Plastic cup (0.5 kg)	Half sack (50 kg)	Full sack (100 kg)
Collectors' price (USD)	0.6	17	28
Wholesale traders' price (USD)	1.1	25	48
Retailers' price (USD)	1.4	28	56
Collectors' margin (%)	40	60	65
Wholesale traders' margin (%)	40	30	20
Retailers' margin (%)	20	10	15

Source: Agea et al., (2008)

African palm weevil (Rhynchophorus phoenicis Fabricius)

Importance: The African palm weevil, *Rhynchophorus phoenicis* (Coleoptera: Curculionidae), is distributed throughout tropical Africa. The larvae of the African palm weevil (*Rhynchophorus phoenicis* Fabricius) are important food resources in nearly all countries in sub-Saharan Africa (Muafor et al., 2017). Analyses of the nutritional profiles of *R. phoenicis* larvae indicate that they are very good sources of protein, fat, carbohydrates, energy and minerals such as sodium, magnesium, manganese, calcium, potassium and iron. The larvae are rich in nearly all the essential amino acids, including lysine, valine, leucine, isoleucine, phenylalanine, threonine and methionine, with most values exceeding those of the standard value required by FAO (Womeni et al., 2012).

The larval oil is rich in total unsaturated fatty acids (61%), comprising mainly Palmitic, Oleic and Linoleic acids (Ekpo and Onigbinde, 2005), and it is safe for consumption by individuals prone to dyslipidemia, diabetes mellitus and cardiovascular diseases (Okaraonye and Ikewuchi, 2008). According to Okunowo et al. (2016) the major water-soluble vitamin *R. phoenicis* larvae is vitamin C (11.14 mg/100 g) and the main fatsoluble vitamin is vitamin E (25.18 mg/100 g).

In addition to the food value, the larvae of *R. phoenicis* have also been reported to be used as traditional medicine to treat ailments such as infertility in women, rashes and wounds, cough and cold, among some local communities in Cameroon and Nigeria (Okaraonye and Ikewuchi, 2008; Muafor et al., 2015). Furthermore, the *R. phoenicis* larvae are important economic resources, providing income for many rural and urban people involved in their exploitation and trade.

Physiology: Adults of *R. phoenicis* have a snout-like projection of their mandibles called a rostrum (Figure 6.6d), which is used for feeding and to make holes in host plant material where eggs are laid. The larvae are legless and have relatively large mandibles (Figure 6.6b). *Rhynchophorus phoenicis* feeds mainly on oil palm (*Elaeis guineensis* Jacq.), date palm (*Phoenix dactylifera* L.), raffia palm (*Raphia* spp.) and coconut palm (*Cocos nucifera* L.). The adults lay eggs (Figure 6.6a) in wounds in the stems of dying or damaged parts of palms. After hatching, the weevil larvae excavate tunnels in the palm trunk and feed on the shoot and young leaves, frequently leading to the death of the host plants.

In Cameroon the larvae develop over four weeks into mature larvae that can be harvested for consumption (Muafor et al., 2015). A fully extended larva measures, on average, 10.5 cm in length and 5.5 cm in width and weighs 6.7 g (van Huis et al., 2013). Once larval development

is complete, pre-pupal larvae spin tightly woven cocoons from palm fibers within which they pupate (Figure 6.6c). Upon completion of pupation, adult weevils emerge, and they may breed within the palm host they occupy or they could disperse to new areas.

(a) Egg (b) Larva (c) Pupae in cocoons (d) Adult

Figure 6.6: Life stages of *Rhynchophorus phoenicis*

Rearing: A semi-farming method for *R. phoenicis* that has traditionally been practiced in Obout village in Cameroon has been described by Muafor et al. (2015). In this method, mature stems of raffia palm are selected and cut down to facilitate their colonization by *R. phoenicis*. Once the stem has been felled, an incision of 20 to 25 cm long and 5 cm deep is made on the trunk at about 1 m from the base of the crown. This incision is then covered with fresh raffia leaves to provide heat, and to prevent predators such as rats, squirrels and other predators consuming the larvae. The stems are then allowed to decay for a period of 25 to 30 days, which gives enough time for the grubs to mature before harvest.

The larvae develop inside the raffia stem within 25 - 30 days and are collected by splitting the trunk from the incision. One main shortcoming of the semi-farming method is the negative environmental impact arising from felling raffia palm trees. For example, Muafor et al. (2015) found that the method has led to the massive destruction of raffia ecosystems in Obout village where it is commonly practiced.

An experimental rearing method for *R. phoenicis* has been implemented to promote palm weevil farming in Cameroon. This method has been described in detail by Muafor et al. (2015), a summary of which is provided here. In the method, *R. phoenicis* is reared in plastic boxes of 60 cm long x 40 cm wide x 40 cm high. The plastic boxes are suspended at a height of 80 – 100 cm above ground under shade using wooden poles. The rearing process involves three main steps:

(i) Selection and coupling of healthy adult *R. phoenicis* in plastic cups for copulation;
(ii) Transfer of fecundated females to larger plastic boxes for egg production; incubation, hatching and development into edible larvae; and
(iii) Provision of slices of young woody stem tissues of raffia or other palms into the containers as egg laying and/or food substrate. A handful of pieces of fresh raffia stem

tissues are added once a week within the first two weeks after hatching and the substrate is replaced by hard stem tissues for two extra weeks.

The larvae can grow to maturity in 25-30 days under suitable feeding and farming conditions. The most critical conditions are humidity and temperature, which are controlled by perforating holes of about 1 cm diameter on the sides and base of the farming boxes. The holes are useful in the renewal of oxygen and those at the bottom of the boxes are essential in removing exudates resulting from the decomposition of the substrate.

Human-insect interactions: Three species of pathogenic bacteria (*Staphylococcus aureus*, *Escherichia coli* and *Salmonella* species) have been isolated from raw *R. phoenicis* larvae and three species of bacteria: (*Bacillus subtilis*, *Pseudomonas aeruginosa* and *Proteus vulgaris*) as well as two species of fungi (*Cladosporum* species and *Aspergillus flavus* from the roasted larvae, which can cause food poisoning (Ebenebe and Okpoko, 2015). This indicates the need for considering standard sanitary measures during collection, processing and post processing period of the larvae.

Capture/harvesting and utilization: Traditional harvesting of *R. phoenicis* involves search and identification of palm trees naturally infested by *R. phoenicis* often through drying foliage and/or detection (by placing the ears on the trunk to listen for larvae nibbling) of characteristic nibbling sound made by the larvae as they feed on the internal tissues of infested trees (Figure 6.7a). Once an infested tree is identified, it is felled, and the trunk split open with axes or machetes to expose the larvae (Figures 6.b and c). The larvae are then handpicked from their feeding chambers in the tree trunk (Figure 6.7d). In Cameroon, the larvae are also collected from the trunks of oil palms when the palms have been cut down for palm wine production (Muafor et al. 2015).

(a)

(b)

(c) (d)

Figure 6.7: Collection of *Rhynchophorus phoenicis*: (a) detection of infestation by listening to larvae nibbling; (b) felling a palm tree infested by *R. phoenicis*; (c) Splitting the felled tree stem; (c) Rhynchophorus hunting crew displaying their catch; (d) handpicking of *R. phoenicis* larvae from split stem

Processing for food and feed: Traditionally, the African palm weevil larvae are collected, washed, slit to drain the gut fluid (Figure 6.8) and fried in their own oil for consumption (Fasoranti and Ajiboye, 1993). Condiments such as salt, onions, garlic and pepper may be added (van Huis et al. 2013). The larvae may also be barbecued in form of brochettes of three to four individuals per stick (Maufor et al., 2017). Very little has been reported on the preservation of the larvae of African palm weevil. According to Meutchieye and Niassy (2014), vendors of the larvae in Yaoundé maintain the larvae alive by regular water sprinkling and sorting of dead or softened individuals. The vendors feed the larvae on decaying palm fibres for 5-7 days after harvesting to improve their survival.

(a) Larvae washed clean (b) Draining gut fluid (c) Larvae fried in own oil

Figure 6.8: Traditional processing *R. phoenicis* for human consumption in Kalangala district, Uganda

Marketing: The larvae of the African palm weevil are marketed in village, and increasingly urban markets, especially in central and western Africa, and some are exported to countries such as France and Belgium (Maufor et al., 2017). In a study of the commercialization of *R. phoenicis* larvae in Yaoundé, Cameroon, Meutchieye and Niassy (2014) found that the main actors in the palm weevil business include harvesters, secondary collectors, middle women, restaurateurs, ambulant retailers and consumers.

According to Maufor et al. (2017), the retailers live in big cities while intermediate suppliers are based in smaller cities and producers in villages. The different market actors generate important income from the sale of palm beetle larvae. In Cameroon, for example, Maufor et al (2017) reported that a glass of 25 to 30 larvae costs USD 1 in local town markets and up to USD 5 in big cities such as Yaoundé and Duala. The monthly income generated by professional collectors in Cameroon was found to vary between USD 180 and USD 600 with annual earnings up to USD 4,800, which were higher than incomes earned by exploiters of bushmeat, unskilled workers in town and rural producers of coffee (Maufor et al., 2015).

In the Kalangala Islands of Uganda, a single fried *R. phoenicis* larva was reported to cost USD 0.06 and elders, usually unable to collect the insects on their own, were willing to exchange a cup-full of about 50 larvae with a cock (Okia et al., 2017).

Case studies: A project to disseminate the box rearing technique for *R. phoenicis* larva among small-scale farmers in Obout village in Cameroon has yielded promising results (Table 6.4). Some two farmers, however, abandoned the trial while some only obtained low yield, indicating the need for close supervision. In this technique, the productivity of a single stem of raffia is at least four times higher than that in the wild, and farmers can produce the larvae at any period of the year.

Table 6.4: Larvae of *R. phoenicis* produced by small-scale farmers in Obout village, Cameroon in two trials

Farmer code	Number of farming boxes	Number of raffia stem used	Number of larvae produced in 1st trial	Number of larvae produced in 2nd trial	Total
1	3	1	191	161	352
2	3	1	158	168	326
3	3	1	253	192	445
4	3	1	148	160	308
5	3	1	230	135	365
6	3	1	201	Abandoned	201
7	3	1	273	118	391
8	6	2	590	512	1,102
9	3	1	159	168	327
10	3	1	139	Abandoned	139
Total					3,956

Source Maufor et al., (2017).

Termites

Importance: Termites are a large and diverse group of insects consisting of over 2600 species worldwide, with over 660 of them occurring in Africa (Eggleton, 2000). Some species cause significant damage to crops, rangeland, trees, and structural timber, but they also play a beneficial role through promotion of essential ecological processes (Sileshi et al., 2009). Termites are also regarded as an important food resource for humans in many parts of the world, and some species are used as poultry feed (van Huis, 2003).

Globally, a total of 45 termite species belonging to four families have been recorded as being used by human populations, with 43 species used in the human diet or for livestock feeding and nine species used as a therapeutic resource (Figueirêdo et al., 2015). The alates, queen, and soldiers of some species in the subfamily Macrotermitinae, particularly those in the genera *Marcotermes*, *Pseudacathotermes* and *Odontotermes* are eaten across most of Africa (van Huis, 2003; Sileshi et al., 2009). For example, local communities in Tororo district, Uganda consume 10 out of 14 termite species occurring in the district, with the three most preferred species being *Marcotermes subhyalinus*, *Psudacathotermes militaris* and *M. bellicosus* (Nyeko and Olubayo, 2005).

Termites are rich in essential nutrients. For example, the alates of *M subhylanus*, *P. militaris, M. bellicosus and P. spiniger* contain very high fat content (44.82–47.31 g/100 g), unsaturated fatty acids (50.54–67.83%), protein (33.51–39.74 g/100 g), carbohydrate (0.72–8.73 g/100 g), iron (53.33–115.97 mg/100 g) and zinc (7.10–12.86 mg/100 g) (Kinyuru et al., 2013). The protein content of the species *Syntermes aculeosus* from the Bolivarian Republic of Venezuela has been reported to be remarkably high at 44% (van Huis et al., 2013). Some termite species cultivate edible mushrooms in the genus *Termitomyces* in their termitaria (Yongabi et al., 2004; Nyeko and Olubayo, 2005). *Termitomyces* species provide a low-fat and high fiber diet rich in protein, minerals and vitamins (Opige et al., 2006), and are also used in treating various diseases (Kabasa et al., 2006).

Termites are also important in human nutrition and health through geophagy (the practice of eating earthy substances), which is common among the nutritionally vulnerable populations, especially children and pregnant and lactating women (Wiley and Katz ,1998). Consumption of soil from termitaria can contribute to improved maternal calcium status, foetal skeletal formation and birth weight, and reduction in pregnancy-induced hypertension, risk of embryonic exposure to teratogens and loss of nutrients through emesis (Wiley and Katz, 1998). Culturally, termite mounds are important in sub-Sahara Africa, being used as burying places and are associated with the spirits of ancestors. Termites also play a role as oracle, in superstitious beliefs, in art and literature (van Huis, 2017).

Physiology: Termites belong to the Order Isoptera but are often wrongly called ants or white ants. Ants belong to the Order Hymenoptera and are structurally very different from termites. Ants have a constricted waist while termites have unconstricted abdomen broadly joined o the thorax. In addition, ants have elbowed antennae while termites have moniliform filiform antennae. Termites are social insects that live in colonies with a caste system involving sterile individuals (soldiers and workers) and reproductive individuals (queen and king).

The colonies live in underground nests or aboveground mounds containing thousands of individuals. The queen lays eggs which develop into workers, soldiers or nymph/developing alates (Figure 6.9). The nymphs develop into primary reproductives (alates), which swarm, mate and found new colonies as kings and queens.

The role of the king is to fertilise the queen's eggs while that of soldiers is to defend the colony. The workers build and repair colony nest, shelter tubes and gallaries. They also tend the queen, eggs and young, forage and gather food and feed for all the other castes. The normal foods of termites include cellulose, fungi and soil.

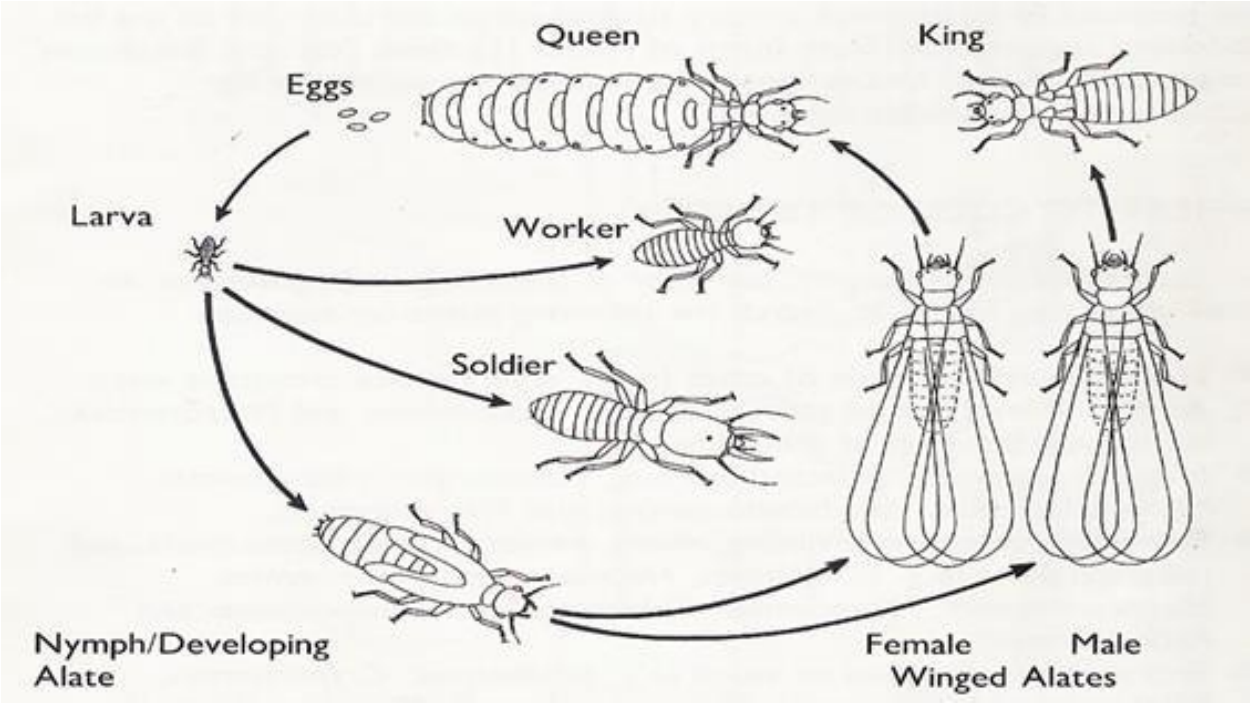

Figure 6.9: Development of termites into different castes. Source: Pearce, (1997)

Breeding: When the primary kings and queens in termite colonies die, new kings and queens rise to take their place. The secondary queens are all genetically identical clones of the original because they developed from unfertilized eggs laid by the first queen through a process called parthenogenesis. These clones then mate with the king to produce the rest of the colony through normal sexual means. Because each of these descendant mates with the king, who has no genes in common with them, the colony avoids inbreeding.

Rearing: A semi-domestication method to collect termites for feeding chicken has been traditionally practiced in western and central Africa (van Huis, 1996). In this method, organic wastes, such as dry stems of sorghum or other cereals and dry maize cobs, are put in a clay pot with a wide opening used primarily to store and cool drinking water, and for cooking. Water is added, and the clay pot is turned upside down with the opening on a termite gallery.

The microclimate within the pot is ideal for the termites to infest the organic materials in the pot. The number of worker and soldier termites increases considerably in the pot after 3 to 4

weeks and the pot is emptied for the chicks. Information on rearing techniques for producing termite alates is however lacking. Rearing termites for the alates may require deliberate efforts to establish termite colonies using paired alates during their swarming periods. For this to be successful in producing substantial quantities of alates, termite conservation areas could be set aside either by local communities or local governments for establishment of termite colonies.

Human-insects' interaction: Termites may bite and sting, but the wounds are not toxic. They are also not known to be human disease vectors. However, people who are living in homes infested by termites may suffer from allergic reactions or even asthma attacks.

Harvesting and utilization: The methods used to collect termite alates vary enormously, depending mainly on the termite species. Traditional methods used for collecting some commonly consumed termite species in east Africa have recently been described by Nyeko and Olubayo (2005) and Okia et al. (2017) and summarized in Table 6.5. Similar principles of termite collection methods are practiced by several ethnic groups in other regions of sub-Saharan Africa (van Huis, 2017).

Traditionally in Ghana, a basin is filled with water and placed under a lamp or other light sources in the evening after rainfall to attract termites (Anankware et al., 2016). In Kenya, a study by Ayieko et al. (2011) found that combining traditional methods and a simple modern light trap technology can enhance mass collection of *Macrotermes subhyalinus* which swarms at night. Whereas alates are seasonal, soldier termites are not and can be gathered at any time of the year.

The process of collecting soldiers of, especially *Macrotermes* species involves locating vents (small openings) on the mound, inserting grasses or tree fibres (as baits) into the vents, withdrawing the bait shortly after insertion, and stripping soldiers and workers hanging on the bait into the harvesting container (Netshifhefhe et al., 2018, van Huis, 2017). Local communities in Burkina Faso collect soldier and worker termites using calabashes, which are filled with baits comprising moist old dung, mango pits and other organic material and placed under the ground. The calabashes are unearthed 3 - 4 weeks later, and the trapped termites are fed to poultry.

Next to nothing is known about the sustainability of termite harvesting methods. In the Vhembe District of South Africa, termite harvesters promote responsible harvesting through mound rotations and protect termite mounds from destruction by not destroying them during ploughing, planting crops around the mounds and families owning mounds found near their homes or fields (Netshifhefhe et al., 2018).

Table 6.5: Methods of collection of alates of different termite species

Termite species	Method of collection
Pseudacanthotermes millitaris (Hagen)	*Pseudacanthotermes millitaris* does not build aboveground mound. A collection hole is dug once the emergence vents for alates have been sighted, usually on bare grounds. A dome-shaped framework is then constructed above the ground exhibiting the vents using flexible reeds, and the structure is then covered with opaque materials, such as, clothes, grass and banana leaves. (Figure 6.10a) A transparent polythene material is used to cover the portion of the structure above the collection

	hole to allow in sunlight which attracts the insect into the hole. A container, which can be a polythene bag or small bucket is placed inside the collection hole to protect the catch from contamination with soil. When the alates stop emerging from the ground, those trapped in the collection hole are hand-picked and packed into polythene bags for transportation. The collection, starting construction of the structure, is done from midday to 5:00 pm during rainy seasons. The alates can also be stimulated to fly or emerge from the ground during dry periods, in which case, the exercise starts in the morning hours by watering and beating the ground surface to imitate rainfall.
Macrotermes subhyalinus (Rambur)	Alates of *M. subhyalinus* swarm at night (8.00 pm – 11 .00 pm). On their expected days of swarming, mounds are checked for appearance of alate emergence vents on the mound during day time and once the vents are spotted, an alate collection hole is prepared at the base of the mound. A source of light, such as a lamp or grass torch, is used to attract the insects to the collection hole and/or container, e.g. saucepan, bucket and basin (Figure 6.10b). Sometimes the vents are smoked with tobacco leaves or bark cloth to fasten the emergence of the insects.
Macrotermes bellicosus (Smeathman), *Macrotermes falciger* (Gerstacker) *Pseudacanthotermes spiniger* (Sjöstedt)	*Macrotermes bellicosus*, *M. falciger* and *P. spiniger* (Sjöstedt) are mound-building termites. The method for collecting their alates is similar to that used for collecting *P. millitaris* alates. Alates of *M. bellicosus* and *M. falciger* swarm early morning (3 - 7 am), but those of *P. spiniger* can swarm anytime during the day when stimulated by pouring water. Construction of a structure for a shelter to enclose the mound starts once the alate emergence vents are detected during the day. The size of the structure depends on the size of the mound. The frame is covered with grass, banana leaves but not clothes (Figure 6.10c). In Uganda, the alates of *M. bellicosus* normally swarm at the beginning of the first wet season, but some local people pour water onto the mounds during the end of the dry season to stimulate early swarming of the alates.
Odontotermes kibarensis (Fuller)	Alate emergence holes are spotted and enlarged using hand hoes. The exposed and enlarged vents are then covered with small lumps of moist clay soil. More clay soil is then used to construct a channel connecting all vents and lead up to a collection container which is fixed at the exit of the main channel. Some leaves are fixed at the entrance of the container to attract and direct alates towards the container. A small hole is also left above the collecting container to let in some light. Ground beating is done continuously to stimulate the flow of Alates. Alternatively, *O. kibarensis* can be collected by digging a collection hole after noticing the vents, placing a clean container (e.g. saucepan) inside the collection hole, placing a light source above the hole and beating the ground. The alates keep following the light as they fall into the collection container.

(a) *Pseudacanthotermes millitaris* (b) *Macrotermes subhyalinus* (c) *Macrotermes bellicosus*

Figure 6.10: Features of traditional traps used for capturing alates of different termite species

Processing for food and feed: Preparation of termite alates for consumption involves mostly frying or boiling fresh harvests, which are sun-dried or smoked for consumption as snacks or sauces of various types. In some cases, fresh alates (not fried or dried) are ground into paste after removing the wings and prepared as a meatloaf sauce. In Uganda, live alates of *Pseudacanthotermes millitaris* with or without salt are commonly consumed without removing the wings (Nyeko and Olubayo, 2005). Recently, novel products such as crackers, muffins, sausages, meat loaf and bread from termites have been produced by grinding sun-dried alates into powder, mixing with other food ingredients and baking, boiling or steaming (Ayieko et al., 2010). Kinyuru et al. (2015) produced nutritious and low-cost complementary foods which were self-stable for six months using termite alates and other traditional ingredients in Kenya.

The processing of soldier termites involves killing them using hot or cold water or by frying after which they are consumed or pounded into cakes and sometimes preserved by sun drying or refrigeration (van Huis et al., 2017). Sometimes the soldiers of some species, such as *Macrotermes natalensis* and *M. michaelseni*, which have bitter taste are vigorously stirred in water and rinsed, apparently to remove the substance associated with the bitter taste, prior to cooking (Netshifhefhe et al., 2018).

Marketing: Although termites are considered as important food and feed resource, very little is known about their marketing. A study conducted in Uganda and Burundi found that *Macrotermes subhyalinus, M. bellicosus* and *Pseudacanthotermes millitaris* (in Uganda), and *M. falcigar* (in Burundi) were commonly marketed in rural and urban markets, with demand often outstripping the supply (Odongo et al., in press). A recent survey of 13 informal street markets in Vhembe district, South Africa by Netshifhefhe et al. (2018) found that termites were sold in about half of the markets surveyed.

The vendors were not actively involved in any termite harvesting but only bought termites from harvesters, and all of them sold throughout the year, six days a week, working half day on Saturdays. The average daily, monthly and annual incomes derived from termites were estimated at ZAR 292 (USD 23.0), ZAR 2395 (USD 188.8), and ZAR 7348 (USD 579.3), respectively, with the annual income ranging from ZAR 2040 (USD 160.8) to ZAR 17680 (USD 1,393.8). The price of termites was estimated at USD 7.8/kg, which was more than the price of fresh Chicken, beef and pork, but less than that of lamb chops and dried meats.

Case studies: In Tororo district of Uganda, famers possess remarkable knowledge of edible termites. They identify edible termites based on: (i) mound building, (ii) size of mound, (iii) presence or absence of vents on mounds, (iv) size, colour, odour and taste of alates, soldiers or workers, and (v) seasonal and diurnal flight periods of alates (Table 6.6).

Table 6.6: Characters used for identification of edible termite in Tororo District, Uganda

Termite species	Main characteristics
Macrotermes subhyalinus Rambur (Agoro)	Builds big mounds without vents. Alates are dark brown and are the largest of all types of alate. Alates swarm in April, between 8 pm – 3 pm. Soldiers and workers have no distinctive odour. There are two types of soldiers and one type of worker (referred to as females by the farmers). It has large soldiers with red head, medium size soldiers with red head and small females with dark brown heads.
Macrotermes bellicosus Smeathman (Ripo)	Builds big mounds with large vents round the base of the mound. Alates are medium-sized and dark brown. Alates swarm from February to March between 5 and 7 am, following the onset of the first rainy season. There are two types of soldiers as for Agoro, but generally smaller than for the latter. Workers are medium-sized with dark brown heads. Soldiers are very aggressive and their bites very painful. The soldiers produce characteristically 'sharp' smell when rubbed between thumb and first finger and are bitter. The alates are generally sour in taste.
Odontotermes kibarensis Fuller (Magrere)	Doesn't build mounds, but usually makes holes (vents) around tree bases. Two types of alates exist: brown type for those found upland and a dark type for those located in lowlands (valleys). Alates swarm in April around 8 pm. Soldiers are of two types: medium-sized ones with red heads and small ones with brown heads. Soldiers produce a smell like *M. bellicosus* and taste bitter.
Odontotermes latricius Haviland (Singiri)	Doesn't build mound. Alates swarm from bare ground (e.g. along road/path sides) in September usually around midday, especially during bright sunshine. Alates are easy to lure out when some noise is made around the exit points (children usually sing songs for this purpose). White soldiers and workers are all dark. The species doesn't produce any distinct odour.
Odontotermes sp. 1 (Ogwee)	Builds nests with only ventilation shafts protruding above ground level. Alates are medium-sized and dark brown. Alates swarm from March to June at any time of the day (but not in hot sunshine) when rainfall is simulated by beating pieces of wood on the nest. Alates and soldiers are generally dark-brown and are tasty. Soldiers have red heads. Workers are small with dark brown heads.
Odontotermes sp. 2 (Mbala)	Doesn't build mounds but forms circular patches on the ground with small vents in the middle of the patch. Alates are medium - sized and brown. Alates swarm in April at any time of the day. Workers are small with dark brown heads. Soldiers are medium-size with brown heads and white abdomen. The specied has no distinctive odour.
Pseudacanthotermes militaris Hagen (Sisi)	Doesn't build mounds. Alates are medium-sized and dark. Alates swarm from 1 to 3 pm between September and December, depending on availability of rainfall. There are two types of soldiers: medium size with red heads and small dark ones. Workers are dark with swollen abdomen.
Pseudacanthotermes species (Wambwe)	Doesn't build mounds. Alates are medium size and brown. Alates swarm throughout rainy seasons, usually between 5 and 6 pm whenever it rains.

	There are two types of soldiers as for Sisi. Soldiers, workers and alates are tasty.
Pseudacanthotermes spiniger Sjöstedt (Miyal)	Builds medium-sized mounds (usually less than 1 m tall) without vents. Two types of alates exist: dark brown ones from upland and very dark ones from valleys. Alates swarm in August at any time of the day, though mostly in the evenings, if sufficient water is poured on the mound and the mound covered with grass or clothes. Soldiers are dark medium-sized with brown heads and dark small workers. Soldiers, workers and alates generally have sour taste.

Source: Nyeko and Olubayo, (2005). Words in parentheses are local Japadhola names of termites (Japadhola is a local language in Uganda)

Crickets

Importance: House and field crickets have long been used as food and feed in many parts of the world. Edible cricket species commonly used as food and feed include *Gryllus bimaculatus* DeGeer, *G. sigillatus* Walker, *Teleogryllus testaceus* Walker and *T. occipitalis* Serville, *Brachytrupes membranaceus* Drury and *Acheta domesticus* (L.) (Megido et al., 2017; Mott, 2017; Okia et al., 2017). Crickets are a good source of food and feed with high nutritional values. For example, Finke (2002) found that 100 g of adult *A. domesticus* contained 20.5 g protein, 6.8 g fat, 0.06 g omega 3 fatty acids, 140.2 calories, 3 mg vitamin C, 6.8 g neutral detergent fiber, 1.93 mg iron, 6.7 mg zinc, 252 mg phosphorus and 352 mg potassium. The high potential of crickets for food and feed has led to the development of rearing systems and establishment of commercial cricket farms in several countries including Thailand, Cambodia, Lao Peoples' Democratic Republic (PDR), Indonesia and Kenya (Haboonsong et al., 2013; Megido et al., 2017). In Thailand, a country where crickets have been consumed traditionally, there is a thriving cricket industry with more than 20,000 farms producing commercial products including adult crickets, eggs and biofertilizer from cricket wastes (Halloran et al., 2017).

Physiology: Crickets are insects in the order Orthoptera that comprise the family Gryllidae. Male crickets produce calling, courtship and combat songs by rubbing their forewings against each other. The females do not sing, but they are attracted to male songs through a process called phonotaxis. Females of different groups lay eggs in stems or twigs, in wood, under the bark, in the ground, or in burrows. Crickets undergo incomplete metamorphism, with even newly hatched nymphs appearing physiologically like adults (Mott, 2017). The optimum temperature for egg hatching and development ranges from 25 – 30 ^{o}C and relative humidity from 60 – 80% (Megido et al., 2017). Nymphs moult 7 – 10 times, depending on species, to reach maturity. Females develop ovipositor in the fourth or fifth instar and wings begin to develop in the last two nymphal instars. Adults have fully developed wings with females being 15 - 25% larger than males. Mating occurs within a day after maturation, females lay eggs within 24 - 48 hours after mating, and the eggs can hatch in 11-15 days. In *A. domesticus* a single mating early in adult life is sufficient to induce egg laying for the duration of the life of a female (Murtaugh and Denlinger, 1985).

Rearing: The first step to farm crickets in a cost-effective way is to build rearing units with available natural resources or low-cost materials that create damp and dark natural environment for crickets (Megido e al., 2017). Four types of cricket rearing units (concrete cylinder pens, concrete block pens, plywood boxes and plastic drawers) are suitable for small and medium

farms (Haboonsong et al., 2013; Megido et al., 2017). Concrete cylinder pens (80 cm diameter x 50 cm height) are inexpensive, easy to maintain, can produce 2 – 4 kg of crickets. Concrete block pens are rectangular (1.2 m x 2.4 m x 0.6 m) and interconnected, each pen can produce 25 - 30 kg of crickets, but there is risk of disease outbreak or overheating as the cricket population is always crowded. Plywood boxes (1.2 m x 2.4 m x 0.5 m), can produce 20 - 30 kg of crickets, do not build up much heat and are easy to clean but are less durable than the concrete blocks. Plastic drawers, comprising a set of three to four drawers (each measuring 0.8 m x 1.8 m x 0.3 m), are stacked on a shelf and can produce 6 - 8 kg of crickets, but there is a risk of overheating and plastic deteriorates.

Other necessities for the structures for rearing crickets include nets which are placed over the containers to keep crickets in and predators out, plastic bottles or plates with water and stones to provide water, sticky tapes or plastic tablecloths glued on the inner side of the walls just below the edge to keep the crickets from crawling out of the area, a layer of sandy loam soil with dry grasses placed in the bottom of the pens and chicken egg cartons as hiding places for the crickets, bowls containing a mixture of rice husk and sand, potting soil, perlite or peat moss for females to lay eggs, and a narrow strip of water around the area where the cricket containers are located to prevent access by ants.

In Thailand, crickets are traditionally fed on 21% protein chicken feed after hatching until they are 20 days old and later a mixture of 14 and 21% protein chicken feed until they are ready for harvest at 45 days old. The high protein feed is replaced with vegetables such as pumpkins, cassava leaves, morning glory leaves and watermelons a few days to harvest to improve taste and to reduce use of the more expensive protein feed (Haboonsong et al., 2013).

There are some risks of disease outbreaks in cricket farming which require proper farm management guidelines. The *Acheta domesticus* densovirus (AdDNV) has been reported to cause high mortality of *A. domesticus* or the insect becomes smaller and less active, especially in the last three nymphal instars and adult stage (Weissmann et al., 2012). However, other edible crickets such as *Gryllus bimaculatus, G. sigillatus and G. assimilis* seem resistant to AdDNV (Szelei et al., 2011). *Acheta domesticus* has also been reported to be infected by the cricket iridovirus (CrIV) (Jakob et al., 2002), *Serratia liquefaciens* (Gray, 1997) and the nematode *Heterorhabditis Georgiana* (Shapiro-Ilan et al., 2009). Eilenberg et al. (2015) isolated a bacteria species, a *Metarhizium* species and the cricket paralysis virus (CrPV) in *A. domesticus* and suggested the appropriate management actions (Table 6.7).

Table 6.7: Pathogens isolated from *Acheta domesticus* and the recommended management actions

Disease agent	Symptom	Action
Bacteria sp.	Increased mortality, red appearance	cleaning of cages
Metarhizium sp.	Some mortality in population	Quarantine, new breeding stock
Cricket paralysis virus (CrPV)	Collapse of cricket population	Switch to new breeding stock or even new cricket species

Source: Eilenberg et al., (2015)

Human-insect interaction: Enterobacteriaceae and spore-forming bacteria have been isolated from A. domesticus and a Brachytrupus species, but generally they do not belong to pathogenic

species (Klunder et al., 2012). Simple hygienic measures such as appropriate cooking and freezing can be applied during food processing to reduce such biological risks. Crickets, like other soil-dwelling insects, are also able to introduce contaminants from solid waste into the food web by preying on discarded consumer products. Chemical bioaccumulation can be managed under rearing conditions through a controlled feedng program, focusing particularly on feed composition and feed contamination by chemicals.

Capture/harvesting and utilization: Traditional collection of edible crickets is a relatively simple process. Adults of the ground and field crickets are identified by their chirping sound and captured. They are also dug out of their holes. The house cricket can be trapped using a basin filled with water and placed under a light source in the evening. The crickets are attracted to light and are trapped in the water or collected by hand into the water to prevent them from escaping. The house cricket can also be harvested early in the morning when they are less mobile due to their low body temperature (Anankware et al., 2016). House and field crickets are used as human food, fish bait and food for laboratory animals. Farmed crickets can be harvested by hand-selection at small scales or using sorters at larger scales to ensure that only live, vibrant individuals are harvested from rearing containers and frozen to kill and preserve them (Mott, 2017). Males of the oriental cricket (*Telegryllus mitratus*) are also caged for their songs.

Processing for food and feed: Edible crickets are processed in various ways for consumption. They are usually washed, pan fried, roasted or boiled and dried. In Thailand, wholesale buyers wash and boil the crickets, package them in 5-kilogram packs and sell to retailers (Haboonsong et al., 2013). Roasted crickets can be ground to a fine, nutritious powder using various types of mills (Rumpold et al., 2017). Cooked crickets can be eaten plain, sprinkled on salads, and used in soups and stews. They can be dipped in chocolate, candied, covered with cinnamon and sugar, or salted. Cricket powder can be used for baking cookies and cakes and can be mixed with flour as an added source of protein.

Marketing: Marketing of edible crickets is pronounced in countries where the insects are being farmed. The marketed products from cricket farms include mature crickets, cricket eggs and fertilizer from waste produced from the cricket farms. Cricket farmers usually sell their crickets through wholesale buyers who supply market, vendors or restaurants, and sometimes directly to local consumers or to gecko or fish farmers for feed (Haboonsong et al., 2013).

The farm gate price for crickets varies generally from 3 – 5 USD/kg in Thailand, 3.7 – 4.9 USD/kg in Lao PDR, USD 3.75 in Indonesia, around 2.3 USD/kg in Kenya, and up to 13 USD in Cambodia (Megido et al., 2017). Egg bowls (typically 20 cm in diameter) are sold at 0.92 – 6.5 USD in Thailand, 1.2 – 1.9 USD in Lao PDR and about 2.0 USD in Kenya while 20 – 30 kg cricket waste biofertilizers are sold at 1.09 – 1.67 USD in Thailand and 2.50 USD in Cambodia (Megido e al., 2017). The cricket price rises at each stage of the marketing chain. For example, according to Haboonsong et al. (2013) cricket famers in Thailand sell the crickets to wholesale buyers for around 2.5 – 3.1 USD/kg. The wholesale buyers wash, boil, package the crickets in 5 kg and sell the packs to retail markets at about 3.7 – 4.7 USD/kg. Street vendors who buy at the retail markets sell the precooked crickets for 7.8 – 9.4 USD/kg.

Case studies: An analysis of income and profit a cricket farmer in Loei Province, Thailand in 2001 showed that the farmer earned a net profit of USD 1,455 per one harvest cycle, which

was about 59% of the gross income that accrued from the enterprise (Table 6.8). The main costs the farmer incurred were cricket feed (77% of total cost) and labour (7%). Others were fixed (concrete block pen and cricket shed), variable (egg cartons, plastic bowls for egg harvesting, food trays, food grinding machine, tape, nylon tape and cricket eggs) and miscellaneous (electricity, water and packing) costs.

Table 6.8: Income and net profit (USD) per harvesting cycle of a cricket farmer in Thailand in 2001

Sales	Total production (kg)	Sale price/kg	Cost/kg	Gross income	Total cost	Net profit per one harvesting cycle
Wholesale	950	2.43	1.01	2304.23	963.59	1340.64
Retail	50	3.31	1.01	165.38	50.72	114.66
Total	1,000			2469.60	1014.30	1455.30

Modified from Haboonsong et al., (2013).

Mopane worms (Imbrasia belina L.)

Importance: The larvae of *Imbrasia belina*, commonly called mopane worms, are an important resource for the livelihoods of many communities in southern and central Africa countries where they are consumed regularly. Mopane worms are considered as a cheap source of animal protein containing comparatively higher quantities of essential nutrients than conventional crop and animal sources. On average, mopane worms contain 55.41% crude protein, 53.3% digestible protein, 8.16% carbohydrate, 8.26% ash, 27.8% neutral detergent fibre, 16% acid detergent fibre, 5.2% acid detergent lignin, 0.9% acid detergent insoluble nitrogen, 16.37% fat, 35.2 mg/g potassium, 16.0 mg/g calcium (mg/g), 14.7 mg/g phosphorus, 4.1 mg/g magnesium, 12.7 mg/g iron, 1.9 mg/g zinc and 33.3 mg/g sodium (Kwiri et al., 2014).

Mopane worms are also an important source of income, especially to women and children who are mostly involved in the collection and trade. For example, it is estimated that income from mopane worm harvesting can contribute nearly 40% of total annual cash income for poor rural households in Mwenezi District of Zimbabwe (Stack et al., 2003). In South Africa, it is estimated an annual population of 9,500m mopane worms in 20,000 km^2 of mopane veld worth £57m, of which about 40% was for producers who are primarily poor rural women. In Botswana, the annual commercial value of mopane worms during a good year is estimated at 24 million euros and the worms provide work for up to 10,000 people (Mpuchane et al., 2015).

Physiology: The mopane worm is the caterpillar of the Mopane Moth, *Imbrasia belina*, and has a holometabolous life cycle. the female lays 50 to 200 eggs on leaves or branches of one host tree, usually the mopane tree (*Colophospermum mopane*), although other tree species are also used. The eggs hatch in about ten days and the larvae feed on the leaves of the tree where they hatch. The larvae moult 4 times (there are five larval stages) before they reach their maximum size in about six weeks and pupate in soil for 6 to 7 months. Adults do not feed and live for only two to three days within which the males and females mate and produce eggs

Rearing: The methods of rearing mopane worms are summarized here as described by Gazhoul (2006). Eggs masses attached to twigs or leaves of the mopane moth are collected from Mopane trees and can be kept in three different ways prior to hatching:

i) Eggs are placed in used tins, which are kept in the house to protect them from parasites and checked daily for hatching activity;
ii) Eggs are tied to branches of trees and left to hatch; and
iii) Eggs are tied to branches of trees as in (ii) but they are covered with chiffon or shade cloth bags to protect them from egg parasites such as *Mesochomys pulchriceps* and *Pediobius species*. The chiffon bag is removed when the eggs are hatched. Tying the eggs straight onto the branch as in (ii) saves time, the eggs do not need to be checked as regularly as with the other methods and on hatching the larvae can start feeding immediately. If parasitism is high the farmer can decide on one of the other methods.

Larvae that hatched from eggs placed in the tin cans are transferred to trees covered with 2 m^3 bags to protect them from predation. A small Mopane tree twig with leaves is placed into the tin to allow the young larvae to crawl onto the twig. The twig is then tied to the branch of the covered tree. Eggs, which were attached directly to the trees, can hatch in the open or within bags placed over the trees for maximum protection. If the larval density is too high some larvae are removed and placed on another tree. The larvae are also removed and placed on a new tree when the leaves from the hosting tree have been depleted.

For pupation: (a) a pit is dug measuring 2 m x 1 m and 30 cm deep, (b) a 3 m x 3 m piece of 40% shade cloth is placed over the pit and positioned so that most of it overhangs on one side, (c) sandy soil is placed back into the pit, (d) a frame is made from six small poles pushed into the soil supporting two pieces along the length of the pit and three pieces across the width; the poles are tied together with a string for stability, (e) the shade cloth is folded back over the frame covering the pit and the sides are then sown together with a string. A small part of the seam is left open through which the larvae can be introduced.

Approximately 1,000 larvae can be placed in each pit for pupation. Once the larvae have been introduced into the pit, they are left for about three to four weeks before being removed. In the first season, once the pupae have been dug up, they are placed for hatching in cardboard boxes, which can be placed in a chiffon bag to prevent attack by Chalcid parasites. Some of these pupae hatch after a very short diapause and storage in boxes allows the moths to hatch without the risk of wing deformation. Second season pupae, and those not hatching from the first brood, are stored in jars or similar containers for better protection over the long dry winter. When the moths hatch the shade cloth bags will be set up over small trees. The day after the moths hatch the male and female moths will be removed from the cardboard boxes and introduced into the bags. The moths can also be released by placing the boxes at the base of a tree under a shade cloth net and opening the lid. The moths will be allowed to lay eggs on the tree and these eggs can then be moved and treated as described above. Two egg parasites *Mesochomys pulchriceps* and *Pediobius* species have been identified in Zimbabwe, with *M. pulchriceps* being common and widespread.

Harvesting and utilization: Mopane worms are traditionally gathered by hand from the ground and from the trunks, branches and leaves of the host trees in December and January and in April and May. The harvesters shake the trees and, in some cases, cut infested branches or a

whole tree to harvest the larvae. However, the cutting of trees should be discouraged because this can affect other mopane herbivores, future mopane worm productivity and other ecological processes. The use of hand gloves during harvesting has been recommended to protect the harvesters from larval gut fluid, which can irritate scratches on the hand, and spines on the larvae which can be painful and cause lacerations and rustication (Gazhoul, 2006).

When descending off the tree for pupation, the larvae empty their guts naturally before going underground and this is the preferred time for collecting the larvae because no squeezing for degutting is required. However, the collecting window where there are enough larvae on the ground to make it worthwhile is relatively brief and hence people collect prior to this (Gazhoul, 2006). During a good year a woodlot of 4000 hectares would support 19 million worms, which would translate to193 tons of Mopane worms (Dube and Dube, 2010), and an individual can harvest between 25 and 50 kg of mopane worms a day. The harvested larvae are principally used as food in the household or sold for income.

Processing for food and feed: Traditional processing of mopane worms basically involves degutting, washing, cooking and drying. Degutting is done by squeezing the larvae with the forefingers and thumbs mostly after harvest, but some harvesters squeeze as they pick the larvae and for this method they either have kitchen gloves, car tire bands around the forefingers and thumbs or bare hands. The degutted worms are washed, placed in a container with some water and salt and cooked on fire for about 15 minutes while stirring to allow even cooking and prevent the worms at the bottom of the pot burning. Traditionally, after cooking the worms, they are dried on a swept ground or bags for 2-4 days depending on weather conditions to prolong their shelf life to almost a year. However, one main drawback of the ground drying method is that the worms are exposed to sources of contamination such as debris and other insects such as dermestids and flies. Dryers made of black plastic with a clear plastic cover and black steel trays with and without clear plastic covers can decrease drying time and the number of insects entering the worms (Gazhoul, 2006).

Mopane worms are also roasted and dried using the charcoal method in which uncooked larvae are mixed with the charcoal from a fire and stirred continuously up to 5 hours then picked out of the charcoal. This method is the easiest, but the product is not of high quality and does not fetch the best price as the larvae do not keep well under wet conditions apparently because they are not salted. Roasting the larvae over a fire on a grid can drastically reduce the drying time to about one hour (Gazhoul, 2006).

Traditionally dried mopane worms are preserved by keeping them in woven polypropylene bags, plastic or metal buckets and clay pots. To decrease the deterioration both from micro-organisms and insects, the mopane worms are taken out of the bags and spread on the floor in the sun. In some cases, a black plastic sheet is placed over worms while they are in the sun, to kill unwanted insects (Gazhoul, 2006). Mopane worms are also canned and packed as snacks (Mpuchane et al., 2015).

Marketing: The market players in mopane worm trade include producers, assemblers, regional wholesalers, retailers and consumers. Producers supply dry mopane worms to local markets for barter trade or cash sale to local consumers or rural assemblers. The value of mopane worms increases along the marketing chains. Rural–urban value-chain analysis indicates that consumers can pay four to five times the price received by a rural harvester (Stack et al., 2003).

In Chiredzi, Zimbabwe collectors selling mopane worms in the 2002 season realised on average Z$97/kg at the collection area, Z$132/kg for sales at a local centre, Z$ 205/kg for urban market sales and Z$409/kg for sales across the border in South Africa. In the same season a retailer at Ngundu in Zimbabwe who bought from traders and then fried and spiced mopane worms for sale at a local council beer hall got a return of about 300% on the capital spent (Kozanayi and Frost, 2002).

Case studies: In South Africa and Zimbabwe, a project was initiated in 2002 to develop strategies for improving livelihoods of mopane worm collector communities through improved production and marketing of mopane worms (Gazhoul, 2006). This project demonstrated that it is possible to establish and maintain a captive breeding population of *Imbrasia belina* over three years. Household scale semi-domestication methods for rearing mopane worms were developed with the participation of local communities. The project also developed solar cooking technologies as an alternative to traditional fire method as it decreases the amount of wood used and the physical labour/ and time spent on cooking. The project also demonstrated that simple modification of placing a grid over the fire and combining cooking and drying has major benefits in reducing processing time.

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